Universitatea *Transilvania* din Braşov

HABILITATION THESIS

Technical-medical Approach of Biomechanical and Behavioral Factors in order to Improve Life Quality

Domain: Mechanical Engineering

Author: Assoc.prof.eng. Cotoros Laura Diana, Ph.D.

University Transilvania of Brasov

BRASOV, 2016

CONTENTS

Part I. Scientific and professional achievements

REZUMAT

Scopul oricărei cercetări bazate pe priorităţi este să se preocupe de problemele majore împărtăşite de cetăţenii Europei şi de pretutindeni. Pentru acest motiv, diferite domenii de cercetare au datoria de a îşi reuni resursele şi cunoştinţele pentru a fi capabile de a se concentra aupra unor activităţi inovative şi centrate pe fiinţa umană.

Una dintre cele mai benefice îmbinări dintre domeniile de cercetare este cea care armonizează tehnologiile inginereşti cu cunoştinţele medicale. Progresul impresionant al medicinii de-a lungul ultimilor decenii nu ar fi fost posibil fără sprijinul neclintit al contribuţiei tehnicii. Contribuţia interdisciplinară a diferitelor ramuri ale ingineriei a dus la rezultate extraordinare care vor fi treptat accesibile la tot mai multe fiinţe umane, îmbunătăţindu-le calitatea şi condiţiile vieţii sau cel puţin acesta ar trebui să fie ţelul suprem.

Având în minte aceste deziderate, autoarea a prezentat pe întreg parcursul lucrării un număr de rezultate ale unor cercetări semnificative care îndeplinesc cerinţele unei cercetări centrate pe fiinţa umană şi tehnic aplicativă. Astfel lucrarea este divizată în două părţi importante: una se referă la realizările ştiinţifice şi profesionale ale ultimilor ani iar cealaltă la planurile de dezvoltare a carierei în viitor.

Partea ştiinţifică a lucrării prezintă de-a lungul a patru mari capitole direcţiile principale de cercetare care au fost abordate în cursul ultimilor ani de activitate şi de asemenea o sinteză a principalelor concluzii şi a contribuţiilor originale rezultate din lucrarea mai sus menţionată.

Primul capitol prezintă în principal probleme legate de mişcarea umană care au fost abordate de către autoare pe baza unui fundament solid de cunoştinţe din domeniul mecanicii, cunoştinţe câştigate în timpul primilor ani de activitate universitară. Aceste cunoştinţe au fost extinse cu minuţiozitate către domeniul aplicaţiilor umane atât prin abordări experimentale cât şi cu ajutorul ştiinţei calculatoarelor. Astfel, a apărut posibilitatea comparării dintre normalitate şi disfuncţii locomotorii accidentale dar şi a celor rezultate din activităţi cu caracter ocupaţional, care pot fi profesii de rutină sau activităţi care necesită performanţe ridicate. Rezultatele obţinute prin modelare şi simulare computerizată sunt coroborate cu încercările experimentale desfăşurate pe baza unor metodologii inovative şi susţinute de un echipament performant existent în laboratoarele de cercetare ale universităţii.

Al doilea capitol se referă la analiza materialelor biomedicale utilizate atât pentru lucrări dentare cât şi pentru dispozitive ortopedice. Aceste materiale trebuie să îndeplinească condiţii mai severe datorită faptului că pe lângă proprietăţile mecanice, chimice şi termice necesare, ele trebuie să fie biocompatibile deoarece vor fi în contact imediat cu ţesuturile umane. Desigur aici

intervine colaborarea interdisciplinară dintre inginerie, medicină şi chimie, deoarece inginerii sunt capabili să analizeze numai proprietăţile mecanice şi termice şi mai puţin cele chimice sau biologice. Cercetarea s-a referit în special la analiza materialelor existente cu scopul de a oferi un instrument fiabil şi ştiinţific atât utilizatorilor (personalul medical) cât şi beneficiarilor (pacienţii) în selectarea variantei optime pentru fiecare individ în parte. Unele cercetări sunt deja iniţiate şi vor continua în vederea identificării unor noi materiale care să corespundă cerinţelor şi în plus prezintă avantajul unor costuri mai reduse şi al unui impact mai redus asupra mediului. Materialele compozite sunt cea mai promiţătoare alternativă iar structura lor specifică poate oferi combinaţii variate şi creative care să corespundă cerinţelor pe viitor.

Al treilea capitol oferă o analiză originală a influenţei factorilor de mediu asupra diferitelor activităţi ale fiinţei umane. Începând cu efectele vizuale şi acustice, poluarea datorată particulelor solide din mediul de lucru şi continuând cu influenţa izolaţiei clădirilor asupra calităţii vieţii, cercetarea este concentrată în special asupra factorului uman şi a felului în care anumite agresiuni ale mediului pot afecta bunăstarea acestuia. În zilele noastre, oamenii sunt înconjuraţi de provocări potenţial periculoase deoarece tehnologia nu a apărut încărcată doar cu avantaje dar şi cu destule dezavantaje nefericite. Aici intervine colaborarea dintre ingineria mecanică şi cea de mediu cu contribuţia inestimabilă a laturii medicale. De asemenea având în vedere cunoştinţele din domeniul prelucrărilor statistice ale autoarei, s-au putut realiza numeroase evaluări pentru a determina varianta optimă pentru toate părţile implicate: oameni, mediu şi tehnologie, şi de asemenea s-au realizat analize pertinente ale situaţiilor existente pentru a fi capabili de a propune îmbunătăţiri sau inovaţii.

Al patrulea capitol sintetizează în două subcapitole principalele concluzii obţinute din cercetările şi studiile prezentate precum şi contribuţiile originale ale autoarei faţă de stadiul actual al cercetărilor.

A doua parte importantă a tezei este dedicată evoluţiei carierei ştiinţifice şi profesionale a autoarei şi de asemenea planurilor de dezvoltare viitoare ale carierei academice şi ştiinţifice. Provenind dintr-un mediu industrial de înaltă tehnologie cum este industria aeronautică, cu o dorinţă puternică de a învăţa şi de a cerceta pe noi direcţii si de a îi învăţa pe alţii, autoarea a avut o carieră stabil ascendentă de-a lungul anilor şi speră ca prezenta lucrare să fie un nou pas înainte pe acest drum. Viitorul poate rezerva o colaborare fructuoasă şi benefică între specialiştii din domeniul tehnic, medical şi din protecţia mediului cu scopul construirii unui sistem integrat şi corelat care să servească bunăstării umane.

SUMMARY

The purpose of any priority based research is to address major concerns shared by European citizens and everywhere. This is the reason why different fields of research should bring together their resources and knowledge in order to be able to focus upon innovative and human centered activities.

One of the most beneficial blends between research fields is the one harmonizing engineering technologies with medical knowledge. The impressive progress of medicine during the last decades would not have been possible without the valuable support of technical input. The interdisciplinary contribution of various branches of engineering lead to extraordinary results which are gradually accessible to more and more human beings, improving their life quality and conditions or at least this should be the ultimate purpose.

Keeping in mind these desiderates, the author presented throughout the entire work, a number of significant research results that meet the requirements of a human centered and technical applied research. Thus the work is divided into two important parts: one is dealing with the scientific and professional achievements of the past years and the other with the plans of career development in the future.

The scientific part of the work presents along four large chapters the main research directions which were approached during the most recent years of activity and also a synthesis of the main conclusions and original contributions resulted from the above mentioned work.

The first chapter presents mainly the issues related to human motion, which was approached by the author based upon the solid fundament of Mechanics knowledge gathered during the first years of academic activity. This knowledge was thoroughly extended to human applications both by experimental approaches and aided by computer science. Thus, the possibility of comparing the normality with accidental locomotion dysfunctions occurred but also with those incurred by occupational activities, which may be routine professions or performance demanding jobs. The results obtained by computer modeling and simulation are corroborated with the experimental tests developed by innovative methodologies and supported by performing equipment existing in the university research laboratories.

The second chapter deals mainly with the analysis of the biomedical materials used for both dental works and orthopedic devices. These materials should comply with more severe conditions due to the fact that besides the required mechanical, chemical and thermal properties they need to be biocompatible as they will be in close contact to human tissues. Of course, here comes again the interdisciplinary collaboration between engineering, medicine and chemistry, as

engineers are able to only deal with mechanical and thermal properties and less with the chemical and biological ones. The research aimed mostly at analyzing the existing materials properties in order to offer a reliable and scientific instrument to both users (medical staff) and beneficiaries (patients) in selecting the optimal choice for each individual. Some research are already initiated and will continue in order to identify new materials that meet the requirements of the biomedical use and additionally present the advantage of lower costs and environmental damage. Composite materials are the most promising alternative and their particular structure may offer various and creative combinations to meet the requirements in the future.

The third chapter provides an original analysis of the environmental factors influence upon various activities of the human being. Starting with visual and noise effects, pollution due to solid particles in the working environment and going on with the environmental influence of building insulation upon the life quality, the research is focused mainly on the human factor and on the manner in which certain environmental aggressions may affect its welfare. People are surrounded nowadays with potentially dangerous challenges because technology did not come only loaded with benefits but has also some unfortunate shortcomings. Here comes the collaboration between mechanical and environmental engineering with the invaluable contribution of the medical side. Also, provided the statistical processing knowledge of the author, numerous assessments can be made in order to meet the optimal choice for all concerned: people, environment and technology, but also to perform pertinent analysis of existing situations in order to be able to propose improvements or innovations.

The fourth chapter synthesizes in two subchapters the main conclusions achieved during the presented researches and studies and the original contributions of the author with respect to the state of the art.

The second main part of the thesis is dedicated to the evolution of the scientific and professional career of the author and also to the future development plans of both academic and scientific career. Coming from a hi-tech industrial environment like aircraft industry, with a strong desire of learning and researching new directions and being able to teach others, the author has been moving along a steady ascending career during the years and hopes that the present work will be another step ahead on this path. Future may provide a fruitful and beneficial collaboration between the technical, medical and environmental professionals with the purpose of building an integrated and correlated system serving mankind welfare.

INTRODUCTION

The thematic priorities of all funding programmes of the European Commission are addressing, in one way or another, people's concern for their livelihood, safety and environment and also strengthening position in research, innovation and technology.[ec.europa.eu/research] Thus, one of the most recent funding programmes released by the European Commission, Horizon 2020 brings forward three fundamental priorities to be followed:

- Excellent science
- Industrial leadership
- Societal challenges

It is obvious that in order to obtain valuable performances in science and research, the results should be based upon the needs of the future society and these needs are synthetically included in the above mentioned priorities.

This is the reason why the research I developed during the years following my Ph.D. thesis have taken a turn towards studies involving mostly societal challenges, meaning the goal of obtaining breakthrough solutions coming from multidisciplinary collaborations in order to address citizens' concern for their health, their environment and their life quality.

After setting the fundaments of my engineering training by developing studies mostly in mechanical applications, such as stability of rigid bodies' motion applied in various mechanical engineering areas focused upon gyro-dynamics and applications in aircraft industry, my interest was aroused by the new tendencies in European research. These tendencies are directed more towards peoples' societal needs and require collaboration between different branches of engineering such as: mechanical engineering, medical engineering, optometry, mechatronics, sustainable and renewable energy and last but not least environmental engineering.

This multidisciplinary approach allows exploring countless possibilities, opens new research directions and leads to higher objectives that have the required potential to respond to European priorities and challenges.

In this respect, my work may be structured into the following chapters:

- **Chapter 1** – ASSESSMENT AND REHABILITATION OF STRUCTURAL DAMAGES IN ORDER TO PRESERVE STABILITY AND NORMAL MOTION OF HUMAN BODY
- **Chapter 2** – ANALYSIS OF PROSTHETIC AND IMPLANT MATERIALS FOR MAINTAINING QUALITY OF LIFE
- **Chapter 3** – ENVIRONMENTAL INFLUENCES UPON HUMAN BEHAVIOR AND LIFE QUALITY

- **Chapter 4 –** FINAL CONCLUSIONS AND ORIGINAL CONTRIBUTIONS

Chapter 1 deals with methodologies of assessing subjects with locomotor disabilities or other motion impairments and finding new correlative procedures to monitor them during their treatment.

Chapter 2 makes an analysis of some composite materials suitable for biomedical use from the point of view of their mechanical properties, chemical and thermal resistance according to the domains they are used for.

Chapter 3 analyzes several environmental influences like sounds, visual stimuli, solid particles pollution upon human behavior and some statistical analysis of residential buildings thermal comfort that may have effects upon human life quality

Chapter 4 presents some final conclusions and the main original contributions developed in the habilitation thesis.

In order to perform the experimental results, the equipments of the Research Centre "Advanced Mechatronic Systems" within the Research Institute of Transilvania University have been used and also the endowment of the "Applied Optometry" laboratory.

Chapter 1 . ASSESSMENT AND REHABILITATION OF STRUCTURAL DAMAGES IN ORDER TO PRESERVE STABILITY AND NORMAL MOTION OF HUMAN BODY

1.1. General considerations on human motion

1.1.1. Motions of the human body

The classical definition of gait is a repetitive sequence of limb movements meant to safely advance the body with minimum energy expenditure, but for a good and complete analysis, it is necessary to understand that this action requires high cognitive neural function and a properly functioning neuromuscular system to achieve its correct execution and that it is obvious far from being a simple automated task. The act of walking has two basic requisites:

- First it is the periodic movement of each foot from one position of support to the next and
- Second there should be sufficient ground reaction forces, applied on the feet, to support the body.

These two elements are required for any form of bipedal walking to occur, no matter how distorted the pattern may be by underlying pathology [135]. This periodic leg movement is the essence of the cyclic nature of human gait [4]. The cyclic nature of gait is shown by help of a rotating circle in fig.1.1.

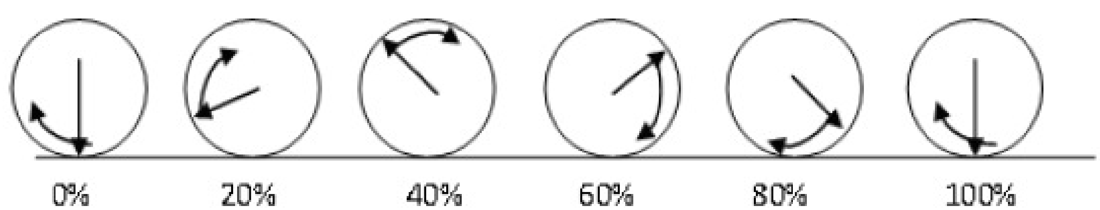


Fig.1.1 Cyclic nature of forward progression in human gait [50]

There are eight phases describing the human gait cycles for a healthy human body and they are sufficiently general to apply to any type of gait: initial contact (0%); loading response (0-10%); mid-stance (10-30%); terminal stance (30-50%; pre-swing (50-60%); initial swing (60-70%); mid-swing (70-85%); terminal swing (85-100%). The cyclic nature of human gait is a very useful feature for recording different parameters. There are hundreds of parameters that can be expressed in terms of the percent cycle. According to other researches there are five key elements to characterize normal gait: stability in stance (foot and ankle); clearance (of foot) in swing; pre-positioning of foot (terminal swing); adequate step length; energy-efficient manner (normal energy used is 2.5 kcal/min, less than twice than those used for just standing or sitting). In order to assess and estimate the gait cycle from the point of view of its malfunctions modeling and analysis it is necessary to place the human body in a 3D reference system and establish the walking, balance or stability directions.[50]

In this respect, the human motion is positioned and measured about the three axes: X (side balance direction), Y (displacement direction) and Z (bipedal stability direction) [134] (fig.1.2).

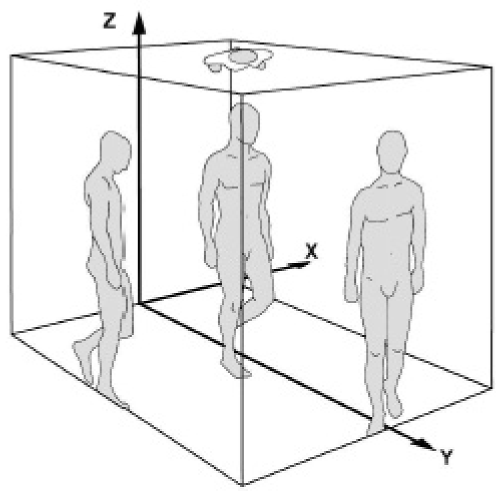


Fig.1.2 Coordinate system for human body motion analysis [134]

The fundamental elements involved in the motions performed by the human body are: bone structure (skeleton), joints (connecting the skeleton elements) and muscles (mobilizing the first two elements). In order to define motions, a reference position called anatomical position represents the starting point, characterized by the fact that the body is vertical, the feet are parallel to each other and flat on the floor, the eyes are directed forward, and the arms are at the sides of the body with the palms of the hands turned forward and the fingers pointed straight down (fig.1.3) [134]

Also in order to analyze the possible motions performed by the human body, three planes of reference are used, as follows: (fig.1.4) [134]

- Coronal (frontal) plane dividing the body into anterior and posterior parts;
- Sagittal plane going vertical through the body and dividing it into the right part and the left part
- Transverse plane, which divides the body into superior (upper) part and inferior (lower) part.

Fig.1.3 Anatomical position [134]

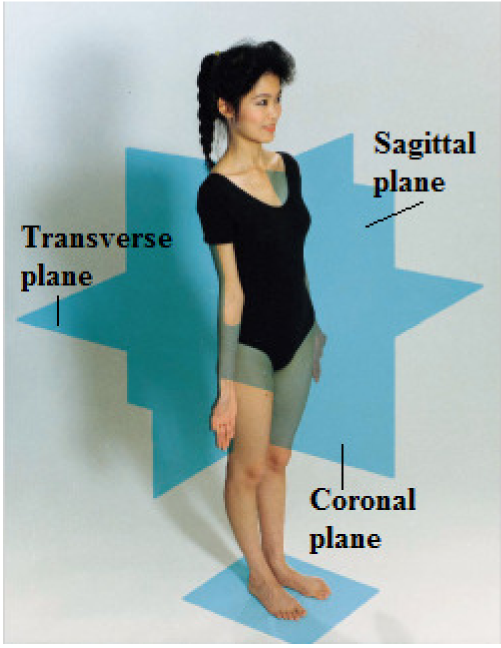


Fig.1.4 Planes of reference [134]

The motions performed by the human body with respect to these planes of reference can be angular motions (flexion – extension in the sagittal plane, abduction – adduction in the coronal plane), circular motions (rotations like pronation - supination and circumduction) and special motions (eversion - inversion, protraction-retraction, depression – elevation). [6]

1.1.2. Modeling human body – possible approaches

The standard biomechanical approach in modeling the human body is to consider it as a system of rigid interconnected bodies.

According to most researchers, like Vaughan and Andrews (1982), there are two ways of describing the dynamics of systems of rigid bodies representing models of human bodies' anatomy. The first one is the method of direct dynamics when the dynamic parameters of the studied system are already known (like forces or moments of forces) and the goal is to determine the kinematic parameters (like accelerations and velocities). The second method is the inverse dynamics method, which calculates kinetic (dynamic) movement quantities, forces and moments of forces, based on known kinematic data, acquired through measurement. [97]

The connection between the dynamic quantities and the kinematic ones is given by the dynamic equilibrium equations:

$$M\vec{\boldsymbol{a}} = \sum \vec{\boldsymbol{F}} \quad (1.1)$$

$$J\vec{\boldsymbol{\varepsilon}} = \sum \vec{\boldsymbol{M}} \quad (1.2)$$

where M is the mass of the system or of a part of the system, a the acceleration, F the forces acting upon the system or part of the system, J the moment of inertia, ε the angular acceleration and M the moment of the forces acting upon the studied system or part of the system.

By definition, a system of rigid bodies consists of a number of bodies linked together (by internal connections) and to the external space (by external connections) in order to achieve a certain purpose [60]. Obviously, by replacing these connections with the corresponding reactions, the results will be internal forces (which respect the principle of action and reaction) and external forces.

According to the parts equilibrium theorem, if the system of rigid bodies is in equilibrium, each part of the system should be in equilibrium while subjected to the corresponding forces. This allows the idea of individually dealing with each part of the system, in this case with each segment of the body by creating the free body diagram.

The inverse dynamics method is mostly used to represent the dynamic behavior of the human body parts but some special conditions are to be met when dealing with it:

- Human body is divided into individual anatomic segments, which are considered as rigid bodies whose mass is concentrated in their centre of mass:
- Anthropometric parameters of the segments are considered to remain unchanged during human motion;
- Air friction is negligible;
- Friction forces due to ground contact and also those in the human joints are negligible;
- The displacement velocity of the entire system is usually constant;
- Gait is considered a repetitive and symmetrical cycle for both lower limbs.

The gravitational force represents the most important external force acting upon all the bodies and their segments. Being gravitational effects, the human body weight and the weight of its segments will act downwards upon the body centre of mass and are also depending on the mass, length, density and number of the moving segments. Though weight is in fact a distributed force, acting upon each particle of a body subjected to gravity, it is well-known that according to the laws of Mechanics, these forces can be replaced with a concentrated force (total weight of the body), which is applied at the centre of gravity (or centre of mass). Therefore, it is imperative to determine the exact position of the centre of mass for each studied part of the human body and also for the entire system, especially when engaging stability and posture researches.[55]

The size and weights of body segments can be very different from one person to another but generally the position of the centre of mass is not so different, as it represents a certain percent of the respective segment length. For this reason, it is a usual practice to express the position of the centre of mass for a certain body segment to be presented as percent of the segment length, measured with respect to the proximal end.

Thus in table 1.1, the positions of the centre of mass for various body segments are presented, as determined from measurements on dead bodies.

Table 1.1 Position of segments CM in percents about proximal end [46]

Source	Braune&Fischer (1889)	Dempster (1955)	Clauser (1969)
Human body	-	-	41,2%

Head	-	43,3%	46,6%
Trunk	-	-	38%
Arm	47%	43,6%	51,3%
Forearm	42,1%	43%	39%
Hand	-	49,4%	8%
Total arm	-	-	41,3%
Forearm and hand	47,2%	67,7%	62,6%
Thigh	44%	43,3%	37,2%
Calf	42%	43,3%	37,1%
Foot	44,4%	42,9%	44,9%
Total leg	-	43,3%	38,2%
Calf and foot	52,4%	43,7%	47,5%

Anyway, there are many possibilities to determine the centre of mass for body segments, like suspension, immersion, modeling or using a force platform, but finally the coordinates of the centre of mass of the entire body are given by the well-known expressions:

$$x_{CM} = \frac{\sum_{i=1}^{n} m_i \cdot x_{ci}}{\sum_{i=1}^{n} m_i}; \quad y_{CM} = \frac{\sum_{i=1}^{n} m_i \cdot y_{ci}}{\sum_{i=1}^{n} m_i}; z_{CM} = \frac{\sum_{i=1}^{n} m_i \cdot z_{ci}}{\sum_{i=1}^{n} m_i} \tag{1.3}$$

where m_i is the mass of a segment i; x_{ci}, y_{ci}, z_{ci} are the coordinates of the centre of mass for the segment i.[60]

In order to determine as accurate as possible, all the anthropometric parameters required by the dynamic equilibrium equations, a lot of painstaking work was done by researchers during the past century and of course many improvements have been made due to technological progress. Based on the average results obtained during these prolonged investigations, the scaling coefficients for length, weight, centre of mass and moment of inertia are presented in table 1.2, according to Winter D.A. [139]

Table 1.2 Scaling coefficients and anthropometric parameters for the main segments of the human body determined for adults (over 18 years old).

Segment	**Length** $L = c \cdot H$ [m]	**Mass** $m = \% \cdot M$ [kg]	**Position of CM about the distal end** $\% \cdot L$	**Moment of inertia** $\% J$ [kg·m^2]
Head	0,126	7,8	50	49,5
Trunk	0,312	49,7	50	50,3
Arm	0,188	2,8	56,4	32,2
Forearm	0,146	1,6	55	30,3
Hand	0,108	0,6	50	39,7
Thigh	0,265	10	59,05	32,3
Calf	0,226	4,65	56.05	30,2
Foot	0,152	1,45	50,85	47,5

where *L* is the length of the segment [m], *c* is the scaling coefficient for length, *H* is the height of the human body [m], *m* is the mass of the segment [kg] and *M,* the entire mass of the human subject [kg] while *J* is the moment of inertia.

Recent studies show that the accurate location of the CM depends on: individual's anatomical structure, habitual standing posture, current position, external support. Generally accepted location of the human body CM is at~57% of standing height for males and ~ 55% of standing height for females, also varies with body build, posture, age, and gender (infant > child > adult - in % of body height from the floor). Also, location of CM remains fixed as long as the body does not change its shape and size. [21, 24]

In order to be able to measure and assess human motion, the velocity and acceleration vectors for the center of mass of each body segment should be determined with respect to a reference axis system. [46] Various two or three dimensional models can be developed in order to perform static or dynamic analysis according to the research requirements.

For example Fisher (1967) and Muth (1978) developed a five link kinematic model as shown in fig.1.5, considering a stationary origin at the ankle joint, axis Ox on the horizontal and axis Oy on the vertical direction.[46]

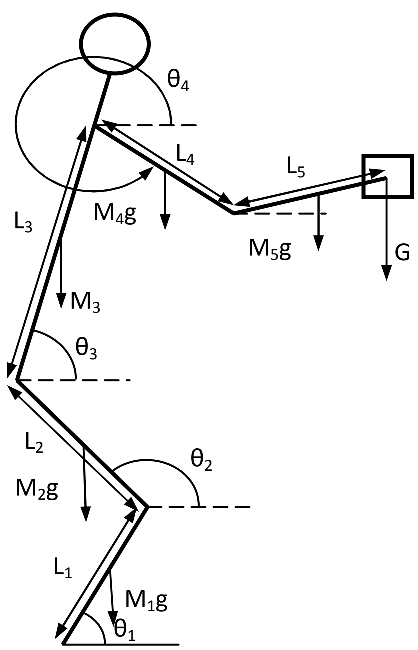


Fig.1.5 Five link model for human lifting an object in sagittal plane [46]

The components of the linear acceleration at the ankle joint, considered to be j=1 are:

$$a_{x1}(t) = 0 \quad (1.4)$$

$$a_{y1}(t) = 0 \quad (1.5)$$

as the ankle joint is considered stationary.

Moving up to the knee (joint j+1) and considering the lower leg length L_1 and the ankle angle $\theta_1(t)$ the acceleration components will be:

$$a_{x_{j+1}} = L_1 \cos \ddot{\theta}_1(t), \quad (1.6)$$

$$a_{y_{j+1}} = L_1 \sin \ddot{\theta}_1(t) \quad (1.7)$$

As the knee joint is moving on a circular arc trajectory, the estimation of the hip joint (j+2) acceleration components should involve relative accelerations of the knee joint (both rotational and linear). For that it is necessary to determine hip accelerations (normal and tangential) considering the length of the upper leg to be L_2.[46]

Thus, the acceleration component normal to L_2 is:

$$a_{n_{j+2}}(t) = \dot{\theta}_2^2(t) L_2 \quad (1.8)$$

while the acceleration component tangent to L_2 is:

$$a_{t_{j+2}} = \ddot{\theta}_2(t)L_2 \quad (1.9)$$

where the first derivative of the angle $\theta_2(t)$ is the angular velocity of the upper leg and the second derivative is the angular acceleration.

In order to obtain the general equations for determining horizontal and vertical components of the acceleration of joints, it is necessary to obtain the projections on Ox and Oy of the normal and tangential acceleration and then combine them with (1.6) and (1.7). The result will become:

$$a_{x_{j+1}(t)} = a_{n_{j+2}}(t)\cos\theta_j(t) + a_{t_{j+2}}(t)\sin\theta_j(t) + a_{x_j}(t), \quad (1.10)$$

$$a_{y_{j+1}(t)} = a_{n_{j+2}}(t)\sin\theta_j(t) + a_{t_{j+2}}(t)\cos\theta_j(t) + a_{y_j}(t) \quad (1.11)$$

After replacing the values of the normal and tangential accelerations, the equations become

$$a_{x_{j+1}}(t) = L_i\left[\dot{\theta}_j^2(t)\cos\theta_j(t) + \ddot{\theta}_j(t)\sin\theta_j(t)\right] + a_{x_j}(t), \quad (1.12)$$

$$a_{y_{j+1}}(t) = L_i\left[\dot{\theta}_j^2(t)\sin\theta_j(t) + \ddot{\theta}_j(t)\cos\theta_j(t)\right] + a_{y_j}(t) \quad (1.13)$$

where L_i are the lengths of the body segments, $\theta_j(t)$ is the angular position of joint j about the considered system of reference, the first derivative of $\theta_j(t)$ with respect to time is the angular velocity of i segment at joint j and the second derivative of $\theta_j(t)$ is the angular acceleration of I segments at joint j.[46]

The equations can also be written for the accelerations of the center of mass for different segments of the body only by replacing L_i with the distance from the joint j to the center of mass of segment i.[46]

1.1.3. Anthropometric measurements

The welfare of the human being depends at a great extent upon the harmonization between the human body size, shape and skills and the things it comes in contact with. The problem becomes most important considering the necessity of customizing prosthetic and orthotic medical devices according to the human subject in order to improve his life quality. This requires accurate measurements of the anthropometric dimensions and also the existence of extensive databases that may be used for various activity areas.

One of the most complex sources of anthropometric measurements was published by NASA in 1978. This database holds measurements for over 306 different dimensions of the human body, coming from 91 different populations all over the world. Of course, each country should have its own anthropometric database as the human body dimensions depend on several factors like: race, age, sex, geographical area, nutrition, health, bone structure type, occupation, genetic inheritance, etc.

The most known and used anthropometric databases are:

- NHANES - National Health and Nutrition Examination Survey (in 3 variants in 1971-1975, 1976-1980, 1988-1994, is being compiled every 2 years to avoid errors)
- ANSUR (or Natick) – United States Army Anthropometry Survey – anthropometric database of American military staff
- CAESAR - Civilian American and European Surface Anthropometry Resource – holds data coming from 3D scans of civilians in different areas of the United States and even Europe. There are approx. 4000 subjects, aged 18 to 65, selected from various ethnical groups, with different body weights, sex and social-economical status.
- DINED – anthropometric database created within the Technical University of Delft, Holland
- BIFMA – Business and Institutional Furniture Manufacturer's Association is based on the military database Natick, considering the fact that users are active persons of corresponding ages
- CLEOPATRA – anthropometric database accomplished with the support of the National Council for Research from Canada in order to facilitate tailoring clothes.

In order to obtain anthropometric data for designing databases, measurements are performed on representative samples, selected according to race, age, sex, occupation, geographical area criteria, etc. Measurements can be:

- Classical measurements or by direct contact with the subject, performed by help of instruments like: special calipers, goniometers, measuring bands, special rulers, etc.
- Measurements without direct contact with the subject, performed by 3D scanning methods and using different software for processing information.

1.1.4. Stability and equilibrium

A material system (including the human body) is said to be in statically equilibrium if the resultant force and the resultant couple of the forces acting upon that system with respect to a certain origin are zero.

$$\begin{cases} \sum \vec{F}_i = \vec{R} = 0; \\ \sum \vec{M}_i = \vec{M}_O = 0, \end{cases} \tag{1.14}$$

Any unbalanced force will produce a linear acceleration, while any unbalanced couple will produce an angular acceleration.

The bipedal stability of the human body is assured by some elements of the body structure and is influenced by a range of external and internal factors acting upon it. Generally, in the studies dedicated to the biomechanical analysis of the human organism, a certain range of factors are considered for study, keeping others (internal, anthropometric and biologic) within normal limits, without significant changes with respect to the organism evolution along the experiments.

The stability, balance, locomotion or other types of processes of the human body are assured by the locomotion system that is supported by the plantar surfaces of both feet. The system elasticity is assured by the joints, muscles and tendons, while the rigidity is secured by the bone structure and the control of the entire system being coordinated by the vestibular, visual sensorial systems by means of the central nervous system (CNS).

Beside the CM another important parameter for defining the stability state is determined by the center of pressure (CP) defined as the point where the resultant of all ground reaction forces act and also defined as the vertical projection of the center of mass to the ground.

From the point of view of stability and balance of the human body structure there is to consider the determination of the stability with respect to the ground position and respectively to the type of motion the structure is involved in. [55]

Also an important input in these determinations is brought by the influence factors due to the environment or due to the arrangement area of the human body structure or due to the equilibrium types (stable, unstable or neutral) and maybe not last due to the psychological and physiological state. Thus, the support surface can be differentiated with respect to the contact zone and external support points in the following forms of size and shape of base of support (BOS): wide-base stance; tandem stance: standing with one foot ahead the other; stance with crutches. The BOS represents the minimum area enclosing the body’s contact with the ground (fig.1.6).

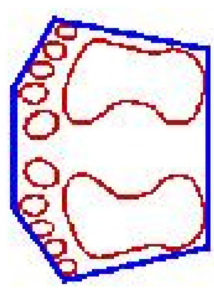


Fig.1.6 Base of support (BOS) [140]

Other aspects related to the influence factors are analyzed in a series of researches out of which the following can be synthesized: height of CM; relationship between CM and BOS; mass of body; friction; segmental alignment; sensory input, visual and vestibular system; proprioception; psychological or mental status; muscle activities acting to prevent collapse of the skeleton; fatigue resistance; physiological and pathological factors.[140]

The biomechanical goal of the human body stability analysis is to adjust the relation between the CM and the BOS.

Situations requiring balance can be classified into three general conditions:

- Keeping a stable position,
- Postural adjustment to voluntary movements, and

- Reactions to external predicted and unpredicted mechanical perturbations (slipping or stepping).

In dynamic stability, both the BOS and the CM are in relative motion. Prevention of falls requires effective balance function under dynamic conditions because most falls are caused by sudden motion of the BOS or by sudden acceleration of the CM.[98]

The main key to dynamic stability is the momentum control of the COM. The distribution of body mass is achieved by two-thirds of mass distributed in the head, arms, and trunk and the rest into different human body parts. Because of the large mass and inertia moment of the upper body, its position and movement (forward momentum) can be critical in the overall stability of the upright stance.

For that, stability can be defined as the ability of human body to return to its original state that means desired actions or movement trajectory after a disturbance or stable position.[55]

Studies were performed using the experimental diagram is shown in fig.1.7.

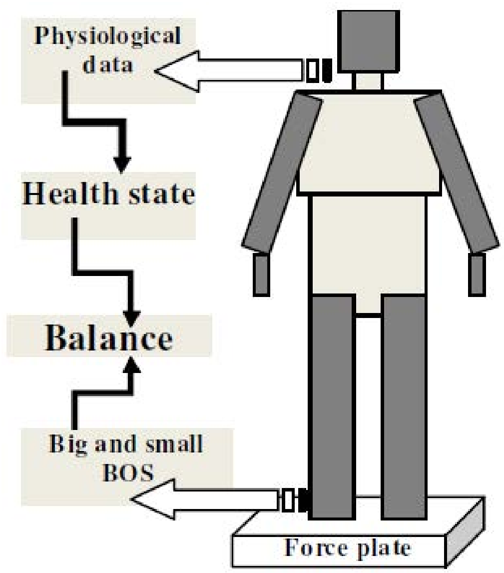


Fig.1.7 Experimental diagram for studying balance [55]

The subjects sample participating in the experiment consisted of 11 persons aged between 23 and 56 years, with normal anatomical configurations but also with specific features. These subjects were investigated in the same environmental conditions, at the same time during one hour in order to avoid the metabolic and physiologic changes.

The experimental setup consists of a Kistler force platform that allows the forces and torques measurement developed by the human body in balanced bipedal position and an assembly of devices for the assessment of the subjects' physiological stance. The setup is completed by a video recording system and also an image processing soft on an advanced computer.

The recordings of the stability stance were developed on the same experimental configuration, during a longer time interval each time, with open eyes or closed eyes, with big support base (corresponding to each subject). The recordings time was about 20 sec for each subject and the results were displayed according to the Oz force (fig.1.8) and respectively to the stability area of the subject upon the force platform. (fig.1.9).

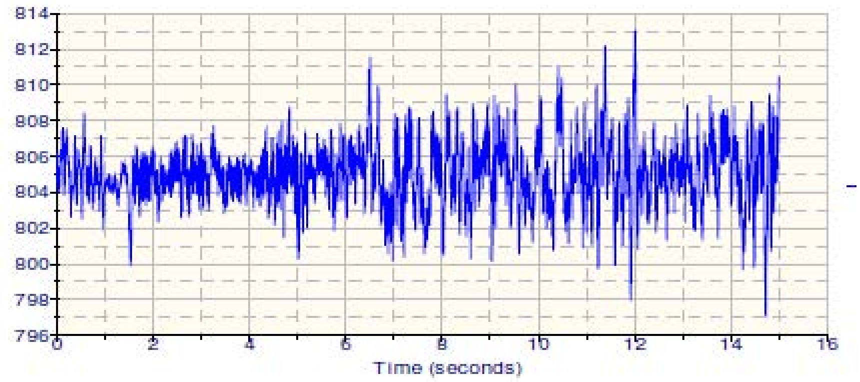


Fig.1.8 Diagram of the reaction force on Oz [55]

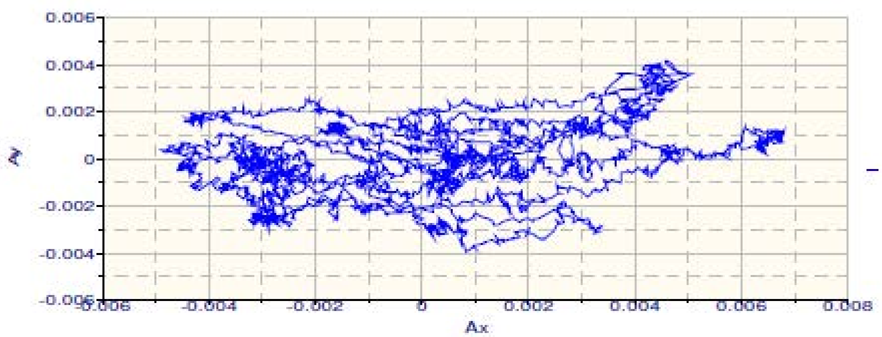


Fig.1.9 Stability area on the force platform [55]

The experiments were developed following the standard procedure, namely the previous briefing of the subjects, performing a set of trial recordings to avoid the acquisition jams, preparing the subjects for recording (position, posture, reactions, etc.), initial physiological data acquisitions and then real recordings. Thus a set of 3 experiments was performed, each with two required situations (open eyes, closed eyes along the recordings on the force platform) for the entire subjects' sample. The 3 experiments consisted of data acquisition concerning the bipedal stability of the subjects in two required situations and took place in the morning (between 9 am and 10 am), in the afternoon (between 1 pm and 2 pm) and in the evening (between 6 pm and 7 pm).

For the results exemplification one of the subjects was chosen, having the weight 80,4kg, female, aged 52, that was recorded in the above mentioned conditions, was instructed to maintain a bipedal position with big base of support, arms along the body, open eyes, look ahead and no visual or acoustic stimulus (the subject wears glasses being near-sighted). The force plate and the data acquisition system were calibrated for each measurement as the subjects have different weights and the filtering basis will change. From the diagram presented in fig.1.10 only the change of the minimum force during recording time in comparison to the maximum values of the force measured along Oz, during the same time provides changed values. By comparing the values presented in fig.1.9 and 1.10 there will be noticed that the subject was more stable (values close to the nominal weight) at the beginning of the recording time, unlike the final time interval when the subject showed unbalance and lateral balance due to a complex equilibrating – re-equilibrating system, which acts every time upon the entire human body and attempts to keep the balance towards the external forces.

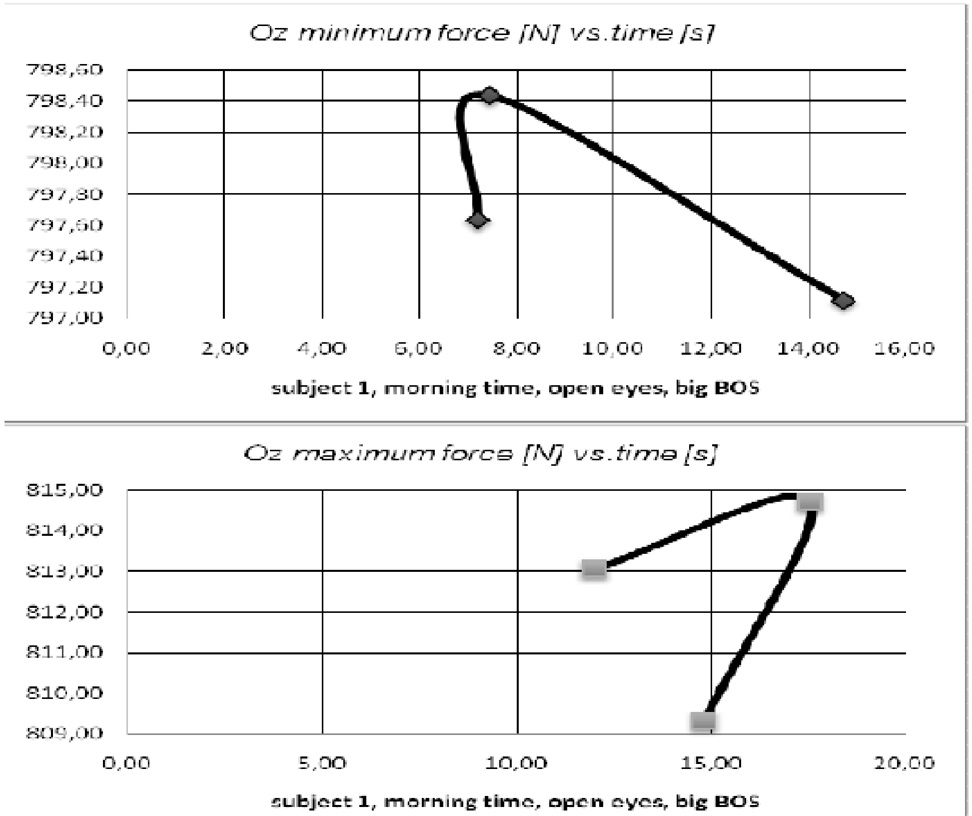


Fig.1.10 Minimum and maximum reaction force during balance [55]

The explanations of human postural control system are very complex approaches and they involve multiple sensory systems and motor components. There are possibilities of investigating human balance control under quasi-static (unperturbed) conditions or dynamic (perturbed) conditions, but despite these approaches, a very important variable remains, the fact that sensorial motor components are integrated into the postural control system and the system uses similar mechanisms and strategies under quiet-standing and perturbed conditions. Having the complexity of the postural control system, it can be considered that its output is highly irregular. For example, during quiet standing the centre of mass (COM) under an individual's feet continually fluctuates in a stochastic manner. (fig.1.11)

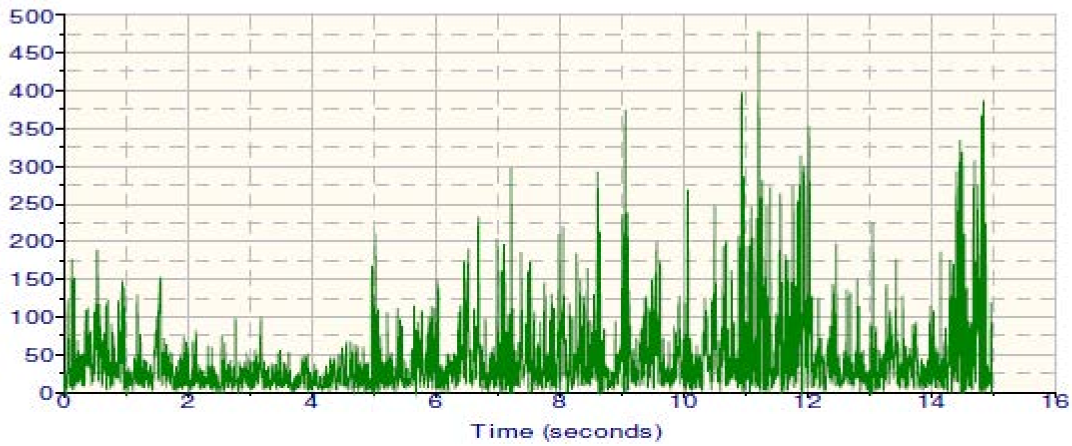


Fig.1.11 Position of COM during quiet standing [55]

From the analysis of the diagrams in fig.1.12, referring to the same subject, in bipedal position, for 16 sec, without external stimuli we may notice a behavior according to the stance (closed eyes) that induces a certain initial instability (first 4 sec) which is fast compensated by the subject due to the neural-sensorial mechanisms controlling the muscular system.

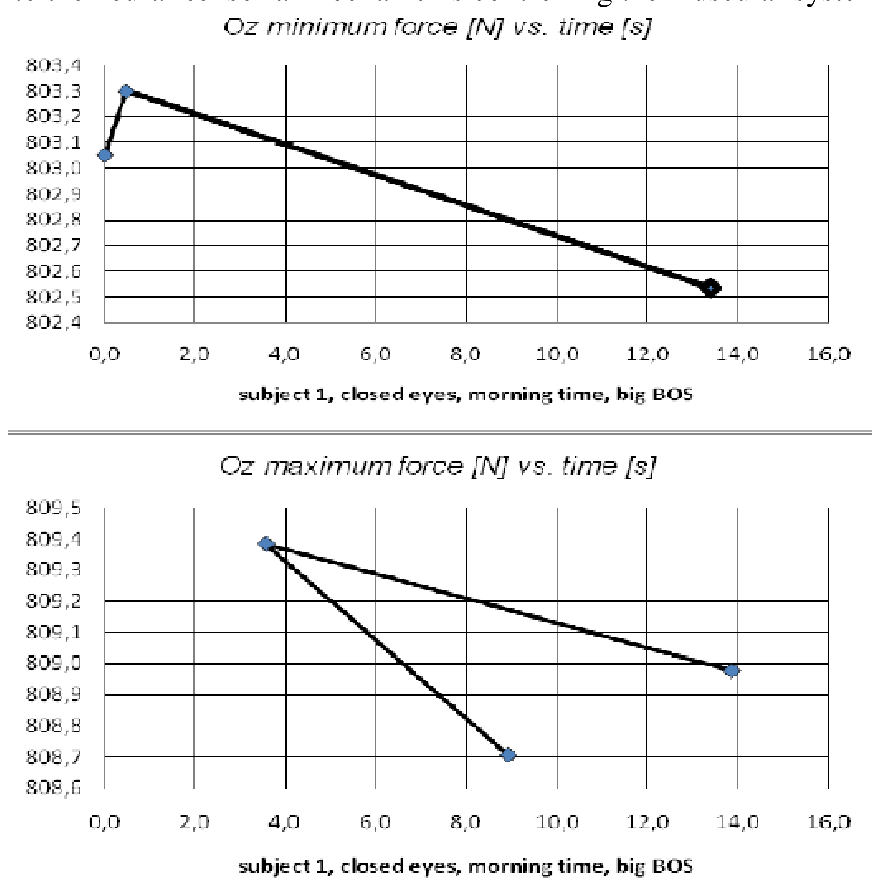


Fig.1.12 Minimum and maximum reaction force, closed eyes [55]

By extending the analysis to the entire subjects' sample similar manifestations may be noticed but also specific aspects according to the analyzed stability type. The determinations made by correlation (accelerations on three directions correlated with the speeds, COM displacements on Oz and Oy, variation of the stability axis correlated to the base position and subject vertical inclination) showed a complex connections mechanism between the human body structures so that once determined a measurement, this may be considered an initial element and transformed in an evolution parameter.

By this set of procedures the behavioral performances of the subjects can be assessed and their physical or psychical fatigue degree along an active day may be determined. These recordings may indicate in time a certain manifestation of the neural-sensorial equilibrium instability and not last some correlations between the metabolic level and the organism wear may be established.

1.2. Assessment and analysis of human motion dysfunctions

The motions of the human subject are reflex acts, meaning responses of the locomotion system, in all its neuro-motor complexity, to the multitude of signals arriving along the sensorial paths. Any motion, as simple as it might be, is a simple unique reflex, resulting from the connection of million reflexes, “informing” of the nervous centers, allowing the assurance of controlled and permanent coordination of motion during their performance. The accurate coordination of motions does not come all of a sudden, it is the follow up of a long series of repeated and interpreted “exercises”, which determine the setting on the cerebral cortex of some temporary connections whose stability increase according to the number of repetitions and exercises stored within the central memory.

As a follow, the motions of the human body are performed by a series of muscles groups, which form a harmonious assembly of muscular-kinematic chains, created according to the motion particularities under the control of the cerebral cortex. The motions performed by the human body have spatial directional characteristics of the motion and of the trajectory length travelled by the body or the body segments. They may be continuous, interrupted or combined according to a certain succession. The ratio between the spatial and temporal characteristics that establish the velocity and also acceleration parameters of the motion and all these characteristics as a whole, represent the kinematic particularities of the motion: where, how much and how is the body and its segments moving, along which trajectories described by the body segments and which controlled way is the complex motion of the human body performed.

All these aspects are important to be known when the dysfunctions of the human body locomotion system are analyzed.[53]

1.2.1. Biomechanical studies of hip implanted persons

Prosthesis and/or orthosis use on neuro-motor deficient persons is absolutely necessary for many patients with bones and joints, ligament, muscular, vascular, peripherical and/or central neural deficiencies. It plays an important part within the rehabilitation measures for these patients. Prosthetics is a mean of replacing a missing anatomical segment (congenital or taken). It may be for esthetical reasons (for limbs or eye-balls), for functional mechanical purpose or using bio-currents.

Orthotic devices are used to increase the functionality of an already existing anatomical segment, which proves to be deficient from morpho-functional point of view. It is highly important that the prosthesis or orthotic device is applied in due time, as soon as possible, first on temporary basis and then on a long term basis or for the rest of the patient's life. The gait re-education is required for all forms of locomotion deficient persons.

Kineto- therapy is an important source, offering the best possible recovery to the patients. Exercises should be carefully dosed in order to avoid the human subjects' fatigue. For better and long term efficiency they need to use relaxation techniques, simple balances and rhythmical techniques, which stimulate the vestibular system in order to obtain the general relaxation of the body muscles. The rocking-chair use reduces the muscular tonus and decreases the stiffness, as well as the rhythmical and slow roll-over the mattress have the same effect. The upside down head posture, such as the patient resting with the ventral area on a big ball produces a general relaxation by activating some medullar centers – methods that should not take too long in order to avoid the change of other physiological parameters. Thus, a series of respiratory exercises are performed with the purpose of increasing the thoracic and diaphragm mobility, while the deep and slow breaths lead to the mitigation of muscular stiffness. In order to obtain optimal results, the active and passive mobilizations must be made several times a day, thus recommending techniques of neural-muscular and prioceptive facilitation: contraction – relaxation, passive prolonged stretching.

At the same time, the exercises should be correlated with the self-caring functions because they raise the motivation and reduce some exercise abandoning manifestations.

During performing the recovery or training actions, some verbal commands even accompanied by musical rhythms are very useful, as well as big mirrors closely positioned may help to the motions regularity

During the analysis of the human motions locomotion disabilities, a synthetic concept model has been developed in order to emphasize the causes and the main milestones in measuring and assessment

In this respect it was found that the locomotion dysfunctions should be treated as substantial changes of the human body kinematics, reflected to the level of reaction forces magnitude and direction between the locomotion system and the ground.

Fig. 1.13 presents a synthetic model of key factors that contribute to quasi-static and dynamic postural control. This model includes feed-forward and feedback control functions. The anticipated postural disturbances, involuntarily known by the subject arise from the forces generated during the performance of voluntary motion, or in anticipation of destabilizing external forces.

This type of postural adjustment, referred to as anticipatory, involves estimation of the magnitude and direction of postural disturbance and initiation of a motor program by the central nervous system. The motor program is a set of commands that is selected based on an internal or previous model of the task to be performed. Once initiated, the motor program is executed in an open loop manner, but with the potentially processing delays inherent in feedback control. Ideally, the motor program activates the musculature that produces a set of appropriately scaled and timed pre-emptive muscle forces and joint moments that precede and deny the anticipated postural disturbance. During feedback control, a postural disturbance, the origin of which may be either internal or external, causes a change in body posture or movements. If the change in kinematics exceeds some threshold value to which the central nervous system has assigned importance, a corrective postural response will be generated.[53]

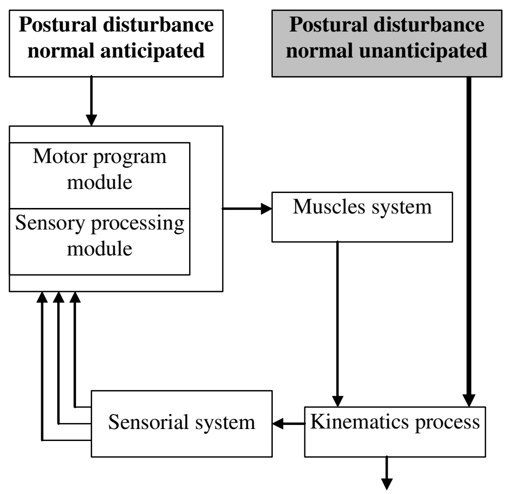


Fig.1.13 Data model of human static or dynamic posture [53]

The changes in the kinematics process stimulate visual, vestibular, and somatic-sensorial system, sensors that transmit the information to the central nervous system. Information processing by the sensorial system involves comparisons for detecting the state of the body into a desired state. In an ideal configuration, if the difference between the detected and desired states, that is, an error signal, is of sufficient magnitude, a corrective postural response consisting of muscle forces and joint moments will be executed to obtain the final response. The muscle forces and joint moments affect body kinematics, generating a new set of sensor information signals and another loop of the feedback process is initiated in this model.

Each patient reacts differently to gait dysfunctions, so each should be treated in a personalized manner, according to the problem gravity, age, weight, anthropometric dimensions, previous illnesses and so on. This is the reason why the assessment methodology should be flexible and adjusted to each studied subject.[53]

This is the reason why several subjects were investigated according to their health issues and adaptability to test requirements.

One of the subjects is female, 74 years old and presents the need of replacing the previously implanted hip prosthesis (7 years old) as shown in fig.1.14.

The analysis of the X-ray images of the human subject reveals functional and position abnormalities and the decision of the medical staff was to replace the implant with a new one adjusted to the new bone configuration.

Due to wear and changes of the bone structure, the subject's gait was changed from the time of implant introduction until the investigation time determining an increase of the locomotor malfunction also accompanied by painful manifestations.

In order to perform the objective researches, a flexible and interconnected system consisting of a Kistler force platform, computerized data acquisition and processing system, high speed video camera with 500 frames/sec and licensed software was developed (fig.1.15).

Fig. 1.14 X-ray image of the previous implant[53]

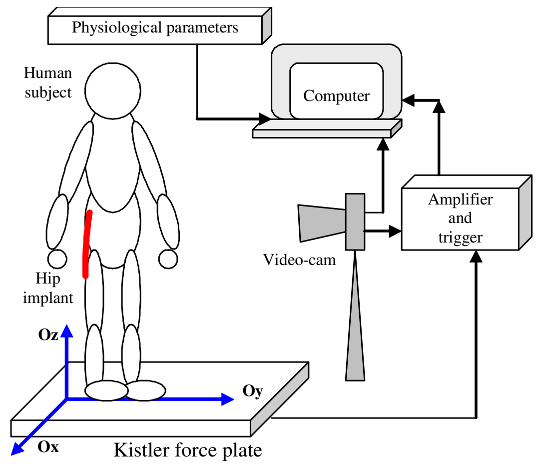


Fig.1.15 Experimental setup [53]

The Kistler platform allows the measurement of the force exerted during contact between human feet and the ground surface. It can be used in both static and dynamic conditions, for studying balance and locomotion. It is equipped with four piezzo-electric sensors, located in the four corners used for transforming a mechanical action into an electric signal. [37]

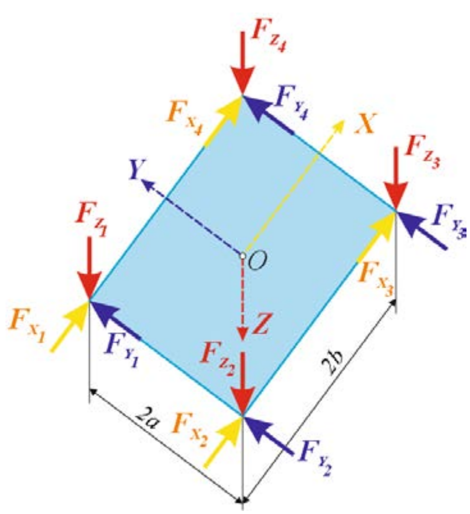


Fig.1.16 Forces components measured by the Kistler force platform [37]

The values of the forces' moments will be determined following the measurements of the reaction forces and the relative positions of the sensors on the force platform. Thus, the force applied on each sensor consists of three components: F_x, F_y, F_z, so finally a number of 12 components is obtained as shown in fig.1.16.

In order to obtain the six components of forces and moments, the following equations are required: [97]

$$F_x = (F_{x1} + F_{x4}) + (F_{x2} + F_{x3}), \tag{1.15}$$

$$F_y = (F_{y_1} + F_{y_2}) + (F_{y_3} + F_{y_4}), \tag{1.16}$$

$$F_z = (F_{z_1} + F_{z_2}) + (F_{z_3} + F_{z_4}), \tag{1.17}$$

$$M_x = [(-F_{z_1} - F_{z_2}) + (F_{z_3} + F_{z_4})] \cdot b, \tag{1.18}$$

$$M_y = [(-F_{z_1} + F_{z_2}) + (F_{z_3} - F_{z_4})] \cdot a, \tag{1.19}$$

$$M_z = [(F_{x_1} + F_{x_2}) - (F_{x_3} + F_{x_4})] \cdot b + [(F_{y_1} + F_{y_4}) - (F_{y_2} + F_{y_3})] \cdot a \tag{1.20}$$

where: F_x is the anterior-posterior reaction force, [N], F_y is the lateral reaction force, [N], F_z is the vertical reaction force, [N], $F_{x1,}$, F_{x2}, F_{x3}, F_{x4} are the components of the anterior posterior reaction forces for each of the four sensors, [N], $F_{x1,}$, F_{y1}, F_{y2}, F_{y3} F_{y4} are the components of the lateral reaction forces for each sensor, [N], F_{z1}, F_{z2}, F_{z3} F_{z4} are the components of the vertical reaction forces for each sensor, [N], M_x, M_y, M_z are the moments of the force platform along the axes *Ox*, *Oy*, *Oz*, [Nm] and *a*, *b,* the coordinates of the platform centre of mass, [m].[97]

The investigation conditions were established at the initial temperature, humidity and atmospheric pressure parameters, within normal limits.

The researched human subject was initially investigated and the physiological parameters such as: pulse, temperature, blood pressure, weight and height were recorded during different times of the day, when the investigations took place. The measured physiological data of the human subject are the following: height 1,6m; weight 55,31 kg; temperature 36,3C^0; blood pressure 14,3/7,4; pulse 70; recording observations – partial help for climbing up and down in order to preserve balance.

By help of a previous established procedure the experiments aimed at the assessment of the dynamic parameters for different gait variants performed by the human subject, thus accomplishing recordings before the surgical intervention, immediately after and one month after, carefully preserving the same investigation methodology.[53]

Analysis processed by help of the experimental structure proposed for this research and presented in fig.1.15 revealed locomotion malfunctions, allowing the development of a faster and optimized gait rehabilitation procedure.

Using this system, a series of recordings were performed according to the following gait possibilities: normal gait, added step gait, dragged gait, paced gait (marching) and backwards gait. These recordings of the gait modes were done before the implant replacement but also immediately after the surgery, when obviously only one gait mode was possible without external help or support.

After the first recovery period (one month) the recordings of the gait modes were repeated, observing by means of the dynamic parameters analysis measured on the force platform, an obvious improvement.

Also the X-ray results prove the regaining hip mobility, these being corroborated with the results obtained from the software modeling and those recorded by help of the experimental setup.

The recordings were made during various times of the day before the surgery and the obtained results are presented in the following figures.

The average period of a recording was 10 sec and the motion was performed in two steps, the first one being the leg without an implant (fig.1.17).

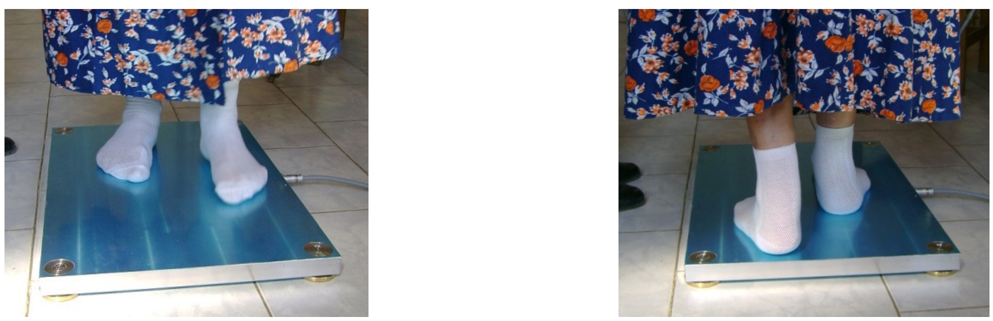


Fig.1.17 Human subject moving on Kistler platform [53]

The results offer valuable information about the values of the ground reaction force Fz, about the stability area, the forces recorded by the four piezzo-electric sensors, also the variation of the centre of forces position (fig.1.18-1.21). The recordings are presented for normal gait, before surgery.

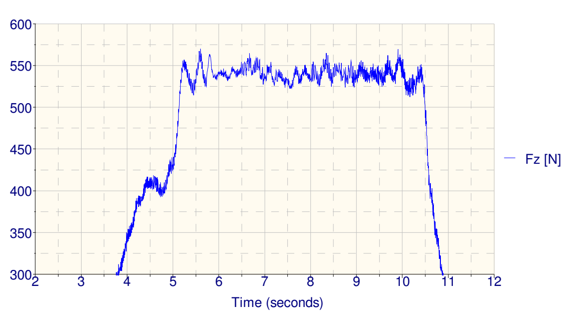


Fig.1.18 Fz during normal gait [53]

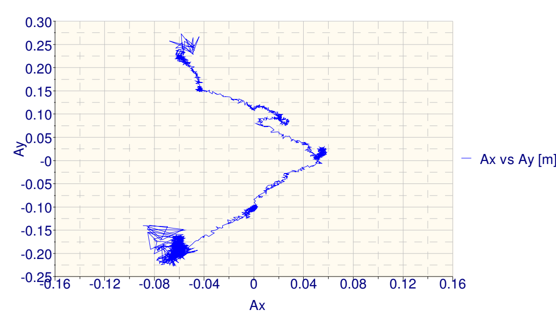


Fig.1.19 Stability area, normal gait [53]

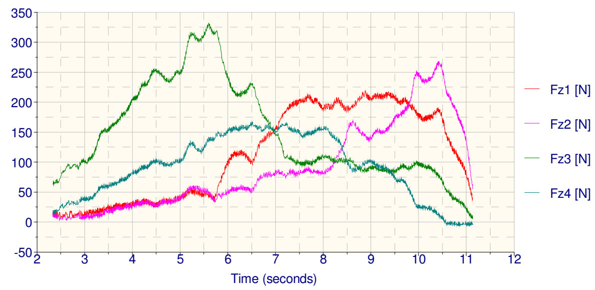


Fig.1.20 Forces in the piezzo-electric sensors[53]

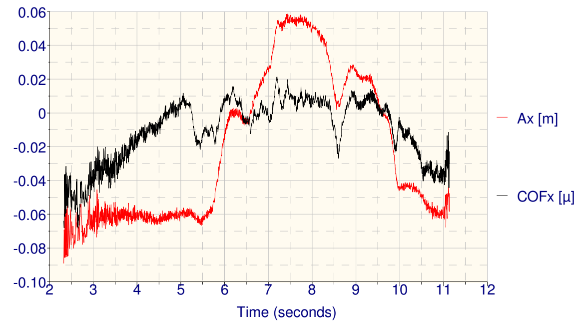


Fig.1.21 Variation of Ax and COFx [53]

As shown in the previous figures, the human subject with a 7 years old hip implant presents an important change of the normal gait, the support during gait is mainly made on the left leg, the right one being protected because it produces pain; also a strong unbalance between the reaction forces on Oz measured by the 4 piezoelectric sensors (fig.1.20) and last but not least a displacement of an important part of the body weight upon the left leg joint, respectively a displacement of the gravity centre projection on the support surface with the tendency of falling outside it (fig.1.21). [53]

In this respect the surgery – change of hip implant – will have to correct the deficiencies and return the mobility and motility of the locomotor system within normal limits.

Analyzing the other gait modes – added, dragged, paced and backwards we may conclude that in all cases important deviations from the normal limits occur, the subject loses balance and requires support and help during displacement, also claiming pains.

One week after the surgery, the investigations were resumed and the same set of measurements was performed in the same environmental conditions.

The recorded physiological parameters during this intermediate investigation (a week after the surgery) were: weight 54,33 kg; temperature 36,3 C^0; blood pressure 12/7; pulse: 77; medical diagnosis: total hip prosthesis surgery using a cemented prosthesis; with the following observations: climbing up and down the force plate required partial help for preserving balance, while during normal gait the subject moves heavily using a metal frame.[53]

In the next figures (1.22-1.25), the recordings results are presented, showing that the displacement period is significantly longer (double), also the values of the force on Oz changed dramatically, thus emphasizing the post surgery discomfort.

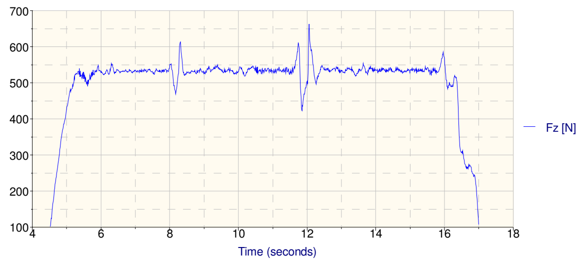


Fig.1.22 Force Fz one week after surgery during normal gait [53]

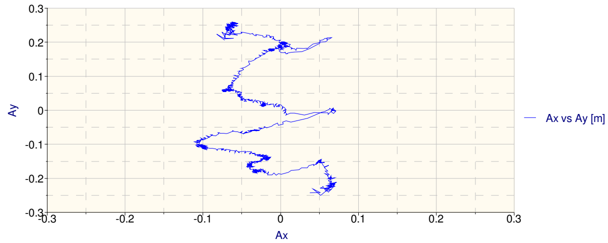


Fig.1.23 Stability area post surgery [53]

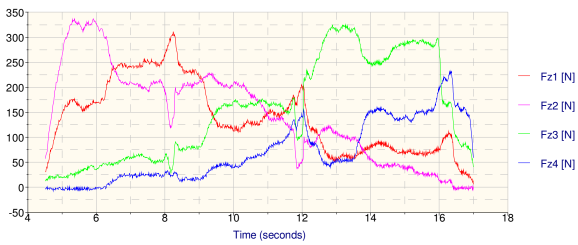


Fig.1.24 Forces in the piezzo-electric sensors [53]

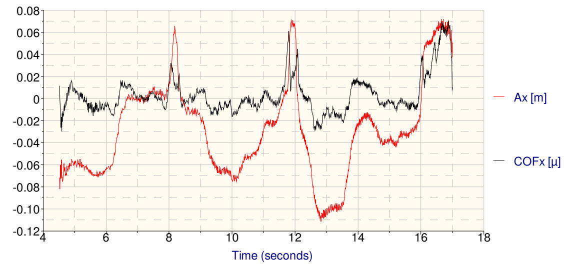


Fig.1.25 Variation of Ax and COFx [53]

After a six week recovery period, the same subject was investigated using the same experimental structure and the same environmental conditions.

The physiological parameters recorded after six weeks from the surgery, changed as follows: weight 56,7 kg; temperature 36,3C^0; blood pressure 15,5/9 at the beginning of the recordings and 14,8/8,6 at the final of the recordings; pulse 77 and respectively 78; observations: partial help on climbing up and down the platform for balance preserving, during gait subject still needs sometimes a crutch; there are slight pains but without incurring locomotor discomfort.

Out of the recorded data at this moment a significant improvement of the subject's normal gait may be observed, due to the similarity increase between the graph of the measured reaction force and the normal graph shape.

An eloquent example proving the above stated is represented by the comparative analysis of the Oz reaction force graph during the dragged gait (because great pains were claimed and previously this type of displacement was used) in three research stages: before, immediately after and six weeks after the surgery (fig.1.26-1.28).

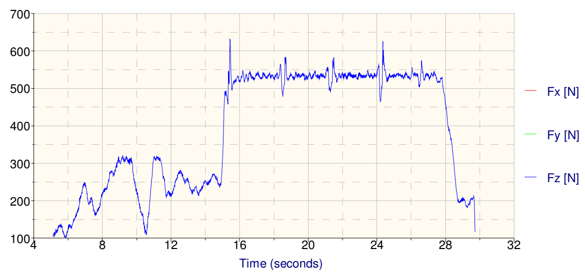


Fig.1.26 Force Fz, dragged gait, before surgery [53]

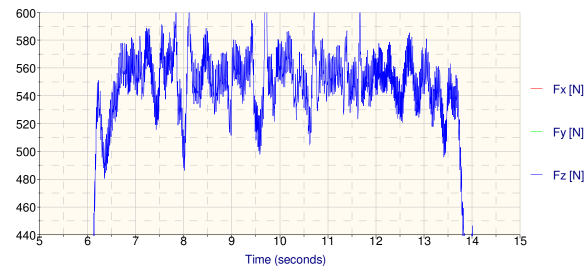


Fig.1.27 Force Fz, dragged gait, one week after surgery [53]

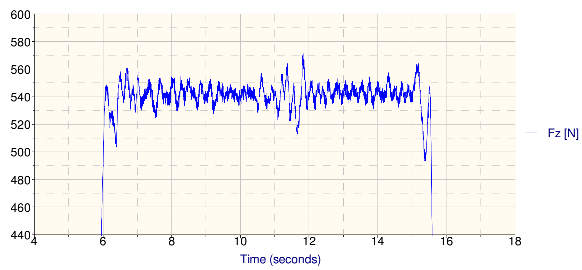


Fig.1.28 Force Fz, dragged gait, six weeks after surgery [53]

In this respect it can be mentioned that the displacement period for this gait mode constantly decreased, the subject having an increased mobility and a correct balance.

Also the variations of the reaction force are constant around 540N in six weeks post surgery situation (fig.1.28), unlike the initial situation when this value was not constant, the variation being between 100 N and 590 N (fig.1.26). [53]

Using these recordings, the recovery stage of the human subject could be rapidly and optimally assessed, it is obvious she gained a better mobility and easier adopted a more balanced posture and firmer displacement.

The used experimental structure is flexible, easy to manipulate and gives the opportunity of creating an objective database for each investigated subject, this way being able to mitigate the locomotion recovery and rehabilitation period of the implanted patients.

The biomechanical analysis of gait, stability and balance analysis, position of centre of mass are important parameters that can be used to assess the results following a hip implant surgery. This is where the medical engineer should be able to provide procedures and methodologies in order to obtain a pertinent assessment of the subjects, before and after the surgery, thus offering to the medical staff enough data to plan the correct rehabilitation methods and the exact areas where the problems are yet to be solved.

1.2.2. Correlative investigations of static and dynamic parameters for hip implanted persons

Mainly, the measured parameters are needed to provide information both regarding the static results (especially balance in different support bases) and dynamical results regarding the forces, dynamic ratio, and plantar pressure during gait, before and after the surgical intervention.

In order to determine the static balance, a Kistler force platform was used, while the subject was required to assume different support bases (small, intermediate, large) and the reaction force on Oz, together with the stability area were represented by help of the dedicated software (Bioware).

For the dynamic part, concerning the subject's behavior during walking, a pressure platform was used (FootScan) while the subject was required to perform different types of gait according to the physiological possibilities (normal gait, added step gait, lateral gait, march, backwards gait), each of the gait types being able to provide various information about the subject's mobility.

Another important factor that might have influence the measurements is the environment. For this reason all the measurements were performed in similar environmental conditions, meaning the same time of the day (so that the influence of light would be the same), same temperature in the laboratory and the subject was inquired about the general health and fatigue status. The subject was a 50 years old woman, in a general good health but suffering from osteoarthritis for a long time. She was advised by her doctor to accept a hip implant and according to the X-ray comparative results, an obvious improvement can be observed. (fig.1.29-fig.1.30). But for an objective assessment, static and dynamic measurements of some kinematic parameters are required.

Fig.1.29 X-ray before surgery

Fig.1.30 X-ray after surgery

In order to perform the static measurements, a Kistler force platform was selected. Of course, it could also be used for dynamical measurements but it was decided to use for the dynamic assessment the plantar pressure platform because the surface available for motion is larger [115] and the subject was able to take more steps [71, 72].

Kistler force platform is in fact an active transducer working on the piezzo-electric principle. It was used to determine the value of the force directed along Oz (normal reaction) and also the position of the CM projections during balance based on which the stability area is represented. Certainly, several other parameters were determined, like forces on Ox and Oy, moments, forces in the piezzo-electric sensors, etc. but only the most relevant ones are presented.

The assembly used for measurement is shown in fig.1.31 and consists besides the Kistler platform, of two wooden platforms having the role of damping the difference of level between the plate and the floor and also a buffer material. So the subject will step naturally on the plate from the wooden platform without being influenced of the gap [98].

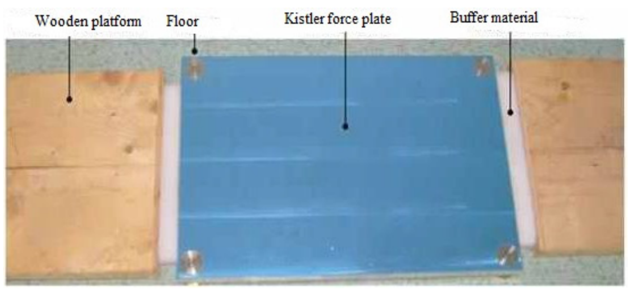


Fig.1.31 Measurement assembly used with the Kistler platform [71]

The Kistler platform is first connected to a laptop provided with the Bioware software and is calibrated in order to eliminate the possible errors. The weight of the subject is determined (70kg) in order to be able to compare the normal values of the reaction force with the measured ones.

The subject was asked to assume an equilibrium position using a small base of support (fig.1.32), then an intermediate one and finally a large one (fig.1.33), for 10 seconds.

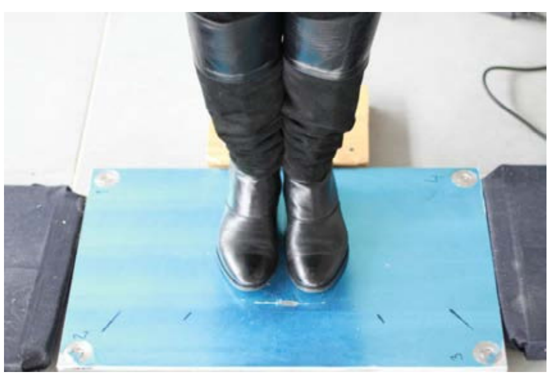


Fig.1.32 Subject assuming small BOS [71]

Fig.1.33 Subject assuming large BOS [71]

The same parameters were measured before and after the arthroplasty surgery: reaction force Fz, area of stability, forces in the four piezzo-electric sensors, variation of the centre of forces position, etc. The most relevant from the equilibrium point of view is the area of stability, presented in fig.1.34 and 1.35, before and after the surgery, for a small BOS, as for this situation the subject encounters several difficulties in maintaining balance.

If the stability area representation is analyzed, it becomes obvious that the subject has the tendency of "protecting" the affected leg by leaning mostly on the healthy one. The projections of the body centre of mass are scattered in the area of the affected leg and they look more uniformly distributed in the area of the healthy leg.

The analysis was also performed for the other two types of bases of support, all indicating the fact that the forces applied to the healthy leg are considerably larger and most of the balance is based upon the action of the left leg (healthy).[71]

The same measurements were performed after the surgery (six weeks after the surgery) when the subject was allowed to walk without any external aid (without crutches). The subject was required to assume the same three positions, three times and the same measurements were determined.

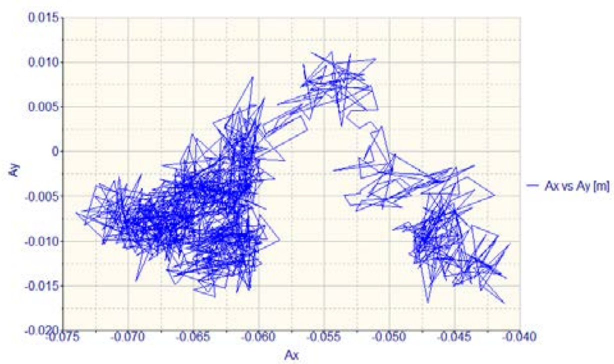


Fig.1.34 Stability area in small BOS before surgery [71]

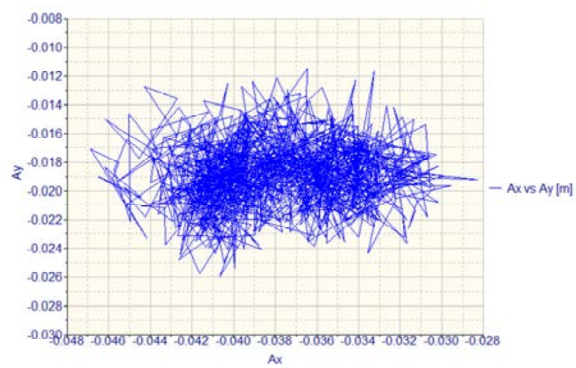


Fig.1.35 Stability area in small BOS after surgery [71]

The analysis of the graphic representation after the surgery shows a very different situation. The subject benefited of suitable kineto-therapy as soon as possible and the results are obvious. The stability area became more symmetric, both legs are subjected to similar loads, which leads us to the conclusion that the pelvis inclination returned to normal while the spinal cord would be no more subjected to abnormal inclinations.

The static analysis provides valuable information regarding the subject's balance and posture but in order to achieve a complete and thorough analysis the dynamic investigations should not be left out.

To perform the dynamic investigations a plantar pressure platform (FootScan RSScan) was used and connected to a laptop provided with the dedicated software that allows 2D and 3D representations, graphical and numerical results.

In order to assure the measurement objectivity the pressure platform was covered with some plastic rugs, so that the subject does not change the manner of walking when stepping on the platform (fig.1.36).

Fig.1.36 Plantar pressure platform covered with plastic rugs [71]

First the platform is calibrated in order to avoid errors and also some personal data, very important being the shoe size. Then the subject was asked to walk in different manners: normal, added step, march, lateral, backwards, starting alternatively with the right foot (affected) and with the left foot (healthy).[71]

Before the surgery, the subject was unable to perform march, lateral gait and backwards, especially when asked to start with the bad foot.

A simple visual analysis of the subject's gait shows an obvious limp, the person is supporting more weight on the healthy leg, the pelvis is asymmetrically inclined and the spinal cord abnormally bent. [89]

The plantar pressure is represented in fig.1.37.

In order to explain the image, it must be said that red color represents higher values of the pressure, yellow a little lower, while green and blue are expressing small values.

The image clearly shows a higher pressure on the healthy foot (left) especially in the heel area, confirming the fact that the subject is trying to protect the bad leg.

After the surgery, the subject was able to perform all types of gait, even march which requires lifting the knee at 90^0.

Visual analysis of subject's gait after surgery leads to the following conclusions: the subject is able to perform all types of gait, the posture is much improved, the head looks up, the limp is almost gone especially when the subject is focused upon the motion and does not surrender to the past habits. The spinal cord is straight and the pelvis has a normal inclination during gait.

The plantar pressure for normal gait after the surgery is represented in fig.1.38, so that the comparison to the old recording can be made.

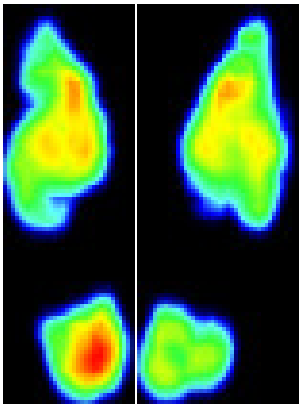


Fig.1.37 Plantar pressure during normal gait before the surgery [71]

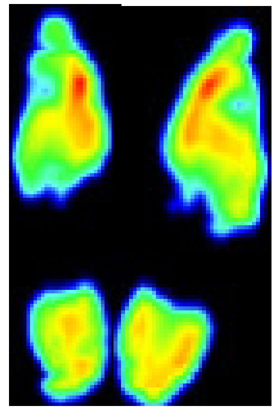


Fig.1.38 Plantar pressure during normal gait after the surgery [71]

By analyzing fig.1.38 it becomes clear that the plantar pressure after the surgery is equally distributed on both feet, the pressure upon the heels is lower, only a little increased upon the metatarsal area but not in an abnormal manner. The subject's posture is dramatically changed for the better and there is more symmetry between left and right foot pressure.

1.2.3. Plantar diseases and stability

The supporting surface of the human body is one of the most important parts of the locomotion system assuring the static and dynamic stability, balance, posture but also displacement possibilities in various ways.

In the case of locomotion system, when the lower limb acts like a closed kinematic chain, meaning the plantar surface is "fixed" on the ground, as in static stability or walking, running etc., the lower leg segment is behaving during action like a first degree lever, with centered support point and support upon the plantar surface.

For example a human subject weighing 70 kg, a force of balance maintenance of approx. 32 kgf is developed, meaning that the tibia will support an approx 102 kgf action. The values of these forces strongly increase when the propulsive motion is performed during gait, assuming the balance "break" and overcoming the gravitational forces. The forces are also high in case the locomotion system is an open kinematic chain. In this respect, regardless if the lower limb acts like a closed or open kinematic chain, the main application point of the forces developed in the lower part of the leg is represented by the centre of gravity of the kinematic system leg-lower leg, which is right above the distal third of the lower leg.[68]

From anatomical point of view, the complicated alignment of leg bones, muscles, ligaments and tendons creates a transverse arc (metatarsal) and a longitudinal arc.

During gait, these flexible, elastic arcades help to the equal distribution of body weight along each leg. These arcades act like rigid areas for a normal mobility but are elastic and flexible, adjusting to the various surfaces that the body is moving about. Everybody has flat foot at birth, but the plantar arcades completely develop around 12 or 13 years of age though in some situations, the arcades never develop normally determining the occurrence of malfunctions with a strong impact upon the bipedal statics. Most people present a vault on the sole surface leaving a clearance between the foot and the ground. Some persons may have a higher plantar vault than normally (fig.1.37). This anomaly is called hollow foot and is the reverse of flat foot. Due to this higher plantar vault, during gait or rest, a much higher weight is acting upon the heel and toes, stressing them additionally. Hollow foot may lead to a multitude of symptoms such as pain and instability and it may develop at any age, manifesting for a single foot or both.[68]

Fig.1.37 Anomalies of plantar vault (flat foot – hollow foot) [68]

Study of plantar pressure took place upon a sample consisting of 10 subjects aged 22-24 years, 3 females and 7 males, with different weights and heights, without traumas or known malfunctions at the lower limbs level. The subjects have been recorded for several types of gait such as: normal gait, backwards gait, added steps, walking with a blocked foot and march.

One of the subjects presented a flat foot and another one hollow foot, so that approx. 10% percent of the sample presents some issues. During normal gait of the analyzed subjects we found the following aspects: plantar pressure upon the two legs is uniformly distributed, allowing the subject to hold balance and stability, while the plantar pressure evolution for each area on the plantar surface is within normal limits and evolves according to the ideal variant for persons with normal feet. Thus, in fig.1.38 the plantar loading for normal feet during a cycle of gait is shown, also the plantar pressure diagrams, for left foot and right foot, fig.1.39.

Fig.1.38 Loading for two normal plantar surfaces along a gait cycle [18]

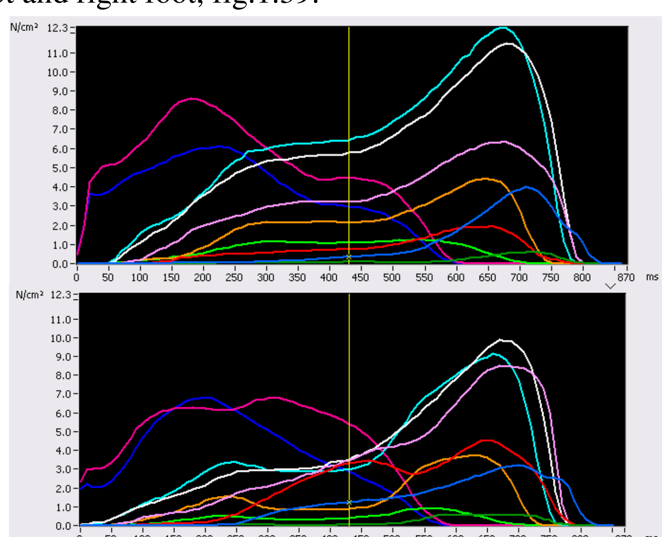


Fig.1.39 Plantar pressure diagrams for left foot (up) and right foot (down) developed in the 10 regions of the plantar surface in normal gait, no malfunctions [18]

Recordings of plantar pressure reveals a series of aspects related to the contact surface with footscan plate, the maximum value for each foot of the cumulative force on the contact areas and also the variation of contact pressure values upon each surface of the plantar pressure (heel, tip etc.).[18]

From the analyzed subjects sample two subjects were chosen for further studies: the one with flat foot and the one with hollow foot in order to analyze them according to the normal values of the same parameters.

Analyzing from dimensional point of view the contact surface between a hollow foot and respectively a flat foot it was noticed that in the last case the contact surface with the pressure plate is bigger by 25% in average and the pressure forces are distributed on the entire surface, which induces a higher usage degree in the anatomical structure of lower leg and sole (fig.1.40).

Also the projection of body weight is shifted forwards and inwards changing both static and dynamic posture, the subject having the tendency to place the foot tips much outwards in order to preserve balance and gait direction.

Though the forces values in all cases are different (due to different weights and heights of the subjects) we notice that the tendency of contact forces variation (a polynomial second degree function was selected for the trend line) the constant is maintained even if the maximum value and slope in each case are different (fig.1.41).

Fig.1.40 Plantar pressures on the contact surface for a subject with flat foot (left) and one with hollow foot (right).[18]

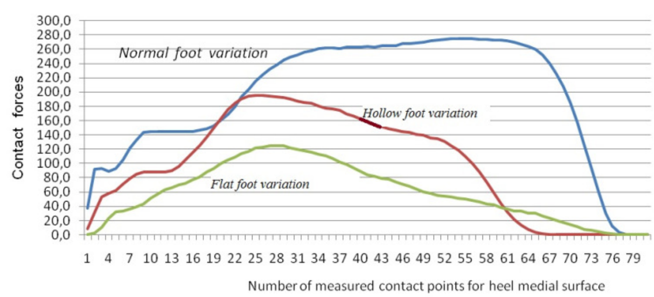


Fig.1.41 Diagram of plantar pressures for the medial heel area for a normal subject, no malfunctions and respectively for a hollow foot subject and a flat foot one.[18]

Also, in the context of the analyses performed upon the subjects' sample the development of a procedure that allows the prediction of motion direction during normal gait with respect to the "map" of the plantar pressure of both feet was developed. Thus, from the processed recordings the variations of the pressure centers trajectories were extracted in order to obtain their direction, orientation and inclination for each foot.

From those presented in fig.1.42 the conclusion is that the subject with hollow foot presents a significant change of the placement direction symmetries of the foot on the walking surface and the different support area determines him to distribute his body weight on the right foot-medial heel, while on the left foot this weight is distributed in the metatarsal area. From this analysis, for the subject with flat foot (left) the displacement direction presents normal symmetry but the weight distribution is also different, straining additionally the normal foot. It was also found that in case of flat foot, there are certain areas in the plantar surface that accomplish a much extended contact about the plantar vault area, contact that induces a certain pressure in teguments and respectively tiredness during displacement.

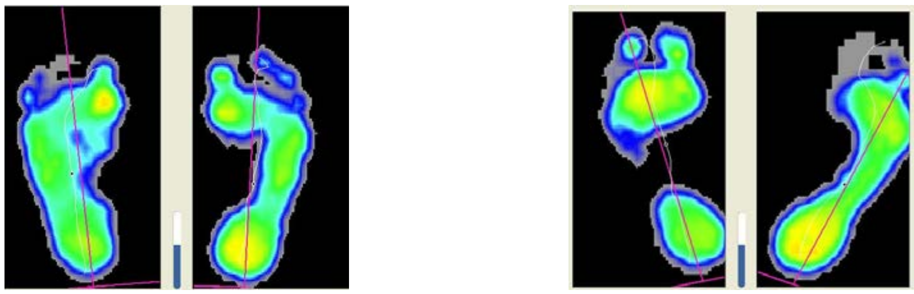


Fig.1.42 “Map” of plantar pressures for flat foot (left) and hollow foot (right) with trajectories directions and angles predictions [18]

1.2.4. Mobility training in rehabilitation activities

A various series of applicative researches highlighted the necessity of conscious and repetitive learning of functional handling during different activities in order to obtain correct and efficient actions of the superior system even if the persons are in a good shape or have implants or other disabilities at the arm level.

The assembly is an interactive process involving an operator (user) and the handled objects, and hence simulation environments must be able to react according to the user’s actions in real time and according with their physical problems. Furthermore, the action of the user and the reaction of the environment must be presented in an intuitively and comprehensible way.

The human factor which is the investigated subject represents in this structure the central platform that collects and directs the information, correlates their structure with the “system requirements” and coordinates the activities in an organizational or cooperative way inside the cognitive learning environment to accomplish the training program.[15, 20]

The experimental equipment consists of the equipment used for measuring the arm’s range of motion (ROM) called ArmTutor, an assembly of devices for anthropometric measurements, physiological parameters and a computer system to record and process the information obtained from the ArmTutor equipment.

In this integrated system it is possible to add dedicated computer games – with different difficulties levels allowing the human subjects to develop and to maintain the moving abilities.

The experiment was performed upon a female subject, 78 years old, having implant rods in the left shoulder, following a shoulder fracture (as shown by the X-ray in fig.1.43) and was aimed at knowing, assessing, determining, modifying and finally improving the motion skills in long term actions.

Fig.1.43 X-ray of the shoulder-arm implant rods

The first stage of the experiment consisted of completing a uniform physical environment evaluation along the entire duration of the investigations, as far as temperature (temperature in laboratory was 21^0C); humidity (air humidity 80%), vibrations, noises and light stimuli are concerned and also atmospheric pressure (755 mmHg).[15, 20]

There also was necessary to acquire anthropometric data regarding the motion possibilities of the subject before the rehabilitation actions by dedicated computer games. In order to accomplish this, the inclinometer Dualer IQ was used. This type of inclinometer is a high class device used for measuring angles in two situations: 1) angles between a human segment and one previously established reference plane (either horizontal or vertical), 2) relative angles between two segments of the human body. All these parameters are necessary to establish a common modeling base to measure and to evaluate the human body behavior in the rehabilitation process.

In the second stage the physiological parameters of the human subject (weight, height, age, pulse, blood pressure) in relaxed stance, without any other general health problems and with a good metabolism (example: blood pressure 165/84 mmHg, pulse 82, face temperature $36,5^0$C, height 160 cm, weight 62 kg) were measured.

The inclinometer was calibrated about the horizontal plane and attached to the subject's arm.(fig.1.44) Then the subject was instructed to perform anatomical and physiological flexion motions with the left arm (affected) and with the right arm (healthy) in order to evaluate the damage upon the motion amplitude. (fig.1.45)

The same measurements were performed for the right arm, and normal results were obtained in accordance with the regulations offered for example by the Health and Social Services Department of the US.

Fig.1.44 Inclinometer attached to the subject's arm

Fig.1.45 Subject performing flexion with the left arm

The good mobility of the right arm is also due to the fact that the subject has an obvious tendency to use it a lot in order to protect the affected arm, whose mobility is diminished to half of the normal one.

The ArmTutor equipment was used to determine the subject's range of motion (fig.1.46), both passive and active, the MediTutor software being able to represent the range of motion by very expressive graphical diagrams, fig.1.47. The passive range of motion starts from 23^0 going to 117^0, while the active one starts at 20^0 and goes to 116^0.

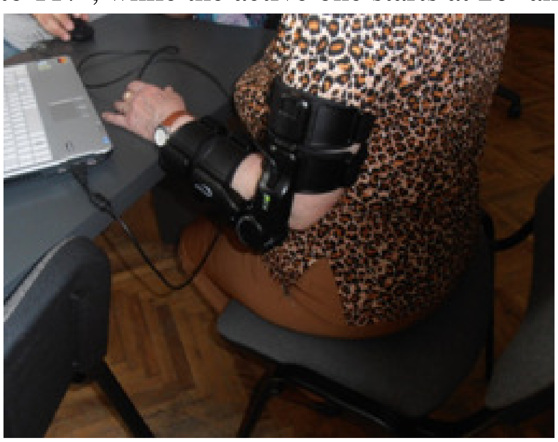


Fig.1.46 Subject wearing ArmTutor

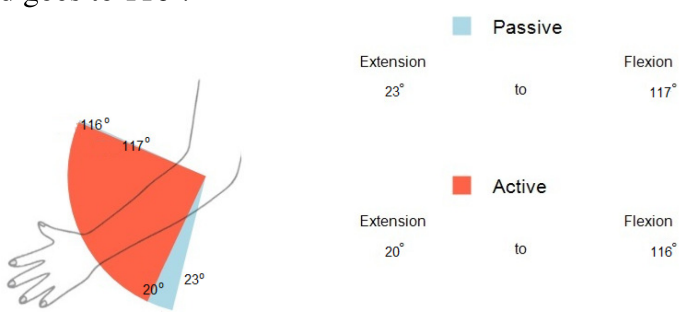


Fig.1.47 Range of motion for left elbow before rehabilitation game

MediTutor was designed also for the rehabilitation of the upper limbs motion problems, offering a gaming interface (fig.1.48). The games are specially designed to help the user in improving the motion range. The games are determining the user to perform certain motions in order to play the game without concentrating upon the motion disabilities and might contribute by frequent and controlled use to the enhancement of motion range.

The subject was asked to play “Track-a-Target” meaning that a small ball had to be kept on a predefined trajectory only by moving the hand-forearm assembly. The game takes customary 170 sec but the duration can be altered according to the subject’s personality and health issues. After playing the game three times, the range of motion was measured again (fig.1.49) showing a slight improvement and no difference between the active and passive range of motion. Both angle values will start at 20^0 and go to 118^0.

Fig.1.48 Gaming interface of MediTutor

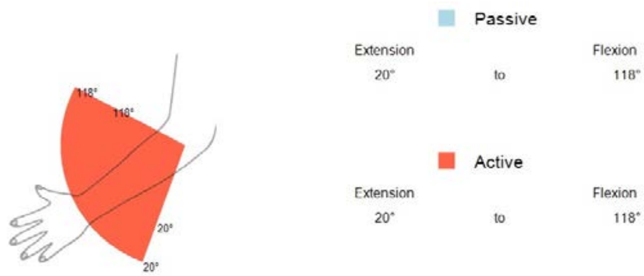


Fig.1.49 Range of motion after gaming

Although there was no spectacular improvement after the rehabilitation game, it becomes obvious that using the gaming interface for some types of disabling health issues that can be cured by controlled and predefined motions. Usually the subjects are more relaxed in a playful environment and have the tendency of “forgetting” about their pains and shortcomings by focusing upon the procedure. If the procedure is repeatedly performed, for an extended time in accordance to the subject’s tolerance, the range of motion improves and may become normal or very close to normal, of course under medical periodical supervision.

1.2.5. Dealing with professional diseases restricting motion

The hand is the main execution tool we use in our daily activities, regardless if they are required by working tasks or if we are engaged in leisure actions. This is the reason why a malfunction of this part of the body may seriously influence the quality of our lives. One of the most encountered problems nowadays relates to the irritation of the wrist tendons, that affects the passageway made of ligaments and bones in the carpal area, a kind of disorder known as Carpal Tunnel Syndrome (CTS). The swelling of these wrist tendons may press upon the median nerve that controls the motion and sensorial actions of the hand. [141]

The person with CTS will experience a reduced ability in performing normal motions with their fingers and wrist from the point of view of amplitude and frequency, while the range of motion will also be limited.

The usual treatment involves besides changing the work conditions that produced the disease, the use of anti-inflammatory medication and painkillers, physiotherapy and in very serious situations even surgery. The use of rehabilitation is in an incipient phase, there are no systematic recommendations suitable for every individual and personalized according to the disease causes, duration, pre-existent pathologies, etc., so the authors researched for a non-invasive methodology that may help the subjects with an early diagnosis and leading an active life.[73]

In order to be able to measure the extent of the symptoms upon the motion performance, an equipment consisting of a set of sensory gloves (HandTutor) produced by Meditouch was used, as a fully computerized system designed to evaluate and rehabilitate hand function [142]. (fig.1.50) The sensory gloves allow anthropometric and physiologic measurements that will be recorded and processed by a computer system provided with dedicated software – MediTutor.[142]

Fig.1.50 HandTutor attached to computer [73]

In order to obtain better and more accurate results, three measurements were performed for each of the established conditions, as follows:

-Random fingers movements (like piano playing) for 10 seconds

-Wrist motion, flexion and extension for 10 seconds

-Fingers movements after performing an effort of 2 minutes, measured for 10 seconds

-Wrist motion after performing an effort of 2 minutes, measured for 10 seconds

-Fingers movements after performing a "treatment game" for 10 seconds

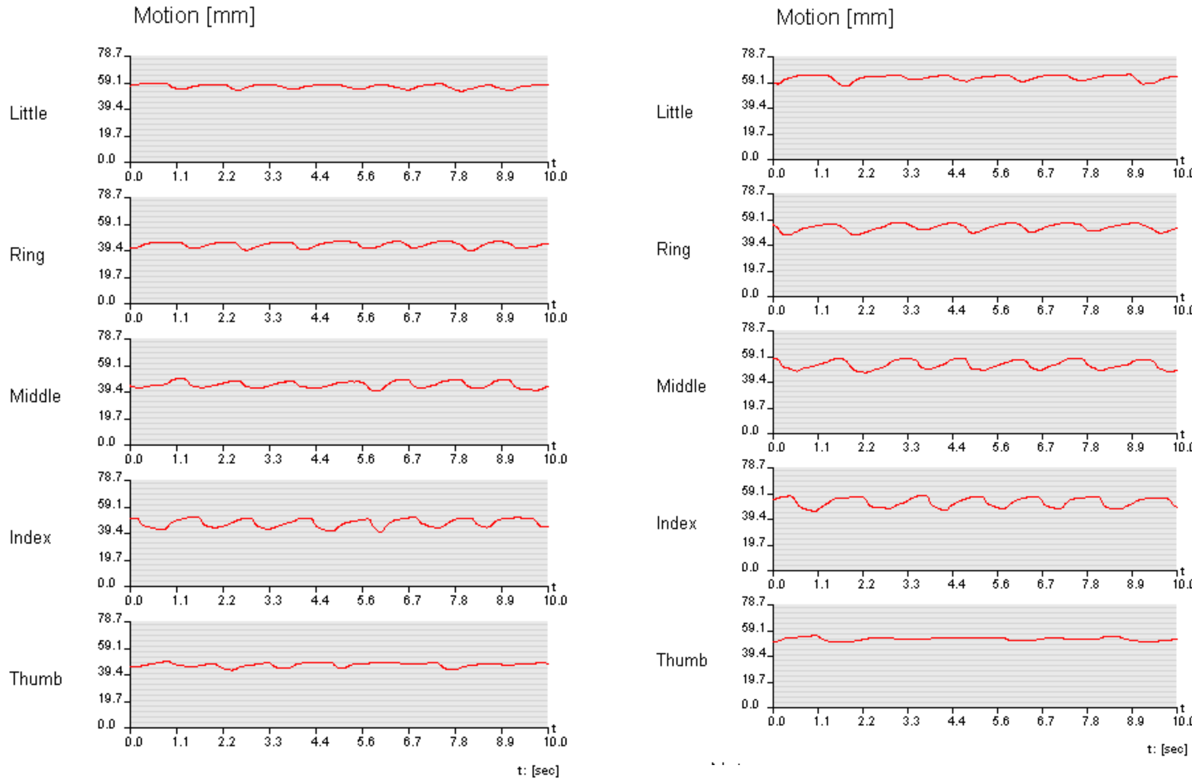
-Wrist motion after performing the "treatment game" for 10 seconds

In order to induce the effort, a dynamometer was used and the subject was asked to apply physiological force (that means in comfortable limits) upon it for 2 minutes.[16] The so called "treatment game" is provided by the MediTutor software and requires the subject to keep a virtual ball on a curvilinear random track using only fingers' and wrist's movements.

The subject involved in this case study is a 37 years old woman diagnosed with carpal tunnel syndrome, following the repeated activities in vibratory conditions due to the use of massage devices and also extensive use of computer. The person experiences numbness, tingling and a slight swelling of the fingers and wrist, which lead to a limited motion amplitude and uncomfortable use of the hand in daily activities.

In the beginning of the recording action, the subject is instructed about the development of the experiment and about the actions to be performed. The conscious cooperation of a well informed and trained subject helps in obtaining meaningful and correct results.

Firstly the subject performs three sets of random movements with the fingers (simulate piano playing) and three sets of flexion – extension of the wrist. Then the subject performs a physiological controlled effort by help of the dynamometer for 2 minutes and another set of recordings is done. The recordings provided by the MediTutor software are shown in fig.1.51 a and b, for one of the three sets of finger movements, before using the dynamometer and after the controlled 2 minutes effort.



a. Before effort b. After effort

Fig.1.51 Amplitude of fingers' random motion [73]

The subject is then instructed how to play some kind of a "treatment game" provided by MediTutor software, three times for 1 minute. Following the "treatment game" the recordings are repeated in the same conditions, the person performing three sets of motions as if randomly playing the piano and one of the obtained records is shown in fig.1.52.

The "treatment game requires the subject to keep a ball on the track using their fingers and wrist while wearing the sensory glove.

The maximum values recorded for the range of motion in all the tested conditions are presented for the five fingers: little, ring, middle, index and thumb in Table 1.3.

Table 1.3 Maximum range of motion (ROM) for fingers

Finger	ROM before effort [mm]	ROM after effort [mm]	ROM after game [mm]
Little	5,8	8,9	9,9
Ring	7,3	9,4	13,4
Middle	9,1	10,9	16
Index	11,5	12	15,2
Thumb	6,5	5,1	7,4

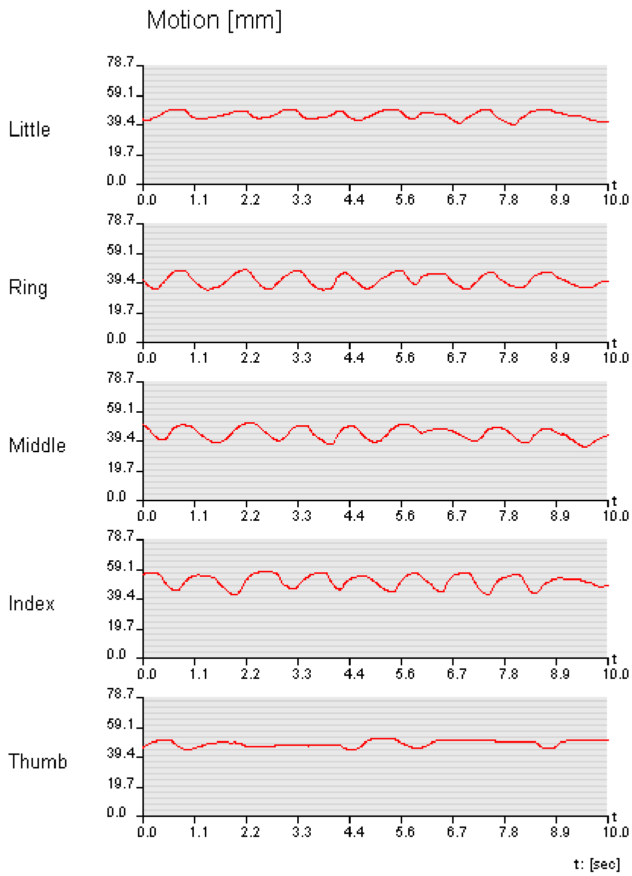


Fig.1.52 Amplitude and frequency of fingers' random motion after "treatment game"[73]

Obviously the "treatment game" significantly improved the ROM for all fingers. Of course, question is if the results will last. As a follow, the subject was tested for a week, every day at the same time and in the same conditions.

The improvement lasts at a certain extent till next day when the training should be repeated. In order to obtain results, the "treatment game" should be done for at least one week or more according to the subject's condition and the doctor's recommendations.

As CTS is also involving the wrist bones, recordings were made for flexion – extension movements of the wrist (fig. 1.53) in all three situations: before exerting effort, after exerting effort using the dynamometer and after performing treatment games. The results are presented in fig. 1.54, 1.55, 1.56 for 10 seconds experiments.

The environmental conditions were the same as for the experiments carried out for the fingers' amplitude and the subject was in a normal state of general health. The subject was instructed to perform physiological motions of flexion and extension of the wrist, while the elbow was supported on the desk.

Fig.1.53 Recording movements of wrist[73]

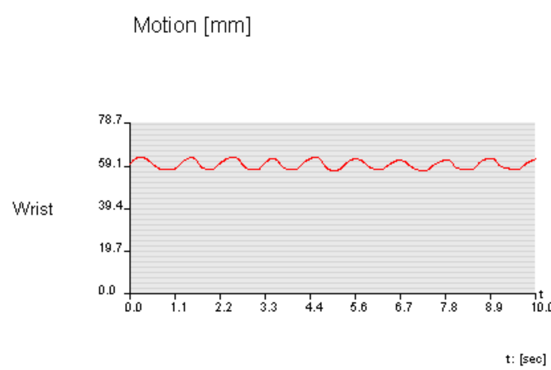


Fig.1.54 Amplitude of wrist motion before effort [73]

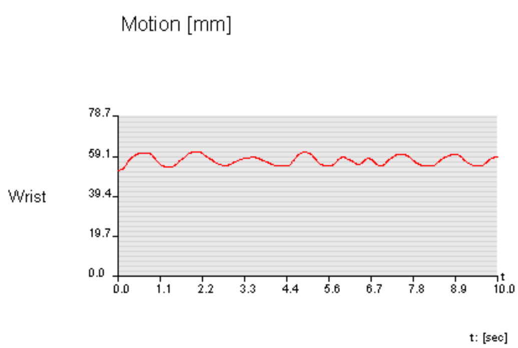


Fig.1.55 Amplitude of wrist motion after effort [73]

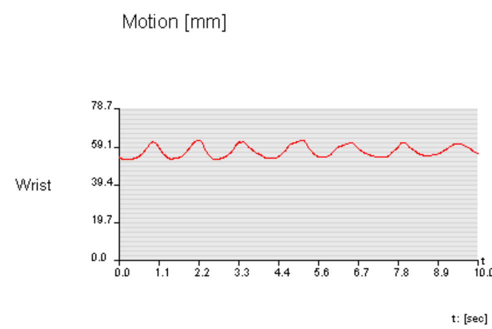
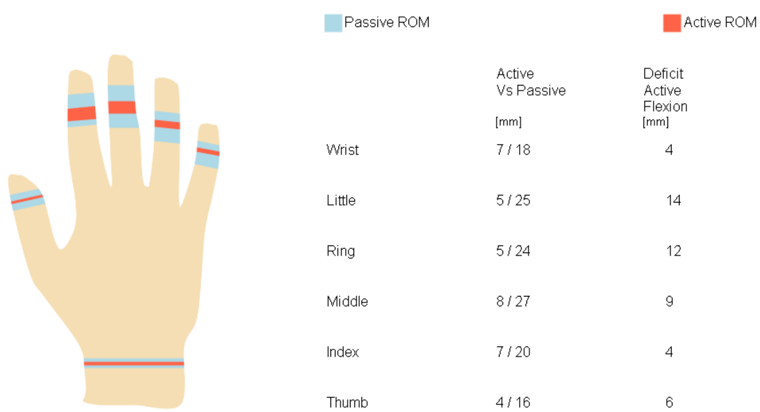


Fig.1.56 Amplitude of wrist motion after game [73]

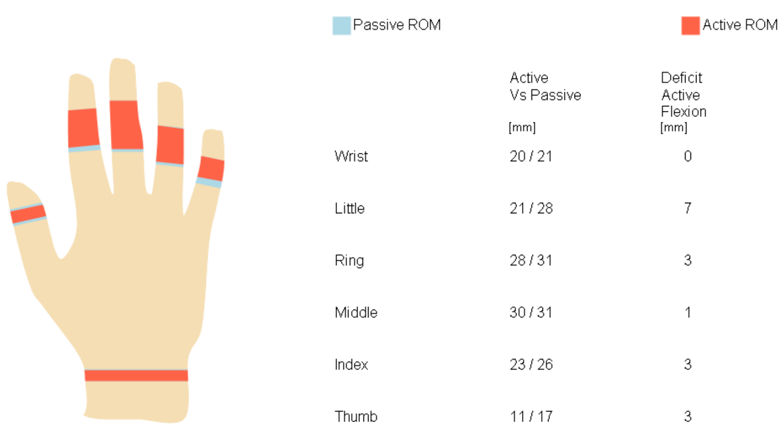
Another parameter that may offer information and enhance the evaluation of the hand performance is provided by the MediTouch system in terms of range of motion (ROM) determined in passive and in active conditions. This will help the assessment of the subject's limitations and will contribute in the selection of the rehabilitation program.

Thus, the ROM for the subject's hand was measured before receiving the "treatment game" (fig.1.57) and compared it with the ROM for the subject's hand after being instructed and performing the "treatment game" (fig.1.58).



	Active Vs Passive [mm]	Deficit Active Flexion [mm]	Deficit Active Extension [mm]
Wrist	7 / 18	4	7
Little	5 / 25	14	6
Ring	5 / 24	12	7
Middle	8 / 27	9	10
Index	7 / 20	4	9
Thumb	4 / 16	6	6

Fig.1.57 ROM before treatment [73]



	Active Vs Passive [mm]	Deficit Active Flexion [mm]	Deficit Active Extension [mm]
Wrist	20 / 21	0	1
Little	21 / 28	7	0
Ring	28 / 31	3	0
Middle	30 / 31	1	0
Index	23 / 26	3	0
Thumb	11 / 17	3	3

Fig.1.58 ROM after treatment [73]

The investigations performed by HandTutor equipment proved without doubt that the subject diagnosed with CTS (Carpal Tunnel Syndrome) presented reduced amplitudes of motion for all fingers and also during the flexion-extension motion of the wrist. The average values of the maximum range of motion obtained after at least three determinations are demonstrating this.

After the subject performed 2 minutes of effort using the dynamometer an obvious improvement occurred, both in the finger motion's amplitude and in the wrist flexion-extension motion, as the values expressed in Table 1.3 show very clearly.

The third investigation aimed at instructing the subject to perform a special computer game provided by MediTouch software, in order to improve the subject's motion possibilities. The new investigations demonstrated an obvious increase of the fingers motion amplitude and also of the range of motion in general. Thus, the range of motion increased finally from 5,8 [mm] to 9,9[mm] for the little finger, from 7,3[mm] to 13,4[mm] for the ring finger, from 9,1[mm] to 16[mm] for the middle finger, from 11,5[mm] to 15,2[mm] and from 6,5[mm] to 7,4[mm], after performing the "treatment computer game". The flexion-extension motion of the wrist also improved from 5,8 [mm] to 8,8[mm]. If we analyze the range of motion diagrams for passive and active actions in fig.1.57 and 1.58 it becomes obvious that after the "treatment game" the range of motion has dramatically improved, additionally the deficit between active and passive determinations is much lower. Of course, the "treatment game" should be repeated daily until the ROM reaches normal values, usually around a week if the affliction is not very old or has some serious involvements of other pathologies.

The methodology used in this investigation proves that it is possible to correctly evaluate a subject by confirming a medical diagnosis and also that by help of controlled efforts and manipulations assisted by specialized computer games, the subject's condition may be substantially improved. The rehabilitation process can be personalized according to the type of motion disorder, personality, age, physical condition so that the best results will be achieved and the quality of life of the afflicted person may be improved by obtaining performances which are gradually closer to the normal ones. Also, if the methodology is applied soon after the person is diagnosed, a lot of unpleasant and invasive treatment methods may be avoided, of course accompanied with some changes in the person's activities that lead to the occurrence of CTS.

1.3. Computer modeling and simulation of motion

The computer analysis of the human motions emphasizes a series of features of the gait cycle concerning the forces developed at the contact support, the duration, the forces developed in the joints, velocities, displacements or spatial positioning of different parts of the human body. Humans possess a unique physical structure that enables them to stand up against the pull of gravity.

To build a model of interaction of human body it is necessary to understand its component parts, the biggest part of the human body is the trunk; comprising on the average 43% of total body weight. Head and neck account for 7% and upper limbs 13% of the human body by weight. The thighs, lower legs, and feet constitute the remaining 37% of the total body weight.

There are 206 bones in the human body and almost all bones are facilitators of movement and protect the soft tissues of the body. The frame of the human body is a tree of bones that are linked together by ligaments in joints.

Skeletal muscles act on bones using them as levers to lift weights or produce motion.

In the human body each long bone is a lever and an associated joint is a fulcrum, acting like a lever which can alter the direction of an applied force, the strength of a force, and the speed of movement produced by a force in moving. [132]

The walking model includes three body parts: an upper link, a lower link, and a foot.

Two joints are represented by the hip and the ankle, the lower and upper links represent the leg and the upper body of the human, respectively and the sources of movements are joint torques and thrust force.

1.3.1. Using Lifemode software in modeling and simulation of motion

Starting from a pre-defined skeleton module and considering the anthropometrical database NASA-STD-3000 the shape of the human inferior locomotion system with direct contact to the walking support is built.[50]

The designed model will be used to simulate human walking in the sagittal plane during the weight acceptance phase, that is, the time duration from heel contact to the middle of the single leg support phase. The equation of motion of the model consists of two parts: the rotational dynamic of the two links and the moving dynamic of the foot. The equation of motion of the links is expressed as follows:

$$[M]\ddot{\theta} = [N]\dot{\theta}^2 + [G] + [\tau] + F_{TH} \tag{1.21}$$

where [M] is the mass and inertia matrix; [N] is the Coriolis and centrifugal force matrix; [G] is the gravitational force matrix; [τ] is the matrix of torques angles and F_{TH} is the thrust force.[50]

For modeling human gait a series of data connected to motion, trajectory, velocity or acceleration are considered but at the same time the boundary values of the gait type (normal, malfunction of the right or left foot, jumps or steps climbing, slips or sliding on plane surfaces etc.) are introduced. The modeling stages aim at introducing data both for the normal mode and for the one used to model a certain gait type in order to simultaneously visualize these differences.(fig.1.59)

Working with LifeMode allows either creating a new model to suit your requirements or loading an already existing model if it matches the requirements.

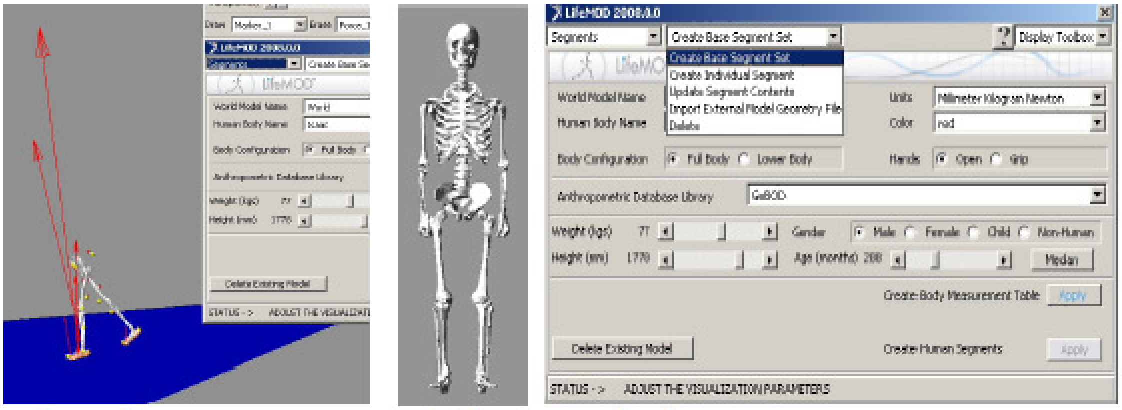


Fig.1.59 Locomotor system model used by LifeMode

In order to create a new model, for example for a hip implanted person, the following steps have to be performed:

- Creating a new set of bone segments according to the age, height and weight of the subject. From the main control panel, the units, name of the model, anthropometric database, etc. can be selected. It is possible to change the length and weight of the bone segments and the joints position.
- Introducing boundary conditions in order to limit joints motion according to the subject's disease
- In order to set the model in motion, a set of motion agents is created by introducing red markers.
- Dynamic analysis is performed leading to an update of the model and a change in the model's posture, new yellow markers appear
- Synchronization of markers location
- Modeling soft tissues (muscles)
- Representing the ground surface
- Introducing limitation conditions according to the person's problems
- Visualizing results by starting animation and obtaining the corresponding diagrams for the reaction forces developed during motion.

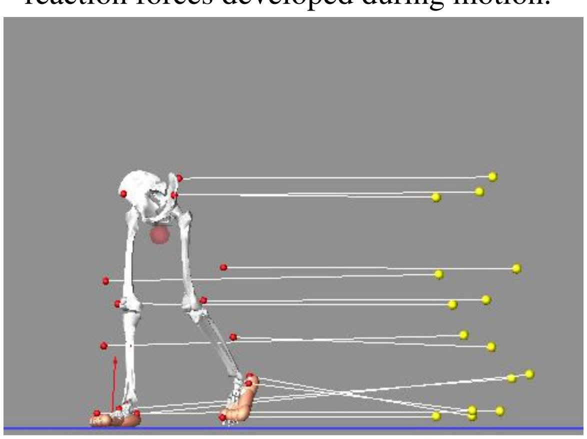


Fig.1.60 Model during animation

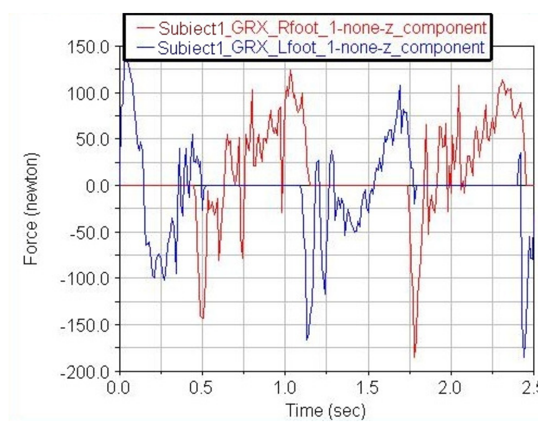


Fig.1.61 Diagram of reaction force

The model during animation together with the reaction forces diagram, for a hip implanted person is presented in fig. 1.60 and 1.61.

The acetabular component of the implant will be defined as a new segment of the model and the initial joint will be erased. The femoral component will also be a new segment that can be imported from the software library. In order to allow the interaction between the model of the lower limb and the implant, a so called "bushing force" is introduced. Also the connection between the two components of the implant is created. A simulation of inverse dynamics is performed in order to record the history of muscular contractions, and then this will be used to create a force to re-create the motion history. The motion agents are removed and a tracker agent is installed in the pelvic area. Finally the animation results obtained while the model sits on a chair are presented in fig.1.62, also the graphic representation of the reaction forces during motion (fig.1.63).

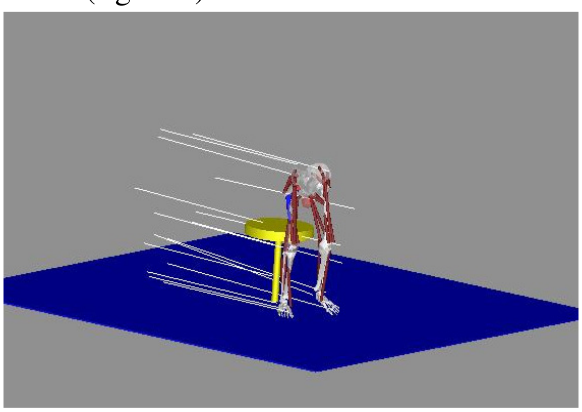


Fig.1.62 Motion simulation

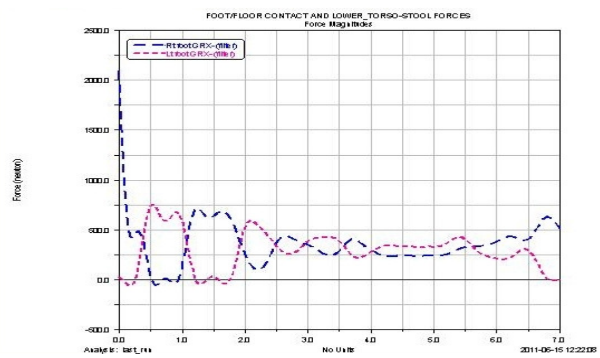


Fig.1.63 Reaction forces due to contact to the ground

In order to be able to predict if the bone structure of the subject is healthy enough to support the implant, the value of the forces exerted by the implant upon the bone can be determined (fig.1.64).

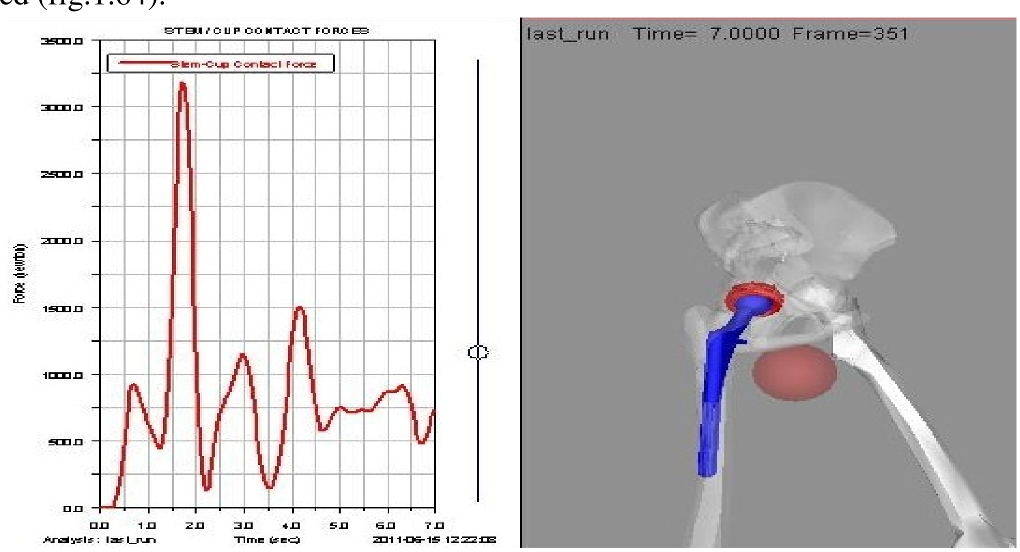


Fig.1.64 Contact forces between the hip implant components

Computer modeling and simulation using LifeMode may represent the opportunity of substantiating a correlative methodology based upon the processing of data obtained by modeling and simulation together with the recorded data in order to check the compatibility of the initial variables. This could be a very useful investigation tool for the medical staff for developing more efficient rehabilitation procedures. [20]

1.3.2. Using Anybody software in modeling and simulation of motion

During the last decades, hip arthroplasty became one of the most successful surgeries, meant to remove the dysfunctions emerged due to medical problems like: osteoarthritis, osteoporosis, rheumatoid arthritis, etc. or due to traumatic accidents.

Obviously, in order to achieve successful results, the choice of the hip implant precise shape and material should be personalized for each and every patient, based on 2D and even 3D images obtained from MRI, CT scan, scintigraphy images that will further be converted in 3D models, generated by various computer programs (usually Computer Aided Design types). This way, the medical staff will be able to select the most appropriate model that can be adjusted for the particular features of the patient. It is critical that the choice of the prosthesis meets the specific requirements of the patient’s normal locomotion, knowing that every person has its own way of walking and a specific posture. [1]

The model can be sent then to a Rapid Prototyping device requiring thus advanced mathematical knowledge and in most cases using very expensive materials. But all these precautions are able only to confirm the static match with certain patient characteristics. Obviously things will change in a dynamic approach; the interaction with other neighboring body parts, with certain environmental conditions might affect the function of the prosthetic addition within the human system. The occurrence of a possible mistake not only will jeopardize or worsen the patient’s status but will also incur unexpected and unjustifiable high costs.

For this reason it was considered advisable to check upon the dynamic interaction between the prosthetic device and the lower parts of the body, using a modeling and simulation software, able to work according to the established conditions, valid for the ongoing investigation.

“Anybody” Modeling System was created at Aalborg University and represents a general modeling system able to run muscle-skeletal models using inverse dynamics. The system allows users to use their own designed models or the already existing models that may be changed according to the users’ requirements. The models are very realistic and can be adjusted based on the subject’s static anthropometric measurements and gait characteristics. This means that Anybody Modeling System is very flexible and adjustable. [75]

The Windows interface of the system is called GUI – Graphics User Interface and has vast possibilities of visualizing models and their corresponding results (fig. 1.65).

Modeling in Anybody is mainly based upon text entries. The language used for these text entries is called Anyscript. It is object oriented, declarative and suitable for dynamic multibody objects, especially for locomotion models.

There are several existing scripts delivered with the software and due to the program's flexibility the instructions can be adjusted to fit the studied subject. In order to be able to perform the required changes on the script certain tasks had to be followed.

First it is necessary to establish the initial conditions regarding the accurate positions of the various body segments at the beginning of the motion. This requires thorough anthropometric measurements on the chosen subject.

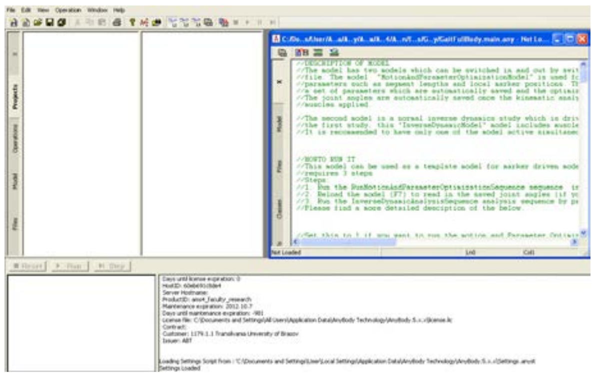


Fig.1.65 Graphics User Interface [72]

Accordingly a suitable subject was identified, as a 50 years old female requiring a hip implant due to a native osteoarthritis. The subject had a bad limp, accused big pain and had a faulty posture leading to spine problems.

In order to be able to predict as accurately as possible the benefits of a hip implant surgery, two models were adapted, one simulating the subject's motion before the surgery and the other for after the surgery.

The subject was thoroughly measured in order to introduce the correct static anthropometric measurements in the script. The bones dimensions were taken between the connecting joints, while the pelvis was measured using a stadiometer, as shown in fig.1.66.

Other important measurements that will provide data related to the joints mobility are the angles between the various segments of the lower limbs: angle between the pelvis and femoral bone, angle achieved when bending the knees, while the subject attempts to perform regular motions like flexion-extension, abduction-adduction, and outside-inside rotation.

Fig.1.66 Stadiometer

Fig.1.67 Goniometry kit

In order to determine the values of these angles, a goniometry kit was used (fig.1.67) and the subject was required to perform the above mentioned motions according to the physiological possibilities at the given moment that is before and also after six weeks from the surgery.

Each segment of the body will be scaled according to some scaling laws considering length and mass properties. [75]

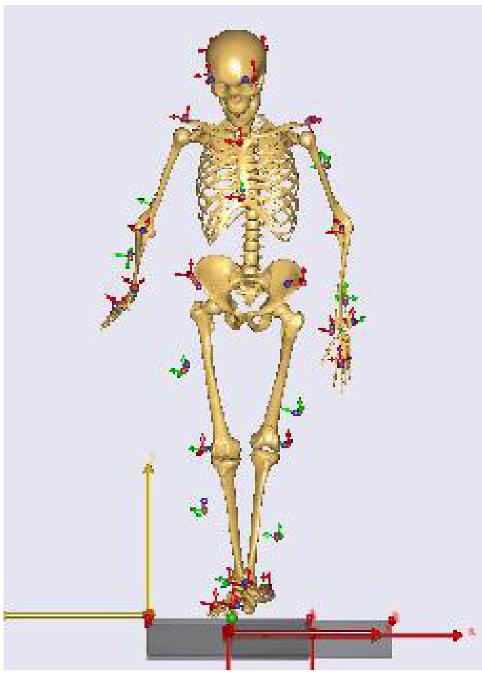


Fig.1.68 Skeletal model in Anybody [72]

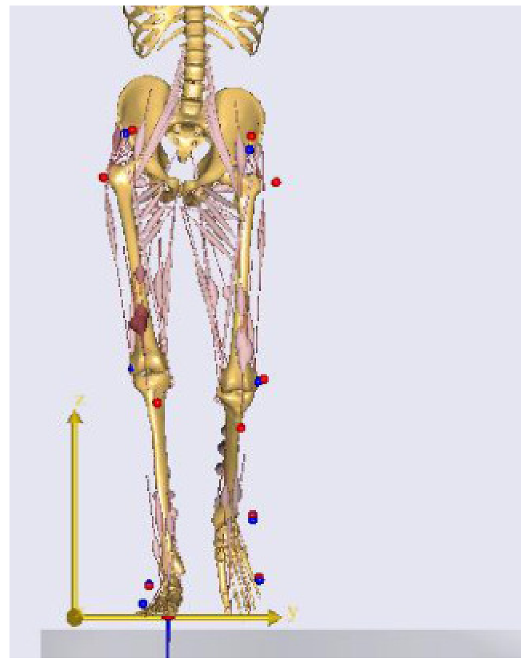


Fig.1.69 Model including muscles of the lower limbs and motion markers [72]

According to the scaling of anthropometric measurements, the skeletal model was accomplished as shown in fig.1.68, where the hips are considered to be ball and socket joints (spherical joints), the knees are considered pin connections and the ankles, universal joints.

The next step allows introducing the muscular system according to the subject's data. The muscles can be introduced for the entire body or only for the part we are interested in. As the main interest of the research concerns the lower part of the body, the muscles were introduced only for the lower limbs and pelvis. The model involving the muscles and motion markers is shown in fig. 1.69. The working model will be loaded in the study section and the gait simulation may start. [72]

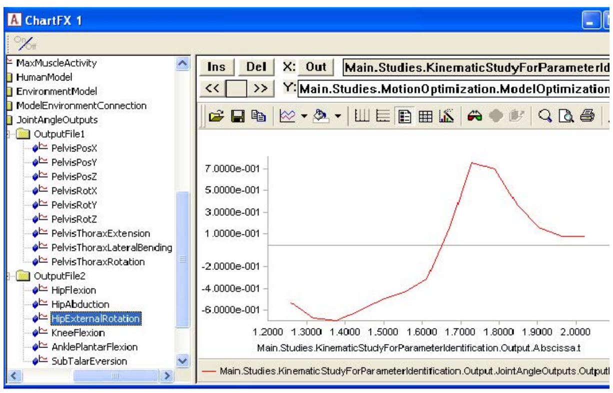
While simulating the subject's locomotion, the program also offers some graphic representations regarding pelvis inclination, hip flexion, hip abduction, external and internal rotation, etc. For example in fig. 1.70, the graphic representation of the hip external rotation before the surgery is shown.

As shown in fig.1.70, the files provided by Anybody studies are able to show various positions of certain points on the pelvis area and also graphical representations of the hip motions.

Watching the animation obtained for the subject's data before the surgery, it becomes obvious that the pelvis presents a strong inclination towards the right (affected hip), also the spinal cord looks slightly deformed. The subject has a limp during walking as if the right leg is shorter than the left one (healthy). According to the anthropometric measurements there is a difference of about 75mm between right and left leg.

In fig.1.71, the pelvic inclination shows an obvious asymmetry due to the difference between the legs length.

All data will undoubtedly show a faulty posture both from static and dynamic point of view, while the animation clearly resembles the subject's motion.



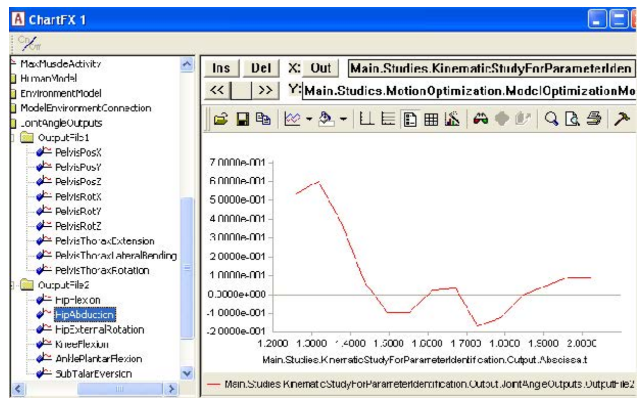
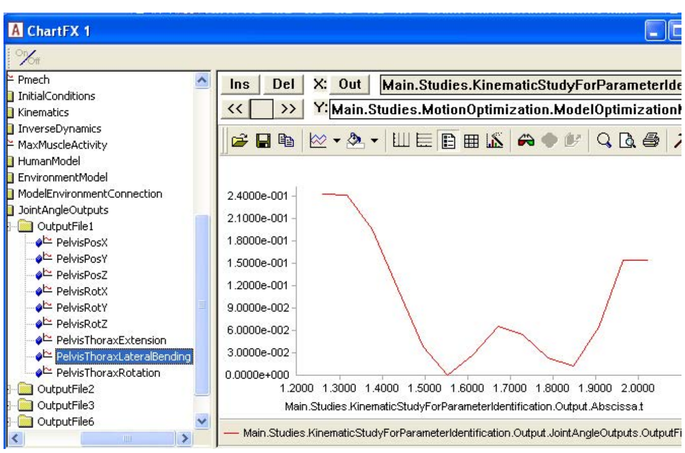


Fig.1.70 Hip external rotation graphic [72]

Fig.1.71 Pelvic inclination during hip abduction before surgery [72]

For after the surgery, a second model is required. The old model is changed according to the new anthropometric measurements that will lead to new initial conditions, both for some segments length and in a greater extent for physiological angles. The mobility of the right leg has greatly increased at six weeks after surgery and kinetotherapy.



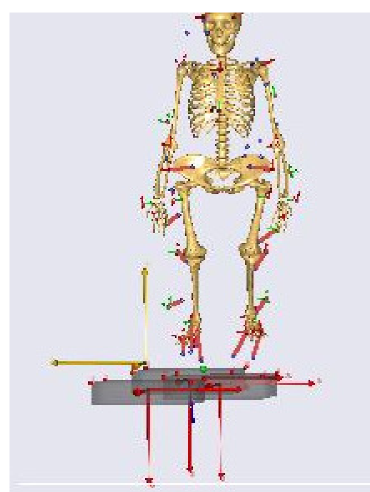


Fig.1.72 Pelvic inclination during hip abduction after six weeks from surgery [72]

Fig.1.73 Capture from the gait animation after surgery [72]

In order to complete the model, the right spherical joint representing the right hip is replaced with the scaled implant that is designed by help of a virtual planning procedure based upon the 3D bone structure of the subject. [99]

After creating and visualizing the new model, it will be loaded in the working section and the new data will be analyzed, also a new animation will be created showing the new dynamics of the patient's gait.

As an example, the graphic representation of the pelvic inclination is shown in fig.1.72. Of course, all the parameters analyzed before surgery are available in the simulation performed after surgery, allowing the possibility of comparing the two situations, both visually by means of the graphic representations and numerically by comparing the values of the analyzed parameters.

Analyzing the graphic representation we find that there is an obvious improvement in the patient's pelvic posture, there still is a slight inclination but the motion has more symmetry and the spinal cord is no more affected as shown by the animation (fig.1.73).

Structural changes at hip level but mostly functional changes due to pains, muscular contractions or retractions represent reasons for mobility limitations of the hip, leading to drastic alterations of posture, gait and position of the body center of mass.

Involving technology and computer science, not only in designing personalized implants but also in biomechanical modeling and simulation of the human body motions will effectively help in the development of prosthetic techniques as well as in reducing the subjects' pains.

Thus, by using a modeling and simulation software like Anybody, medical engineers will be able to create models according to the subject's static anthropometric dimensions, simply by changing the initial conditions in already existing human body models and analyze the kinetic parameters provided by the program. The models created for the after surgery situation may be then used to predict the possible improvement of the gait parameters according to the implant's characteristics and the degree of changes in posture and locomotion. The graphic representations will show the changes occurred in the pelvic inclination and also the symmetry or the lack of symmetry in the limbs' action.

Also, by using the models' animation created by help of Anybody software, it will be possible to visualize the improvements in the subject's posture during motion.

Chapter 2. ANALYSIS OF PROSTHETIC AND IMPLANT MATERIALS FOR MAINTAINING QUALITY OF LIFE

The new approach of compatibilities issues for Romanian integration in an European social-economic environment requires strong integration and interaction between various fields of engineering, medical care, technical and technological aspects related to the interface with the human factor, statistics and human performance aspects.

For example the field of protection and rehabilitation/recovery techniques of human vital functions by rigid implants can be considered as an integrated and interconnected domain, including classic contributions of mechatronics, mechanical engineering, computer science but also more recent developed areas like biomechanics, bioengineering, non-conventional materials and computer aided design. All these research areas are involved in design, command, control and results interpretation of biomechanical systems in order to maintain, preserve and improve the human life quality.

Currently the tendency of modular design of all biomechanical structures, of designing artificial intelligence structures is worldwide present in order to accomplish interdependencies between real environment and human factor without “aggression” on any component of the system.

Also it is well known that dental problems do not solve themselves, they need to be approached in due time and very seriously, otherwise the irreversible loss of teeth may occur, also additional suffering and other related disorders. Caries incidence for example in our country is about 80%, a large number of people avoiding the dentist appointment either for fear of painful interventions or mostly because of financial reasons. A person with dental problems may have pulmonary, renal, cardiac etc. disorders and will never be accepted for an implant, for example. The suitable care for denture may reduce up to 30% the risk of heart attack, stroke but also other cardio-vascular diseases.

By neglecting these aspects, especially by the disadvantaged population and even by persons with an average income lead to the increase of destructive dental diseases incidence, requiring restorative actions, reconstructions or even prosthetic works with consequences upon social comfort and welfare.

To this purpose, several interdisciplinary research teams from well-known universities like: Berkeley University London University, Ecole Polytechnique Federale de Lausanne, University of Copenhagen or University of Leuven performed fundamental researches aiming at structural and functional optimization of biomechanical systems, modeling and simulation of implants, designing recovery and rehabilitation systems for various forms of medical issues.

Therefore, our university and department are also following this trend of developing interdisciplinary researches in order to create technical and methodological premises of an improved life quality as a competent response to the societal challenges.

2.1. Analysis of dental materials

2.1.1. General considerations regarding dental materials

Over time, there were a multitude of researches and solutions concerning dental prosthetics, which was in its turn subjected to a major revolution at the time of a new procedure emergence, namely oral implantology. Today, millions of dental implants are used as oral implantology providing the possibility of using additional pillars that may be inserted wherever needed. Thus, a wide range of edentations that not long ago were benefiting only of mobilizable or mobile solutions can be approached today by fixed prosthetic restorations. From the point of view of a simple classification the prosthetic parts can be attached exclusively upon implants (pure implanter) or can be mixed (dental-implanter).

Prosthetic works upon implant may replace from a single tooth to an entire arcade. They can be made of various materials: metal-acrylate or metal-ceramics. Metal-ceramics works (with porcelain antagonists) are preferred today for their structure rigidity. Acrylic works present the benefit of shocks damping, but they are not resistant enough. The abutment applied on the implant represents the trans-mucous component and the implant package is covered in order to rebuild the aspect of a natural tooth. The hexagonal shape of the implant's end prevents the abutment rotation and the contact surface between this and the implant is especially important especially in the process of occlusion with upper arcade. The dentist may reshape some part of the abutments used in implantology today, while the micro-prostheses edges may be placed sub gingival without being followed by complications. Also, upon an implanter support we can create the so called prosthesis upon implant, which is a mobilizable prosthetic device. On a small number of implants, the prosthesis with special aggregation systems can be manufactured, systems that confer much higher stiffness and support to the prosthesis on implant than to the usual prosthesis. [65]

Artificial teeth are usually included in one of the following situations: *single maxillary mobile prosthesis*, with noble alloys as antagonists, acrylic or diacrylic resins, in order to prevent their accelerated wear; *alveolar ridge*; *rubbed off or periodontal antagonists*; or the case when there is a *single dental prosthesis or a metal bridge on the antagonist arcade*.

Wherever would be the position of teeth in prosthetic area, artificial teeth are defined by characteristics related to color, shape, dimension and occlusal shape. Besides for the frontal teeth the order of importance is color, shape, height and width. From the material point of view, the used artificial teeth are consisting of PMMA co-polymerized by reticular agents and usually these are provided with an increased resistance to cracking by using a greater amount of reticular agents. In the contact zone with the prosthetic basis, a lower concentration of reticular agent is recorded, than in the incisal, respectively occlusal areas, in order to facilitate the chemical connection to the polymers in the prosthetic basis. To provide the most physiognomic aspect, artificial teeth use a large range of pigments and to increase resistance of teeth, they are treated with inorganic micro-particles.[65]

For long-term successful performance of all dental implant types the following general factors should be considered: biomaterials, biomechanics, dental evaluation, medical evaluation, surgical requirement, healing processes, prosthodontics, laboratory fabrication, post insertion maintenance. All practitioners involved in patient care should be knowledgeable regarding these factors and their interrelationships.

Standards of dental practice would suggest the following general contraindications for the above three categories of dental implants: debilitating or uncontrolled disease, pregnancy, lack of adequate training of practitioner, conditions, diseases or treatment that severely compromise healing, e.g., including radiation therapy, poor patient motivation, psychiatric disorders that interfere with patient understanding and compliance with necessary procedures, unrealistic patient expectations, unattainable prosthodontic reconstruction, inability of patient to manage oral hygiene, patient hypersensitivity to specific components of the implant.[65]

Teeth used in treatment with telescopic prostheses should be covered generally with porcelain or noble metals crowning and require extended preparations. By help of implants, abutments can be created upon which different structures connected to the skeletal or fixed prosthesis are applied. Nowadays, fixed implantologic prosthetics is dominated by screw fixing but prosthetic works can also be cemented.

In dentistry there were used non-metallic materials to manufacture dental prostheses even since ancient time. Nowadays, three groups of non-metallic materials are used:

- organic (different plastics);
- inorganic (ceramics);
- composites (organic + inorganic).

It is well known that plastics are non-metallic compounds produced in a synthetic way. These are generally made of organic parts that can be modeled (in the plastic phase) in various shapes and then harden creating rigid bodies. As ideal properties of a non-metallic material used for prostheses manufacturing, we may enumerate the following: they should have the color and shade of the tissue they are replacing, to posses transparency or be translucent, properties that allow its esthetic reproduction; to avoid the color and transparency change after manufacturing or within the oral environment; not shrink or expand, nor to distort during processing or afterwards in the oral environment; to present elasticity and abrasion resistance; to be waterproof for the fluids in the oral cavity preventing the occurrence of an unpleasant halitosis or taste disorders; food and other materials should not adhere to the processed surface, once introduced in the oral cavity, allowing the same hygiene procedure as the oral dental tissues; to present a small density and high thermal conductivity; lamination temperature should be much higher than the temperatures of all liquids and foods introduced in the oral cavity. [65]

Presently, the properties of the polymers used in manufacturing prostheses are enhanced along three directions: by **radio-opacity**; by **increasing impact resistance** and respectively by **increasing rigidity**.

Radio-opacity can be obtained by introducing organic components of bromine that determine the plasticity increase, water absorption and respectively a decrease of material rigidity. By means of additive phase separation (organic component based on bromine) during the paste phase, we are able to obtain a transition temperature around 110 °C and a rigidity of 2,0 GPa preserving at the same time the esthetic properties and reaching a high radio-opacity degree. Increase of shock resistance can be obtained by homogenization during the paste stage of two or three different polymers. For increasing the rigidity and shock resistance, we know from dedicated literature that some types of fibers were experimented (glass, alumina, carbon, Kevlar) used to reinforce PMMA or Bis-GMA resins. [65]

From the properties of acrylic thermo-polymerizable resins, the most important are the following: **structure** (from structural point of view methyl polymetacrylate consists of linear polymerized macro-molecular chains); **porosity** (in resin's structure air inclusions of small or bigger dimensions may appear and microscopically determined); **spherical inclusions,** small, inside PMMA (these may appear as a result of too fast heating of acrylate paste and a temperature increase over 100°C, thus, boiling and monomer evaporation determine the bubbles occurrence inside PMMA); **different shapes inclusions,** small, countless, distributed along the entire thickness of the acrylate (this type of porosity is due to the insufficient compression of the acrylate paste); **different shapes inclusions**, big, distributed along the entire thickness of the acrylate (the cause of their presence is due to lack of homogenization of acrylic paste, distorted distribution of monomer or too high variation of polymer molecular mass); **water absorption** (phenomenon is evaluated by weight increase of acrylate sample, which was assessed per resin surface unit, immersed in water at 37^0C for 24 hours and then well dried; **solubility** (evaluated by determining the weight diminishing per resin surface unit, immersed in water for 24 hours and well dried); **volume variations** (during polymerization process the following physical phenomena take place successively: thermal expansion, contraction of polymerization and finally thermal contraction); **thermal expansion** (is due to the temperature difference between the environment and the 60°C temperature of the water meant for polymerization); **contraction of polymerization** (these is generated by the methyl polyacrylate that presents a 21% volume decrease during polymerization); **thermal contraction** (occurs during the pattern cooling phase and is limited by PMMA adherence to the pattern margins, but the most important of the thermal properties is the thermal expansion coefficient which is evaluated at $81 \cdot 10^{-6}$/deg. Thermal conductivity of PMMA is low, the thermal conductivity coefficient being $4{,}5 \cdot 10^{-4}$ cal $\cdot$ cm^{-1} $\cdot$ s^{-1} $\cdot$ deg^{-1}). [65]

As far as the *mechanical properties* of the acrylic resins are concerned, the most important are the following: **hardness** (Knoop hardness is 20 times lower than that of dentine (65) or enamel (300)); **bending resistance** (compression resistance is approx. 75 MPa; traction resistance is approx. 52,5 MPa; abrasion resistance is low, being a major inconvenient for these resins).

The most known *chemical properties* are: **corrosion** (PMMA presents a high chemical inertia, being very stable in the oral cavity- still an unfavorable evolution in time is possible so that the initially translucent resin becomes opaque and yellow and due to micro-cracks occurred in time, the mechanical resistance is also lowered); **biological properties** (ceramics consists of metallic and non-metallic components – oxides, nitrites, silicates).

Introducing ceramics in dentistry, as it is or as lead material on metallic support is due first to their outstanding esthetic qualities as well as to the fact that it is an inert material, very well tolerated by tissues. From chemical point of view, ceramics is a complex silicate. The basic raw materials in its composition are: feldspar, quartz and kaolin. Beside these basic components, ceramics also contain a large range of ingredients only in pure state, because of the multiple requirements related to color, resistance, fragility, insolubility, translucence. [65]

2.1.2. Microscopic analysis of restoration materials polymerization process

According to the agent that triggers the polymerization process (thermal or chemical), two categories of PMMA are encountered:

- Thermo- polymerizable, whose polymerization is initiated by heat;
- Self- polymerizable or polymerizable without heat.

Self-polymerizable resins come as powder and liquid and are used for immediate restoration or manufacturing of dental prosthetics. Polymerization takes place under the action of the liquid polymerization agent, no high temperature required. Polymerization degree is lower than the one reached by thermo-polymerizable resins.

The polymerization process takes a certain time to finalize and the results might be very different according to the type of materials used. One of the analyzed aspects was the surface roughness, because it highly influences the degree of bacteria attachment to the dental structure. This is the reason why a lower roughness prevents bacteria development upon the dental restoration.[65]

Modern materials consist of composite materials based on vinyl-estheric resins where the filling agent was an inorganic substance: hydroxyapatite (present in dental tissues), which is compatible to natural dental tissues (35% organic: proteins like collagen, 65% inorganic like hydroxyapatite).

These dental materials are delivered in syringes where a mixture of vinyl-estheric resin (which is more accessible for manufacturing) together with a reticular agent are stored (but there is no reticular reaction during storage). Then the material is introduced in the established location of the cavity for example and subjected to a UV lamp. In a few seconds, the hard and high resistant composite material is created. Because it reticulates under the action of the UV lamp, without any chemical reaction, the process is very fast and easy to manage.[65]

In order to perform the tests on the selected material (more often used in dental offices), some working samples were manufactured from various materials, all of the same size and volume, but using different polymerization periods.

First working samples were made of Te-Econom material and were polymerized for various time intervals (5 min, 6 min, 7 min and respectively 9 min), monitoring the photo-polymerization process in order to avoid other environmental influences.

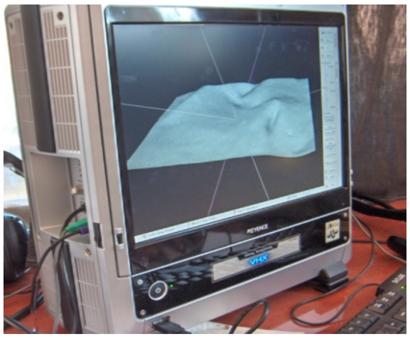


Fig.2.1 Keyence digital microscope [65]

The experimental setup used for the microscopic analysis of the polymerization dental materials samples consists of a digital microscope Keyence VHX-600 type (fig.2.1), with objective magnification between 500x and 5000x, an object field of 0,25 mm^2 and software suitable for the assessment studies and surface quality measurements, roughness, 3D representations. The used samples were manufactured in the same conditions and assessed according to the same procedures.

In fig.2.2 the first sample of Te-Econom material type, polymerized for 5 min was analyzed by the digital microscope in order to assess the surface roughness.

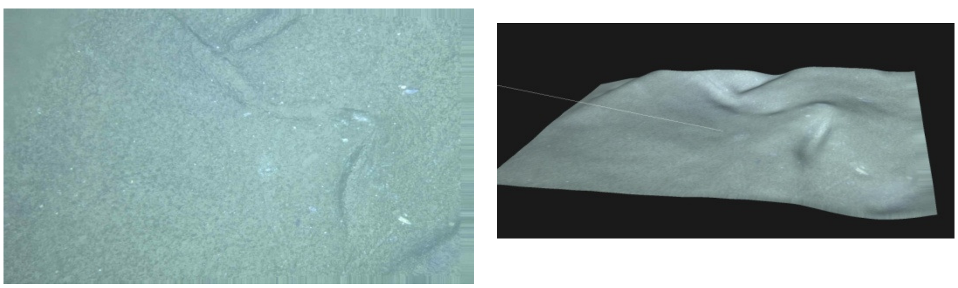


Fig.2.2 Sample 1 (Te-Econom) structure, photo-polymerization time of 5 min (500x magnification) and detail [65]

The roughness profile variation is presented in fig.2.3.

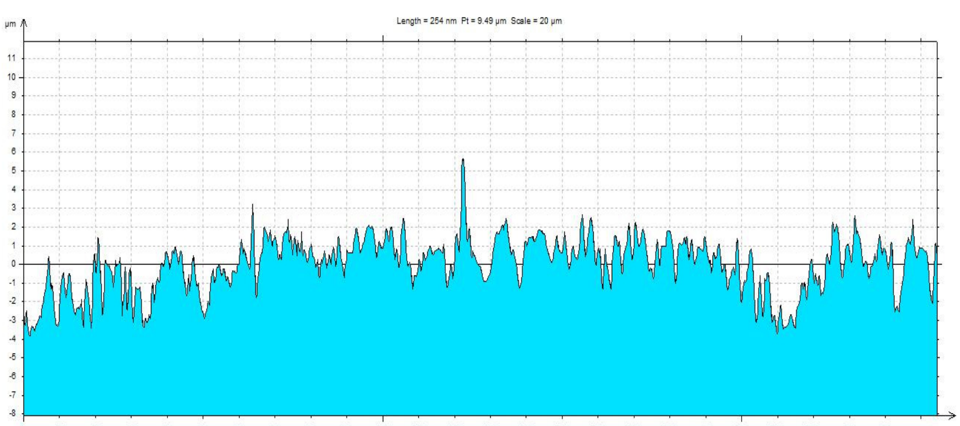


Fig.2.3 Roughness profile variation for sample 1 [65]

Another example is the analysis of the third sample of Te-Econom, for 7 min polymerization, and the roughness profile variation is presented in fig.2.4.

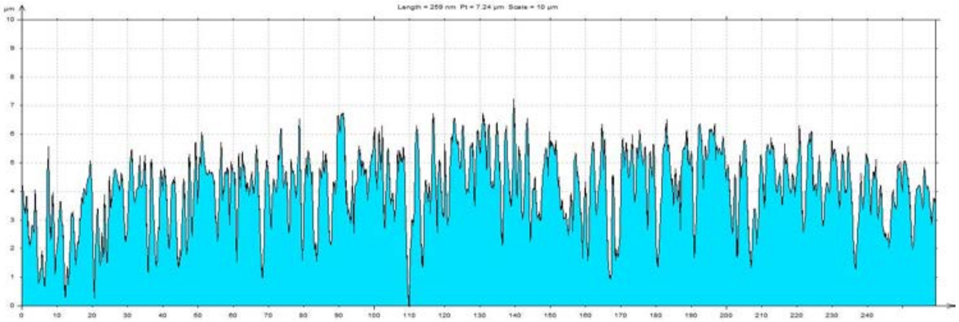


Fig.2.4 Roughness profile variation for sample 3 (Te-Econom) [65]

For the second set of samples the studied material was: Valux-Plus**,** and the chosen time intervals were the same – 5, 6, 7 and 9 minutes.

Thus, fig.2.5 and 2.6 show the microscopic image of sample 1 together with the roughness variation.

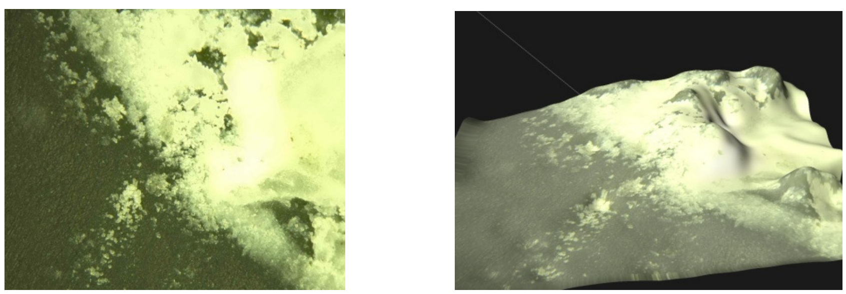


Fig.2.5 Sample 1 Valux-Plus structure, photo-polymerization time 5 min (thickness 4mm) (500x magnification) [65]

The roughness profile variation is shown in fig.2.6.

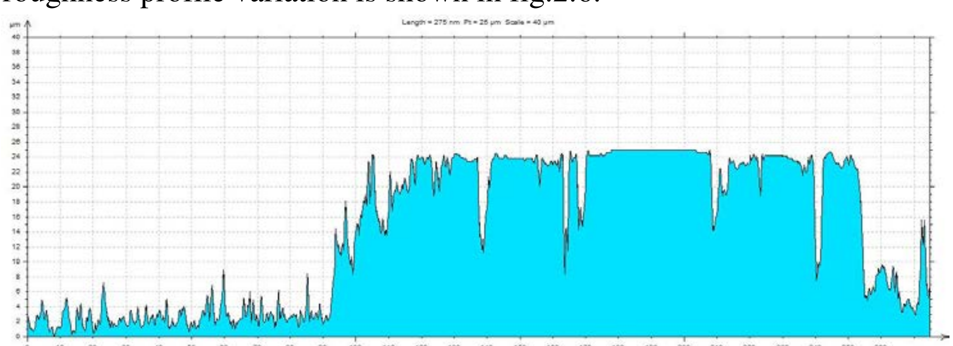


Fig.2.6 Roughness profile variation for sample 1 Valux-Plus [65]

All the other samples made of Valux-Plus, for 6, 7 and respectively 9 min polymerization time were analyzed the same way, using digital microscope with 500x magnification and then determining the roughness profile variation in order to be able to make the final comparison and draw conclusions upon the results.

The next samples were made of Concise – 3M a self-photo-polymerization composite that was subjected to the same photo-polymerization methods (5, 6, 7 and 9 minutes). The images obtained for sample 1 are presented in fig.2.7 while the roughness profile is shown in fig.2.8.

Fig.2.7 Sample 1 structure Concise 3M – photo-polymerization time 5 minutes [65]

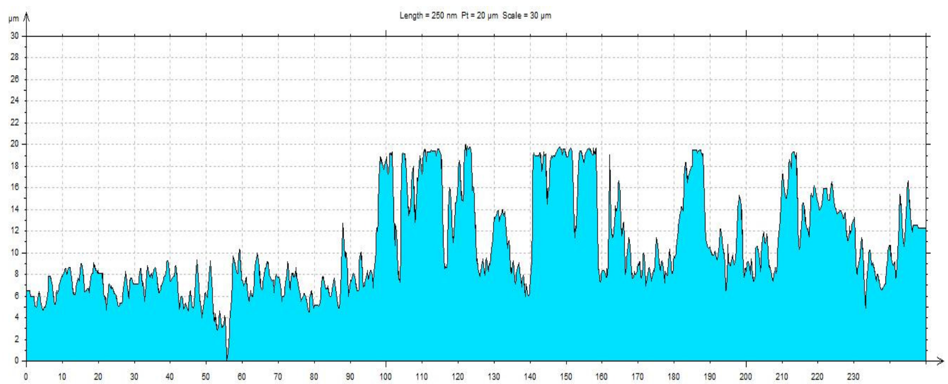


Fig.2.8 Roughness profile variation in the marked area for sample Concise 3M [65]

From the performed measurements presented above the following may be observed:

- According to the materials polymerization degree changes are noticed in their aspect depending on the photo-polymerization time interval;
- For Valux Plus material an incomplete polymerization is observed due to the white spots upon the material surface, while for all the Te-Econom samples, the photo-polymerization was uniform, there were no white spots on the material surface;
- The two materials surfaces are very different, as for Valux Plus the surface does not appear entirely homogeneous, while for Te-Econom, the surface is much more homogeneous and uniform;
- There also was noticed that based on the surfaces profile analysis that the photo-polymerization process determining the best surface quality must take place along a 6 min time interval for Te-Econom material and respectively along 9 minutes for Valux

Plus material. As far as Concise 3M is concerned, regardless of the photo-polymerization time, the surface aspect presents an extremely changeable profile, which requires a prior processing.(fig.2.9)

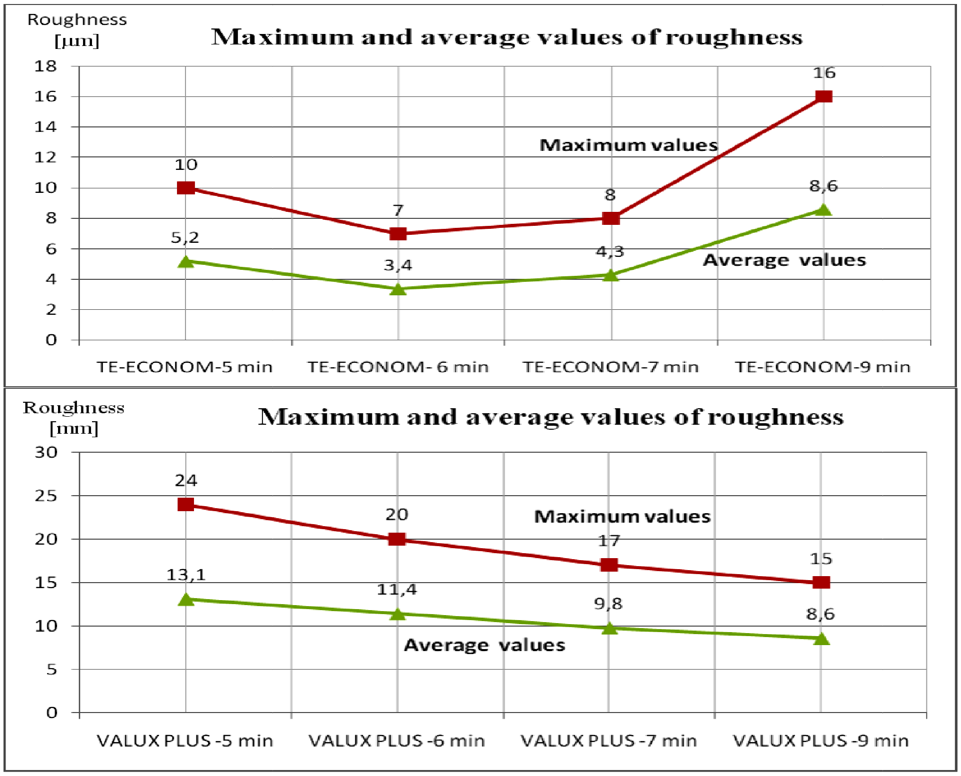


Fig.2.9 Comparison of diagrams for roughness values [65]

2.1.3. Analysis of mechanical properties for restorative dental materials

Most of the restoration materials should withstand forces during manufacturing or mastication, so the mechanical properties are important in understanding and predicting the material behavior under load. Because a single mechanical property cannot represent a quality measure, the application of the involved principles in a range of mechanical properties is essential, especially considering the human factor implication.

One of the most important applications in dentistry is the study of the forces applied to teeth and dental restorations. The maximum forces recorded by strain gauges and telemetry devices reach 250 to 3500N. The forces developed in the dental occlusion for an adult subject decrease from the molar area towards the incisors, reaching forces values from 400 to 800N, upon the first and second molar. Of the same importance for the study of forces developed in the natural teeth occlusion, is the determination of stress and strains in the restoration type works, such as insertions, fixed connections, partial and total prostheses. One of the first investigations of the occlusion forces shows that average biting force in patients with replacement of first molar is determined at 250N for the restored part and 300N for the opposite side, in comparison to the average biting forces for permanent teeth, reaching 665N for molars and 220N for incisors. In a different study, forces measured for patients with partial prostheses are form 67 to 235N. Generally, the force in women bite is 90N smaller than the one applied by a man. These studies indicate that the mastication force on the first molar with a fixed connection is approx. 40% of the force exerted by the patients with natural teeth.

Recent measurements performed by help of strain gauges devices are much more accurate than those performed with other previous equipments, but generally the conclusions are the same. These measurements concluded that the forces distribution between the first premolar, second premolar and first molar in a complete dentition can be established as approx. 15%, 30%, and 55% of the normal force. From the point of view of the polymerization process, an important aspect is represented by the polymerization time, which is a parameter affecting the mechanical characteristics of the prosthesis teeth, dental restorations or implants. Polymerization time for the composite diacrylic polymerizable resins cannot be measured based on viscosity changes. Approximately 75% of the process takes place in the first 10 minutes, the reaction continues slowly for 24h. The sub-polymerized layer at the surface has an internal conversion ratio of approx. 25%. By comparing some materials used for artificial teeth construction we may notice that in the case of *dental acrylate* (having the following characteristics – compressive strength of 84 MPa, elastic modulus of 1700 MPa and elasticity limit of 55 MPa) this is used in dental technique offices in 80% situations unlike the ceramics materials which are present only in 20% of situations. *Duropont composite material* (having the characteristics – compressive strength of 90 MPa, elastic modulus of 1600 MPa and elasticity limit of 45 MPa) presents a highly superior hardness to the presently used acrylates. Unlike these, the duropont composite polymerizes in 6 atm external pressure conditions and even if it does not show the *cromasit* hardness, the favorable price makes it the most used material for dental prosthetic works. [65]

Mechanical properties of dental materials are defined by some characteristics, representing their behavior in certain working conditions and are expressed by several parameters.

Experiments used several types of dental composite materials, often used by dentists. Their composition is partially similar but there are some differences related to the type of dental work, teeth color, costs and possibilities of supply. The following materials were chosen: NexComp, Biner LC, Brilliant Flow, Amaris Flow, Filtek Z 550 and Valux Plus.

Filtek Z 550 is a composite material activated by visible light, designed for the use in anterior and posterior teeth. It is recommended for direct restorations, immobilizations but also indirect restorations.

Brilliant Flow is a fluid radio-opaque composite used for repairing dental cavities. It consists of metacrylates, barium silica and hydrophobic amorphous silica.

Composite **Valux Plus** due to its high wear resistance is used in more sustainable works. Bending and traction resistance are the ones providing the growth of durability for this material, but it is not very compression resistant. It consists of BIS-GMA and TEGDMA resins with synthetic minerals involving zirconium or silicon and inorganic elements.

Biner LC is a restorative material with fluoride release and radio-opaque characteristics. It is considered to be a basic material specially designed for using with adhesives, composites and conventional restorative materials. For solidification, polymerization light is used.

NexComp is a reinforced nano-filler composite used for restoring anterior and posterior teeth.

Amaris Flow is a photo-polymerizable fluid composite for special aesthetic restoration works. It has an excellent light dynamics and high color stability.[149]

Determination of mechanical characteristics is done following the procedure of testing on special equipment according to the proposed goal. The samples behavior is studied until they break and parameters are recorded, also the manner and aspect of breakage is analyzed.

If the compression force is not applied along the centre of gravity of the tooth cross-section, then the compression is eccentric. In this case, beside the axial compression force, bending moments will occur.

Compression testing was performed on a LS-100 compression testing machine produced by Lloyd's Instruments, United Kingdom. This has a maximum capacity of 100 kN, accuracy of testing velocity <0.2%, maximum stroke length 840 mm, load resolution <0.01% from the used force cell, extension resolution <0.1 microns, force cell XLC-100K-A1, analysis software is NEXYGEN MT. (fig. 2.10).

The testing precision class is 0.5, the equipment being provided with a digital control device in closed loop and also a computer for data control, acquisition and recording.

At the critical time, when the first crack occurred, the compression force reached maximum value and started decreasing after the total destruction of the sample.

The experimental data were recorded and the characteristic compression curve was obtained, while the tested sample was fixed in the device. In fig. 2.11, the breakage point is presented.

Fig. 2.10 Testing equipment for compression[149]

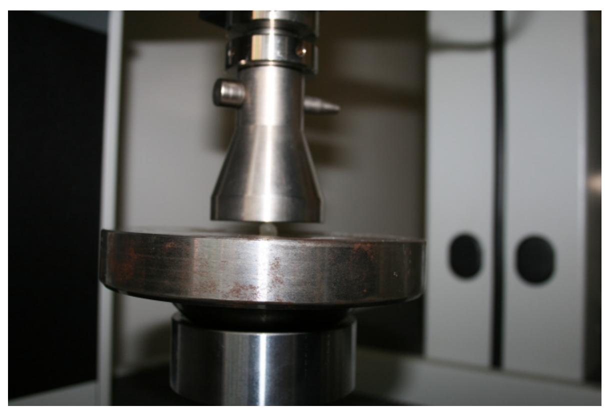


Fig.2.11 Breaking the sample [149]

The crack firstly occurred at the surface as very thin line, then it propagates to the depth of the material leading to spontaneous breakage.

During the tests, diagrams were obtained for several types of dental materials (Amaris Flow, Brilliant Flow, NexComp, Valux Plus, Filtek Z550, Biner LC), using 3 samples of each and by help of the machine software, showing the dependence of the compression force versus the specific linear displacement (compression characteristic curves). In fig.2.12, the force-displacement diagram for 3 Amaris Flow samples is shown.

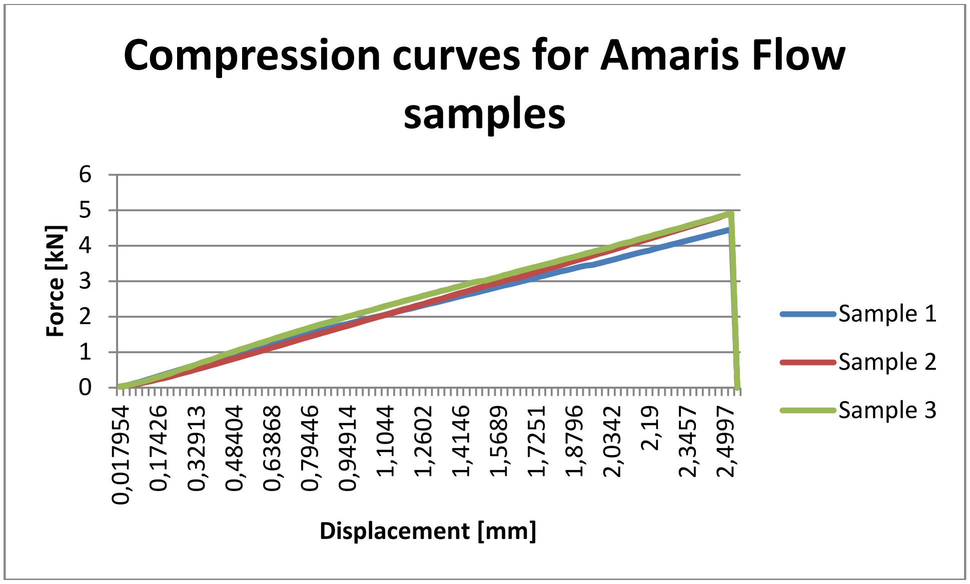


Fig.2.12 Compression characteristic curves for Amaris Flow [149]

As shown in the diagram, the first part of the characteristic curve is a straight line, the unit efforts being proportional with deformations. Up to a certain value of the unit effort the material behavior is perfectly elastic. When the unit effort grows higher than the strength at break, the material deformation becomes concentrated in a single point and the sample will crack suddenly in this case.

Another interesting example is offered by Valux Plus material. Its compression characteristic curves are presented in fig.2.13.

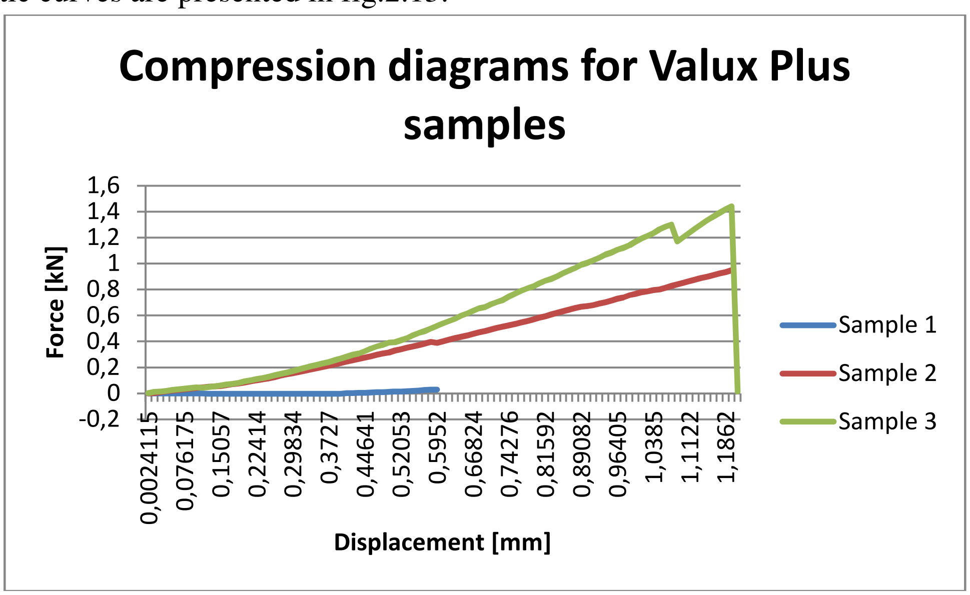


Fig.2.13 Compression characteristic curves for Valux Plus samples [149]

It is obviously a totally different situation, some of the samples follow the pattern of sudden break, and others go through the plastic phase when the material has the tendency to "flow" before it breaks.

In fig.2.14 – 2.17 the diagrams for the other tested materials are shown.

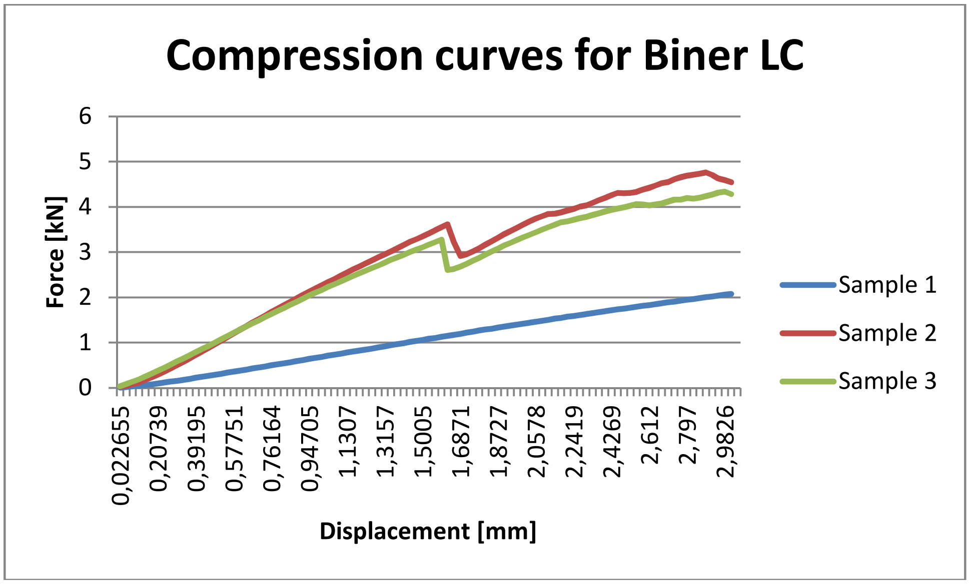


Fig.2.14 Compression characteristic curves for Biner LC samples [149]

The samples present an elastic behavior to a certain point, two of them will show a small drop in the force value as the material starts to give in.

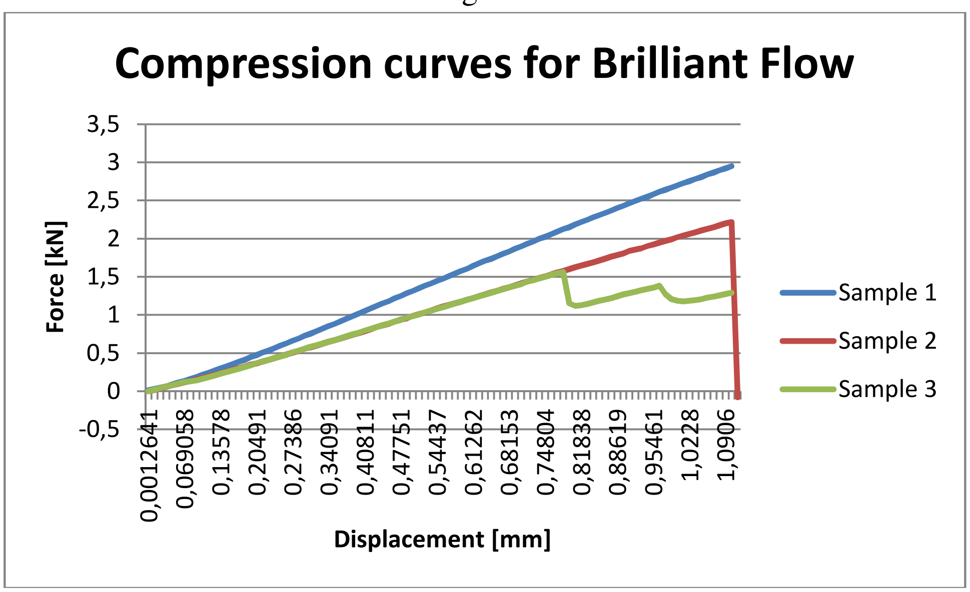


Fig.2.15 Compression characteristic curves for Brilliant Flow samples [149]

The samples of Brilliant Flow are behaving differently to one another, there is an obvious tendency of sudden break without the plastic flow, which occurs only for sample 3 at a certain extent. The material is more resistant than the others except for Amaris Flow.

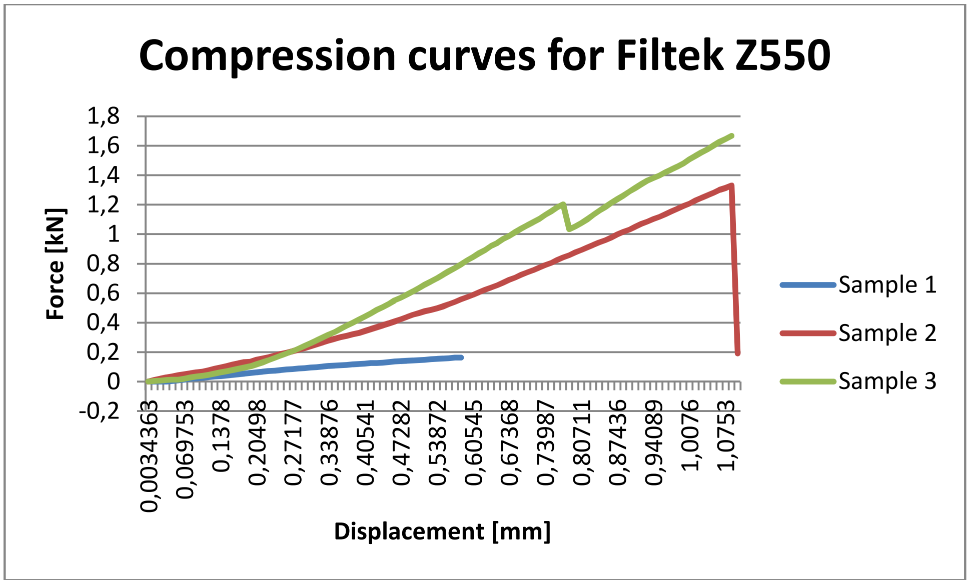


Fig.2.16 Compression characteristic curves for Filtek Z550 samples [149]

Fig. 2.16 shows the characteristic curves for Filtek Z550 samples. All three behave differently proving the fact that the samples composition is not exactly the same, it is possible to have different concentrations of the components leading to different results. Still the breaking values are high enough by comparison to other materials.

In fig.2.17 the compression curves for Nex Comp are displaying a smooth slope in the elastic domain, breaking suddenly at rather average values of the load.

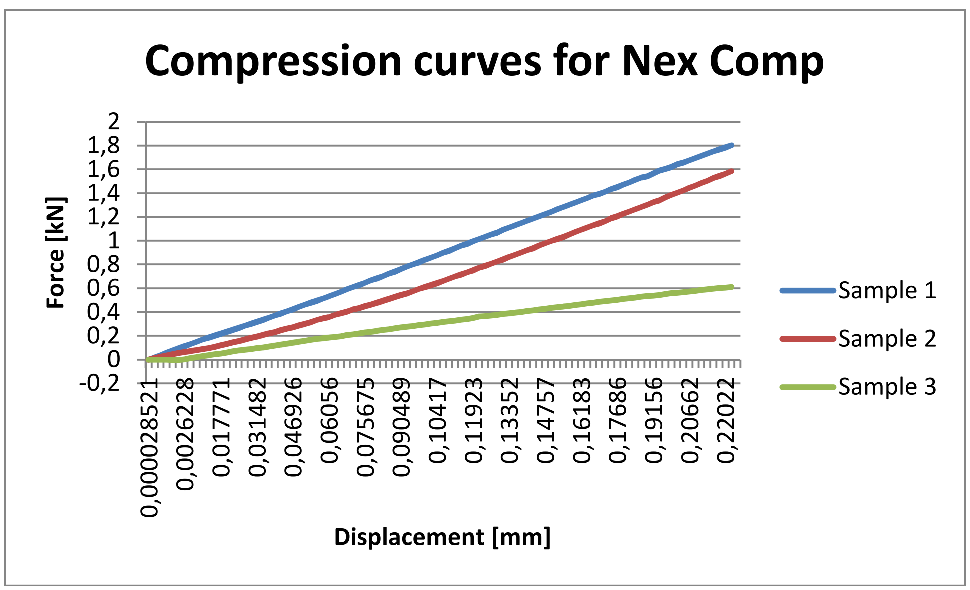


Fig.2.17 Compression characteristic curves for Nex Comp [149]

By summarizing in table 2.1 the results obtained for the average load at break for each tested material, it becomes obvious that Amaris Flow is the most resistant material as it breaks suddenly for an average load of 4,5kN, while Valux Plus breaks for only 0,835kN. But all the materials are strong enough to resist to the usual forces applied during mastication upon the restorative dental materials, they usually do not increase over 0,8kN.

Table 2.1 Average load at break for restorative materials

Materials	Average load at break [kN]
Amaris Flow	4,505
Brilliant Flow	2,606
Valux Plus	0,835
NexComp	1,344
Biner LC	2,093
Filtek Z550	1,067

Anyway, a direct correlation between the mechanical properties determined in laboratory conditions and the clinical behavior is not very strong yet. Specialists still consider that the laboratory tests take place in ideal conditions; this is why several directions of study of correlating aggressions upon restorative materials are to be considered in order to resist clinical trials. [65], [149]

Another interesting fact is related to the visual aspect of the breakage, this is the reason why all the broken samples were studied using the digital microscope with various magnifications. The microscope images are presented in fig.2.18 – 2.29.

Fig.2.18 Biner LC, 20x [149]

Fig.2.19 Biner LC, 100x [149]

Fig.2.20 Filtek Z550, 20x [149]

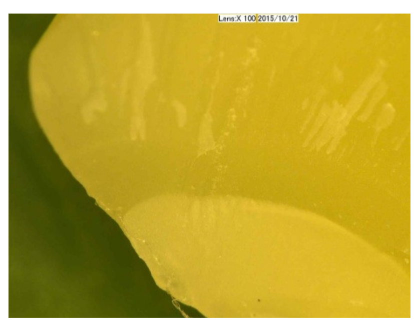


Fig.2.21 Filtek Z550, 100x [149]

Fig.2.22 Valux Plus, 20x [149]

Fig.2.23 Valux Plus, 100x [149]

Fig.2.24 Amaris Flow, 20x [149]

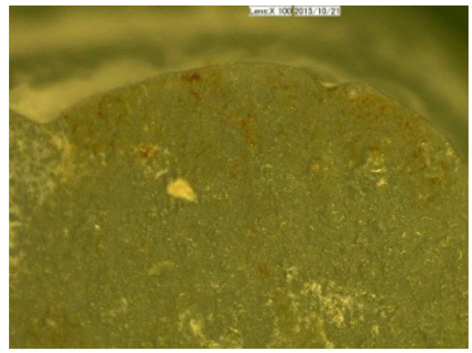


Fig.2.25 Amaris Flow, 100x [149]

Fig.2.26 Brilliant Flow, 20x [149]

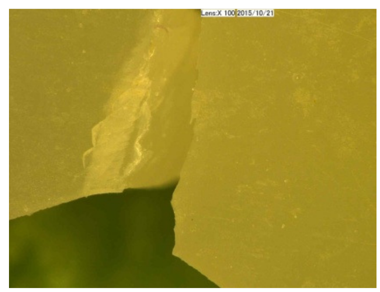


Fig.2.27 Brilliant Flow, 100x [149]

Fig.2.28 Nex Comp, 20x [149]

Fig.2.29 Nex Comp, 100x [149]

As shown in Table 2.1, the highest average load required for breaking the sample was obtained for Amaris Flow. Additionally, the compression characteristic curves show the lack of plastic flow, meaning that the material is fragile and breaking abruptly. This is obvious in the clean cut cross-sections shown in fig. 2.24, 2.25. The next values are reached by Brilliant Flow and Biner LC, whose cross-sections and characteristic curves show a certain plastic flow for some of the samples, the fracture takes place after the material suffers some plastic deformations. The following two materials, Nex Comp and Filtek present low elastic deformations, some insignificant plastic behavior for Filtek, while the cross-section shows a sudden break. The weakest material proved to be Valux Plus, giving in at the lowest force but still strong enough to resist the mastication forces.

2.1.4. Analysis of chemical aggression upon cracks in prosthetic dental materials

The multi-curvilinear primary morphology of the teeth represents a biological structure with optimized and ergonomic mastication efficiency working on the principle of minimum energy consumption in order to obtain a maximum functionality. When the human subject ages, the primary morphology of the dental structure is changing, as a follow of the slow and progressive wear of enamel and dentin, determining a physiological abrasion. These abrasions will occur at the occlusive surfaces and incised edges and also at the level of inter-proximal dental surfaces, due to the teeth friction during the mastication or deglutition process.

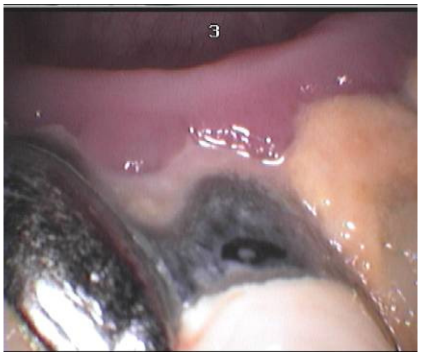
This wear in its turn is determined and maintained by the individual and independent physiological mobility of each strained tooth plus the influence of various edible, liquid and solid substances that add to the structural changes of the teeth surfaces, be they natural or from dental prosthesis.[57]

When the occlusive surfaces present a primary normal relief and driving of the food fragments represents the main element in the mastication cycle, there is the possibility of a successive discharge pressure of the mastication forces by driving the food fragment along the grooves or cracks existing in the dental structure.

During the fragment pressing, even if the oblique components of the mastication forces have projections on the occlusive surface, there is although a concentration within the tooth axis of a large amount of pressure that affects both the dental stability and the surfaces and enamel quality, leading to premature abrasions or even breaks.

In this context, the mandible is no more directed according to the mastication cycle, and the food is sliding along the entire occlusive area but constrained by the antagonist surfaces of the maxillary-mandible corresponding teeth it will determine the peripheral positioning of the food and also the exertion of some eccentric pressures upon the teeth, mandible joint and mandible arcade.

Also the prosthetic conjugated works, made from very hard metal alloys or the ceramic micro-prostheses, respectively the mobile skeletal prostheses or even total prostheses, with porcelain teeth, may generate strong abrasions upon the antagonist dental occlusive surfaces and even malfunctions of the entire dental-mandible apparatus (DMA) (fig.2.30). At the same time the existence of some bad habits (cutting thread with the teeth, introducing needles between teeth, using the pipe, etc.) or of some malocclusions may contribute to the initiation of the localized abrasions that will determine further changes or even the occurrence of surface or profound cracks.



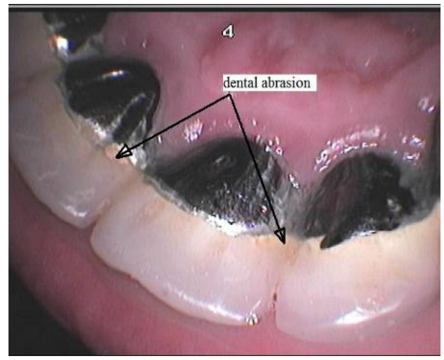


Fig.2.30 Superior fixed prosthesis with dental abrasion accomplished by movements of mandible teeth [59]

In case of designing a partial or total prosthesis, fixed or mobile, skeletal or only physiological, the specialist task to suitably choose the materials is based on the establishing of their biocompatibilities but also on the mastication habits of the subjects.

Not in the last, it is important to observe the interaction between these materials used in prostheses manufacturing and various liquid or solid food that makes contact with the prostheses teeth in each situation. Due to an extremely fast development of the field, there are at the moment three basic materials used in dental reconstruction by partial or total prosthesis: ceramic materials, (inorganic salts, crystalline ceramics, glass), metals (alloys, inter-metallic compounds) and polymers (rigid polymers, waxes, elastomers).

A wide spectrum of properties is present within each basic material type; nevertheless, there is a "family resemblance" among the varieties of each material type. For example, although metals exhibit a wide range of strengths, melting ranges, they resemble one another in their ductility, thermal and electrical conductivity, and metallic luster. Similarly, ceramics can be characterized as strong yet brittle, and polymers tend to be flexible (low elastic modulus) and weak. Knowing thus the technological, mechanical and physical characteristics of each type of material and adjusting them one to the other by correlating their biocompatibilities, we may obtain some constructive variants that eliminate some disadvantages by increasing the mastication comfort and not last to offer a normal and aesthetical physiological and physiognomy structure.

These aspects are influencing in a decisive way the subjects behavior from the mastication comfort point of view and in the meantime if not corrected it may influence or even change the head position and this way the static or dynamic stability.

For this study an analysis structure (fig.2.31) was designed by image processing, using the images captured by help of a Keyence digital microscope, magnification between 500x and 5000x, with continuous illuminating system, total open slot and *sharpen* type filtering, of some dental prostheses samples, made of metal support and acrylate surface, and respectively of some acrylate teeth samples for the total prosthesis.

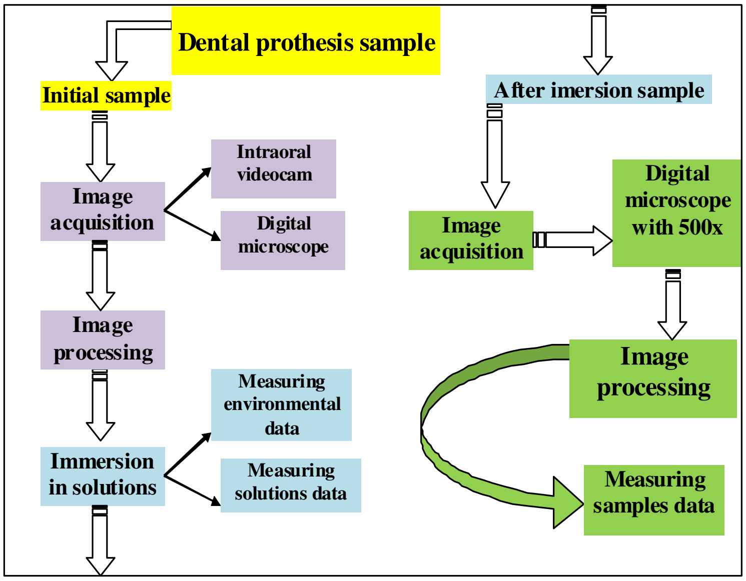


Fig.2.31 Principle of structure based on image processing analysis of the dental prostheses samples [59]

The samples were analyzed in the beginning on the active surfaces by help of an intraoral video camera type TopCam (fig.2.32) and then by the Keyence type digital microscope (fig.2.33) that acquired the images of some assembling areas (fig.2.34a) upon the teeth of fixed or mobile combined prostheses made of metal-acrylate and also of the occlusive surface (fig.2.34b and c) where abrasions may be observed on the primary relief.

Fig.2.32 Intraoral camera [59]

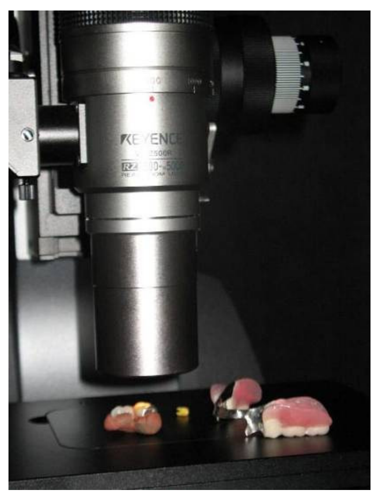


Fig.2.33 Keyence digital microscope (500x) [59]

a b c

Fig.2.34 The assembling-cementing surface (left), occlusive surface of the same tooth (middle) and abrasion with the change of enamel structure on the intermediate tooth (right) [59]

The prostheses and prostheses teeth samples were introduced in edible solutions (9 solutions), along 144 hours, at the same temperature, in closed recipients, without being exposed to excessive light radiation or other environmental aggressions.

Fig.2.35 Samples of prosthetic teeth immersed in edible solutions [59]

The solutions selected for testing were ethylic alcohol 70%, milk 3,5% fat, cooking oil, solution of sugar and water 40%, salty water 40%, tea, instant coffee, coca-cola, natural juice, considered to be the most usual substances that prosthetic teeth come in contact with (fig.2.35).

The acquired images aimed at highlighting the influences of these substances upon the occlusive surfaces, frontal surfaces and those in the metal-acrylate interface, especially in the area where some surfaces cracks or deteriorations occurred. The results are shown in fig.2.36-2.42.

Fig.2.36 Dental prosthesis sample based on metal (chrome-cobalt alloy) and acrylate surface immersed in 40% salty solution before (left) and after 144 hours (right) [59]


Fig.2.37 Sample before immersion in sugar solution and same sample after 144 hours [59]


Fig.2.38 Sample before immersion in milk and same sample after 144 hours [59]


Fig.2.39 Acrylate on metal support tooth sample before immersion and same sample after 144 hours of immersion in cooking oil [59]

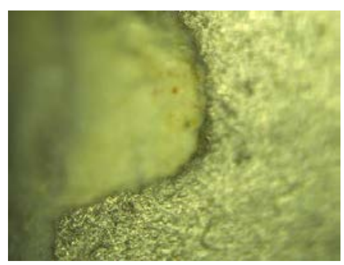



Fig.2.40 Acrylate on metal support tooth sample after 144 hours of immersion in natural juice (left) and instant coffee (right) [59]

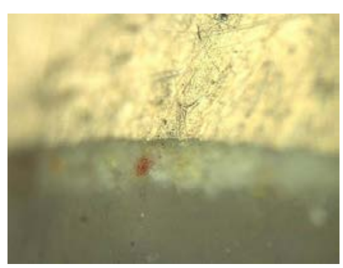



Fig.2.41 Acrylate on metal support tooth sample with abrasions and small cracks before immersion in coca-cola and same sample after 144 hours [59]

Fig.2.42 Acrylate tooth sample from a total prosthesis before immersion in white tea and same sample after 144 hours [59]

Then by applying a sequence of image processing methods, captured by the digital microscope it becomes possible to extract a set of dimensional data concerning the size and enhancement of the surfaces affected by the immersion solutions upon the prosthetic teeth or the metal support of the skeletal prostheses, as shown in fig.2.43.

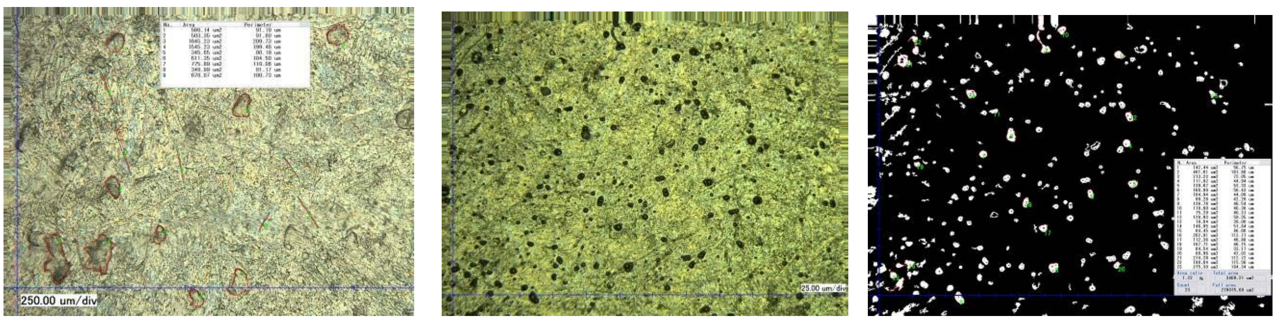


Fig.2.43 Image processing methods in order to perform measurements upon the teeth samples of the skeletal, fixed or mobile prostheses [59]

Following the processing of the acquired images and the performed measurements it was possible to emphasize some aspects both in the microscopic analysis and in the general analysis of the samples shape and colors, before or after the immersion in the experiment solutions.

The substances chosen for the experiment were of general use, found in the usual nutrition component, and they were selected as being different in their type of action, density, color, while the duration was established as a first analysis module.

By analyzing the used samples it was possible to identify some factors favoring abrasion, which influence the wear degree and type of the teeth in the mobile, skeletal or fixed prostheses: organic-mineral components of the teeth and the implantation quality inside the support basis; occlusion type used on the subjects; food consistency, their abrasive and chemical aggressiveness; saliva quantity and components; nature of the mandible mobilizing muscles and the entire mastication system morphology.

Thus the adherence of the micro-particles of instant coffee or of the pigment in coca-cola in the acrylate porosity, fact that changes its color aspect was highlighted (fig.2.39 – 2.41). Also the surface of the metal support of the skeletal mobile prosthesis subjected to the natural juice action, that does not change the surface roughness was measured, the biggest measurement on the sample being 1645,23 μm^2 (fig.2.43).[59]

In addition to the edible substances effect during mastication, for the subjects with total dental prostheses or mobile skeletal ones, there is the requirement of increasing the prostheses stability by manufacturing an occlusive cuspidate relief and a frontal occlusion, having such a structure that it allows mastication only by vertical motions, fact that diminishes the possibility of abrasive harmful horizontal forces, that affect the prosthesis stability and resistance. This requires more care in teeth manufacturing especially in the occlusive area and the use of some materials more resistant to the aggression of various substances.

2.1.5. Chemical aggression upon restorative dental materials

There are several dental illnesses that can be fixed by help of restorative materials, the most common being the cavity, then of course dental erosion, abrasion or even some traumatisms.

When the dentist selects the restoration type that is going to be used upon the affected tooth, the selection will be between several types of the same material, such as various categories of amalgam or between two types of basic materials (metal amalgam or gold). Due to the fast evolution of dental materials during the last years, selection of the suitable material is made between few basic materials: hybrid composite resins and polymer and ceramic composites with a ceramic crown.

Each basic material presents a large specter of properties, sometimes similar among the variety of materials. For example, metals may resist to a large range of force values, melting temperature intervals, etc. they resemble by ductility, thermal and electrical conductivity and metallic luster. Similarly, ceramic has a little lower resistance, polymers tend to be more flexible and with lower hardness. Understanding the key concepts of these basic materials offers a significant perspective regarding the behavior of each class of materials as restorative dental material, as well as an idea about the potential of these materials concerning the possibilities of overcoming their shortages. [127]

Following the same procedure as for the prosthetic teeth, the materials samples (consisting of Amaris Flow, Brilliant Flow, Nex Comp, Valux Plus, Filtek Z550, Biner LC) were introduced in various edible substances like: vinegar, ethanol, sugar solution, salt solution, orange juice, coffee and cola, considering that these solutions may affect the dental composites and are often in contact with restorative dental materials in the patient’s mouth.

After performing the contact simulations with chemical agents coming from various liquids or nutrients, the samples were examined by help of the Keyence digital microscope, as in the previous paragraph.

Samples were subjected first to a primary analysis, before subjecting them to any contact to substances. The size of the samples were different but the interest was focused upon the changes occurred on the surface aspect and color. Then the samples were introduced in recipients with solutions as follows: (fig. 2.44)

Fig.2.44 Recipients with test solutions [149]

Vinegar (5% solution) is in fact acetic acid used in salad dressings and pickles preparation.
Ethanol (38% solution) is used to simulate alcohol consumption. It is a colorless and odorless substance, having a slightly acid character.
Sugar solution (10%) covers the contact with cakes, chocolate and sweet fruit.
Salt solution (10%) simulates salty foods like pretzels and chips or even saliva.

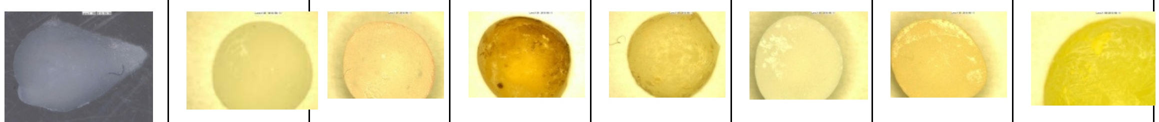
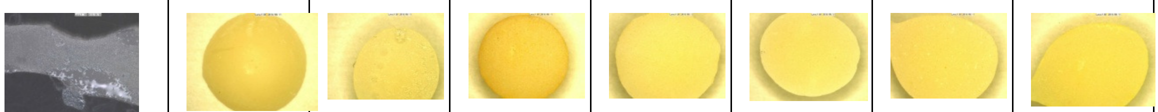
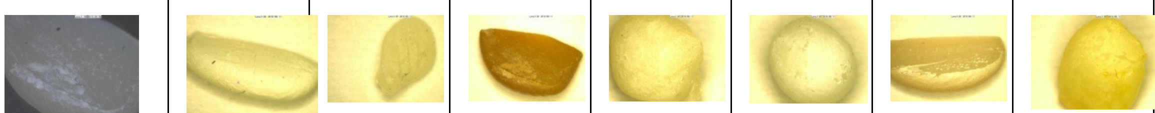
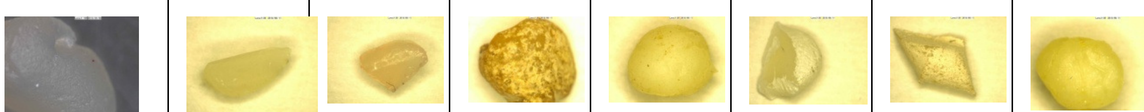
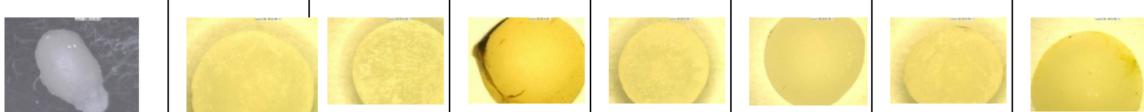
Coffee is a beverage used by most people and it is a known fact that it colors the teeth so probably it will do the same to the restoration materials.

Cola is one of the most used refreshing beverages, with a specific taste and color, has acid character and includes caffeine.

Orange juice is a very healthy beverage due to its high content of vitamins and minerals, but at the same time it has acid character and strong color.

Materials were left in contact with the above mentioned solutions for 8 days (192 hours) at the same temperature and in normal daylight. The results obtained after analyzing them by microscope are presented in table 2.2.

Table 2.2 Restorative materials images before and after subjected to chemical agents

Materials	Salt	Sugar	Coffee	Cola	Ethanol	Vinegar	Orange juice
Filtek 							
Amaris 							
Biner 							
Valux 							
NexComp 							
Brilliant 							

As shown in the pictures in table 2.2, no material remains exactly the same when subjected to the action of chemical agents. It is obvious that coffee affects most the chromatic stability, followed by orange juice. The acidity of some solutions like coffee, orange juice and vinegar creates slight cracks and cavities at the material surface. The other solutions also affect color at a lower extent. After a visual analysis of the materials surface it becomes clear that Biner LC remains the most stable regardless of the aggression agent, while Brilliant also behaves very well except for the contact with coffee. [149]

2.1.6. Thermal stress of dental materials

Restorative dental materials are subjected to a very tough environment involving mechanical stress due to mastication or some pathologies, chemical attacks due to various ingested substances, humidity and last but not least thermal stress due to ingestion of hot or cold beverages or other nutrients or even due to dental works. Many experimental studies have been published that use thermal cycling regimes to test dental materials characteristics, but there is no standardized procedure in doing these tests. [100]

The heat propagation in dental materials is mostly done by conduction or convection.

Thermal conduction means heat transfer in a continuous environment with an irregular distribution of temperature. The heat is transferred by direct contact between the particles with different temperatures, meaning an energy exchange between molecules, atoms or/and free electrons (phenomenon occurs due to contact with solid food or during dental works). [7] This process is governed by Fourier's law:

$$d^2Q_\tau = -\lambda \cdot 1_n \cdot \frac{\partial t}{\partial n} \cdot dA \cdot d\tau \qquad (2.1)$$

where: Q_τ is the vector of heat quantity passing through the body [J]; A is the area of the contact surface [m^2]; λ is the thermal conductivity [W/mK] depending on the type of material, $\partial t/\partial n$ the temperature variation on normal direction. The sign "-" is a consequence of the second law of thermodynamics (heat vector should be oriented towards the decreasing temperature).

Thermal convection means heat transfer between liquid or gaseous substances in motion and the surface of solid bodies (phenomenon occurring due to the contact between ingested drinks and dental materials). The law governing the convection process was proposed by Newton:

$$\dot{Q} = \alpha \cdot A \cdot \left| t_f - t_s \right| = \alpha \cdot A \cdot \Delta t \qquad (2.2)$$

where $\dot{Q}$ is the heat flow transferred by convection [W]; α coefficient of heat exchange by convection [W/m^2 °C] ; t_f, t_s – temperature of the fluid and respectively of the solid material [°C] ; A is the area of the contact surface between the fluid and the solid (dental material).

The exposure to high and low temperatures may lead to damages of the marginal integrity of the restoration, causing the micro-leakage phenomenon that may lead to staining, marginal breakdown, hypersensitivity and development of pulpal pathology. [45]

As there is no standardized methodology for testing the influence of temperature variation upon the dental materials, researchers usually select themselves the temperature limits, duration of one cycle, number of cycles, etc. according to the available conditions. The same materials were used as for the chemical tests: NexComp, Biner LC, Brilliant Flow, Amaris Flow, Filtek Z 550 and Valux Plus.

The samples were introduced in water at 5^0C for 10 sec, then in another recipient with water at 55^0C again for 10 sec, as recommended by [45] as the material will not come in contact with the cold or hot liquid for more than 10 seconds. The cycles were repeated for 10min (the approximate duration of a short meal), three times a day, for one week.

The samples were then analyzed using the digital microscope, especially in the marginal area which is the most exposed in the dental works and the results are presented in fig. 2.45-2.50.

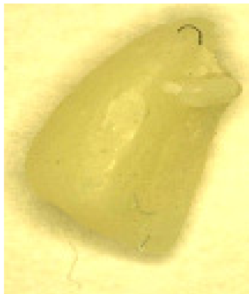


Fig.2.45 Sample of Filtek Z550, magnification 500x

Some very small cracks are visible on the material surface, especially at the upper edge; otherwise the surface seemed to behave very well. Anyway, no study has been done for a longer period of time in order to observe the aging of the dental material due to thermal cycling.

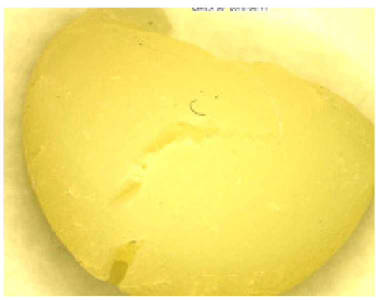


Fig. 2.46 Sample of NexComp, magnification 500x

The material shows multiple cracks, both on the surface and mostly on edges, this will lead to microleakage and will destroy in time the bond between the restorative material and the restored tooth, leading finally to possible pulpal pathologies or at least the damage of the dental work. The material shows high vulnerability to temperature variation.

Fig.2.47 Sample of Valux Plus, magnification 500x

Some very small porosity can be seen on the surface, but the edges behaved very well. It is possible that in a longer period of time the surface might sustain higher damage and lead to the destruction of the restoration.

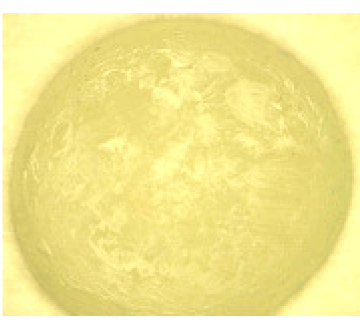


Fig.2.48 Sample of Amaris Flow, magnification 500x

The material surface presents small cracks and exfoliations following the thermal cycling. The edges look rather good but probably a longer exposure to temperature variations will destroy the dental work.

The behavior is although encouraging and will last more than an average period.

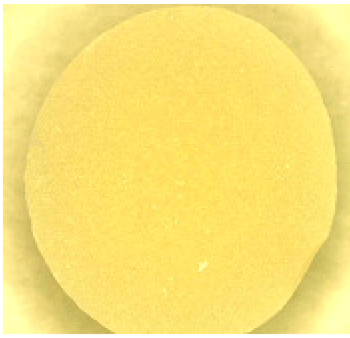


Fig.2.49 Sample of Biner LC, magnification 500x

There are no important changes of the sample after it was subjected to temperature variations; the edges present minor chippings, which may be the results of handling the sample with the tweezers.
Generally the sample behaves well and seems to be the most resistant from the point of view of temperature changes.

Fig.2.50 Sample of Brilliant Flow, magnification 500x

Some exfoliations occur upon the sample's surface, seen as light colored spots; the edges seem to maintain their shape rather well.
The general conclusion is that the sample resisted successfully to temperature changes for the study period.

2.2. Analysis of properties of materials for biomedical use

The diagnosis and treatment expenses have been growing constantly as a result of new investigation techniques, new types of implants, prosthetic and orthotic options and also instruments used for fixation or even joint replacement. One of the most promising possibilities of decreasing these costs is to identify and study new materials that may be used for biomechanical devices and decide if they correspond both from mechanical and biomechanical point of view.

Based upon the definition of composite materials stating that they consist of several materials with different structures and compositions which enable better properties than the component materials, we may say that the human bones are in fact some natural composite materials, so the idea of working with composites in order to support the healing of the bone structure seems an obvious choice.

As far as the bone tissue is concerned, collagen acts like a resin representing the matrix, while the mineral crystals are reinforcement elements. These minerals are 20nm long and are exceptionally tensile resistant but their natural position is like a curve so they cannot perform alone the task of structural support. The combination between these minerals and the collagen creates the bone tissue that is able to fulfill this supporting task very well. [143]

The attention becomes focused on some types of polymeric composite materials whose processing and manufacturing involve reasonable costs, in order to determine the suitability of their mechanical properties.

The polymeric materials are the most representative class of materials used in the current manufacturing of various technical components and consumer goods. A special place is taken by the composite polymeric materials as a distinct and spectacular proposal for new and effective solutions.

2.2.1. Testing compression and bending properties

Regarding the mechanical tests meant for the study of polymeric composite materials behaviour a principle similarity with the tests applied on metals may be taken into consideration. The differences concern only the shape and size of the test specimens or the magnitude of the applied forces.

Most of the conception procedures either simple or sophisticated will be based on data concerning the stiffness and will be connected to the assessment of the deformation or bending limit. As a consequence, the values of Young's modulus are usually required for the principal directions on both planes using perpendicular axes. Young's modulus controls the displacement/ deformation within the material. [56]

For an isotropic material, the connection between the stiffness parameters, Young's modulus (E) and transverse elastic modulus (G) is given by (2.3).

$$G = E/2(1+ v) \tag{2.3}$$

the equivalent equation for the elastic modulus on both planes G_{12} being

$$\frac{G_{12}}{G_m} = \frac{(1+\xi\eta V_f)}{(1-\eta V_f)} \tag{2.4}$$

Where

$$\eta = \frac{(G_{12f}/G_m)-1}{(G_{12f}/G_m)+\xi'} \tag{2.5}$$

and the reinforcement constant ξ' is 1.

This determines different absolute values and also different ratios of the transverse elasticity and tension on both planes.

The bending stiffness denoted R for a sandwich type element consisting of thin layers with identical thickness is the result of the addition of the external layers bending stiffness and the core stiffness about the cross-section axes:

$$R = E_s \cdot \frac{b \cdot t^3}{6} + E_s \cdot \frac{b \cdot t \cdot d^2}{2} + E_c \cdot \frac{b \cdot c^3}{12}, \tag{2.6}$$

where E_s and E_c represent the Young's modulus of the layers and respectively of the composite core.

If the layers are made of different materials, with different thickness, as the analyzed structure, and assuming that the bending stiffness between the layers cannot be neglected, it means that

$$\frac{d}{t} > 5.77 \tag{2.7}$$

The bending stiffness of the structure can be written as follows:

$$R = \frac{b \cdot d^2 \cdot E_{s1} \cdot E_{s2} \cdot t_1 \cdot t_2}{\left(E_{s1} \cdot t_1 + E_{s2} \cdot t_2\right)} + \frac{b}{12} \cdot \left(E_{s1} \cdot t_1^3 + E_{s2} \cdot t_2^3\right) \tag{2.8}$$

[128]

The following materials have been used for the analyzed structure:

• MAT 600 - fibreglass composite (short wires) in the matrix of epoxy resin with specific weight 2x600g / m2, 2-2, 6 mm thick;

• RT 800 - fibreglass composite (fabric) in the matrix of epoxy resin with specific weight of 4x 800g / m2, thickness 3,2-3,6 mm;

• MAT 450 - fibreglass composite (short wires) in the matrix of epoxy resin with specific weight 2x450g / m2, 1.6-2mm thick.

The used equipment is a testing machine with constant compression speed, consisting of a fixed part provided with specimen fixing clamps and a moving part also with fixing clamps, also a driving mechanism.

The testing machine type LS100 is manufactured by Lloyd's Instruments, Great Britain and is presented in fig.2.51.

It presents the following characteristics: Force field: 100kN; speed testing accuracy <0.2%; Force cell: XLC-100K-A1; Analysis software: NEXYGEN MT.

The equipment allows the acquiring of experimental results in electronic form by help of the NEXYGEN Plus software.

Fig.2.51 Tensile testing machine [56]

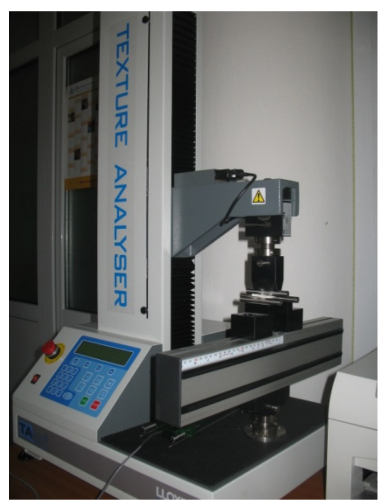


Fig.2.52 Three points testing machine [56]

For the three points bending test we used another equipment coming from the same company as the tensile testing machine, that is a LR5K Plus machine (fig. 2.52) providing a maximum force of F_{max}= 5 kN.

The three points are materialized by two supports and a hemispheric punch. Their alignment should be achieved according to a 0,02 mm accuracy. The radius R_1 of the hemispheric punch and the radii R_2 of the supports should be as follows: R_1= 5,0 mm ± 0,1 mm; R_2 = 2,0 mm ± 0,2 mm for specimen thickness smaller or equal to 3 mm and R_2= 5,0 mm± 0,2 mm for specimen thickness higher than 3 mm.

Compression testing results

Before specimens testing the dimensions of the cross-section and width were measured exactly; these dimensions are introduced as input data in the testing machine computer, which works with corresponding software designed to gather the experimental data from the machine and to process them.

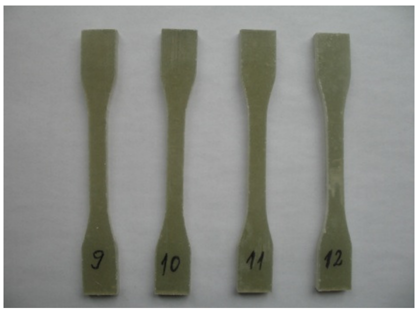


Fig.2.53 Specimens before testing [56]

The specimens were taken from a plate of 8 mm thickness, with a white gel coat layer. The specimens were polymerized for 24 hours at a 20^0C and are presented in fig.2.41.

The testing results are shown in fig.2.54 and 2.55.

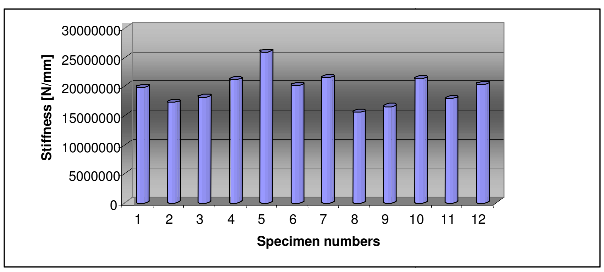


Fig.2.54 Stiffness distribution for compression testing [56]

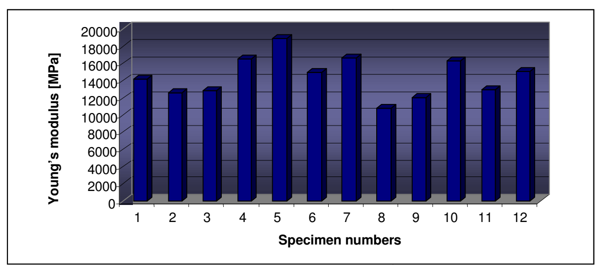


Fig.2.55 Young's modulus diagram [56]

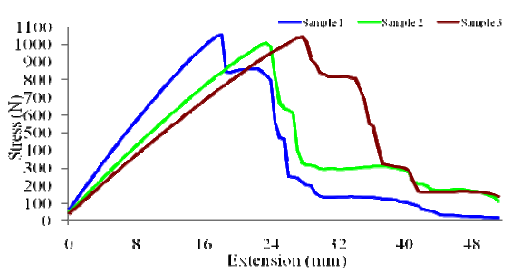


Fig.2.56 Force-displacement diagram for specimens 1,2,3 [56]

The results for Young's modulus presented in fig.2.55 are the following: minimum value is 10820 [MPa] and maximum values goes up to 18932 [MPa].

The compression testing is considered to be a significant source of data concerning the polymeric materials mechanical properties and behaviour. This can be shown also by help of the force-displacement diagrams (fig.2.56) providing information about the material behaviour during gradually bending.

Bending test results

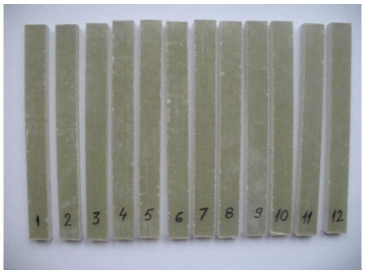


Fig.2.57 Specimens prepared for bending tests [56]

In order to perform bending tests we used specimens manufactured according to the standard requirements.

The specimens (see fig.2.57) were taken from a 7 mm thickness plate, whose surface was protected with a white gel coat layer. The specimens were polymerized for 24 hours at 20^0C.

In fig.2.58 the stiffness values for the 12 tested specimens were presented. It is noticed that the minimum value of the stiffness is 60330 N/m for the specimen no.10, while the maximum value 79870 N/m is met for specimen 7.

In fig.2.59, the Young's modulus values for the 12 specimens are shown. Analyzing the diagram the minimum value of the Young's modulus comes up at 3440 MPa and the maximum one at 4122 MPa.

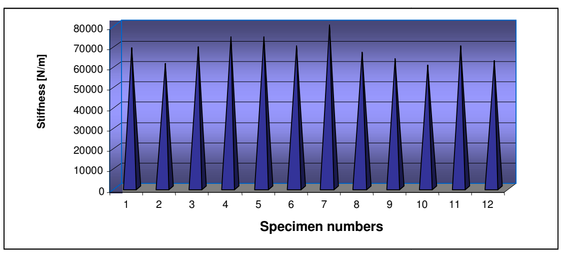


Fig.2.58 Stiffness diagram for bending tests [56]

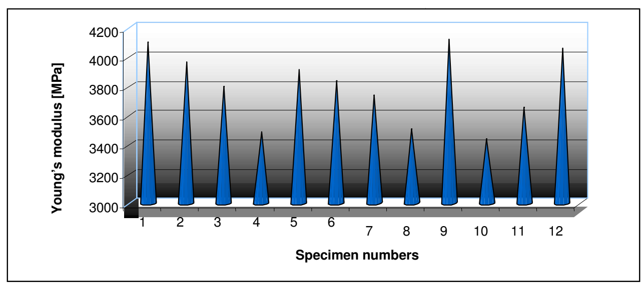


Fig.2.59 Young's modulus diagram for bending [56]

The force displacement diagram is shown in fig.2.60.

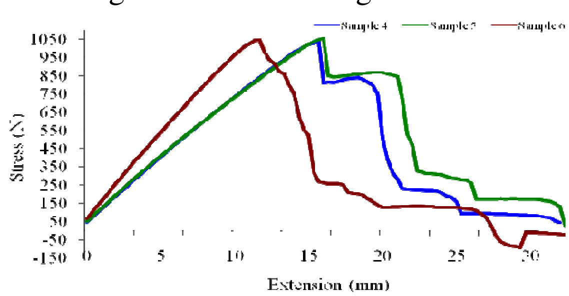


Fig.2.60 Force-displacement diagram for specimens 4,5,6 subjected to bending [56]

Based on the performed experiments meant to determine the behaviour during compression and bending, and especially by analyzing the force-displacement diagrams it becomes obvious there are differences between the values determined for each specimen, thus:

- for compression, along the axis X the displacement has shown values between 0 – 1,17 [mm], while along the axis Y the force increased from 0 to 15000 [N], the differences being due to the geometric variations of the specimens;
- for bending, along the axis X the displacement was between 0 - 0,65 [mm], while along the axis Y the force presented values between 0 – 1500 [N] due to the geometric differences of the specimens and also due to some structure variations. [56]

As a follow we can say that the tested materials, even for the worst specimens structure, meet by far the mechanical conditions required by an orthopedic prosthetic or orthotic device but future researches need to establish the biomechanical compatibility in order to be able to accept them as a viable alternative for the more expensive materials.

2.2.2. Microscopic analysis of breakage in materials for biomechanical use

In everyday life, the various orthopedic devices, together with the bones they are supporting, might be subjected to various stress and strains due to common motions like running, jumping or climbing, or due to unexpected accidents leading to impacts and shocks. Considering the fact that most of the devices are in direct contact with the human tissues, it is of utmost importance to analyze what happens at microscopic level inside the material during an extreme strain that might lead to rupture. The way the material breaks provides valuable information related to the weak points, the elasticity and stiffness of the tested sample.

Provided a multilayer composite material based on a polymeric matrix is used, some things must be taken into account: the fact that the bending resistance is strongly influenced also by the environmental conditions and by the resistance of each lamina. There are several rupture criteria applicable to fiber reinforced composite materials, some of them using empiric relations, others are experimentally determined.

Microscopic analysis can be both an intermediate control method and a final one. Its importance is given by the fact that the control can be made upon the breakage surface, upon the forming surface and also upon special processed surfaces (honed or corroded). Several defects occurred in different stages of processing can be emphasized, namely: capacity defects (porosity, cracks), surface defects or depth defects. They may be of different nature, size, shape, relative distribution and may lead to faulty products. [62]

In order to be able to study the alterations occurred within the composite material during the breakage process two devices were used: an oral video cam and a digital microscope. The oral video cam has the role of pinpointing the area of interest that is going to be studied by help of the digital microscope. This method will facilitate the search for problem areas.

The samples were subjected to traction and bending and studied in the vicinity of the breakage area.

The Acclaim system is comprised of a camera hand piece with a USB umbilical (embedded USB 2.0 interface control module). The Camera Handpiece is extremely lightweight with a high resolution, high sensitivity, auto-exposure controlled CCD sensor and a high performance lens system illuminated by ultra-bright white LED lamps. The fixed focus lens has a broad depth of field bringing all objects measuring between 6 and 50 mm into focus enabling the camera to finely detail a section (see fig.2.61 and 2.62).

Fig.2.61 Oral video cam [62]

Fig.2.62 Images during analysis on digital microscope [62]

Fig.2.63 Keyence digital microscope connected to PC [62]

The VHX-500 Keyence microscope provides a depth of field at least 20 times larger than optical microscopes. Thus, the VHX-500 can accurately observe a target (even with a large height difference) that could not be focused on with conventional microscopes. It can be connected to the PC and save the images required for analysis. Magnification is between 500x and 2000x (see fig.2.63).

Fig.2.64 Samples subjected to bending[62]

We used various types of composite material samples for testing, thus: 5 samples made of 4 layers Roving material with different types of fabric orientation (weft or warp fabric), 10-12 samples of 4 layers Mat-Roving type of material (fig.2.64). The samples were tested both for traction and bending until they reached the breaking limit, then we analyzed the aspect of rupture using the video camera and also the digital microscope.

In the following the most spectacular and eloquent examples were selected.

In fig. 2.65 and 2.66, sample 2 subjected to traction is presented; the sample is made of 4 layers of MAT-Roving combination and was polymerized for 24 hours before testing. The images show that the fibers are breaking towards the external part of the sample, while the matrix is not very damaged.

Fig.2.65 Sample 2, magnified 5x [62]

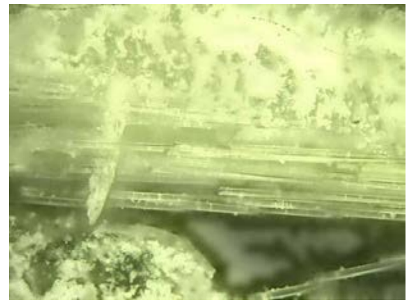


Fig.2.66 Sample 2, magnified 500x [62]

Sample 5, made of the same material was subjected to bending and the results can be visualized in fig.2.67 and fig.2.68. It can be seen that the fibers broke in a dangerous way, while the microscopic image shows even a significant delaminating of the material.

This phenomenon could be very damaging in case the material is used in the implant construction. On the other hand, we found that the average value of the bending stiffness is around 68000 N/m, which is more than satisfactory for the intended needs.

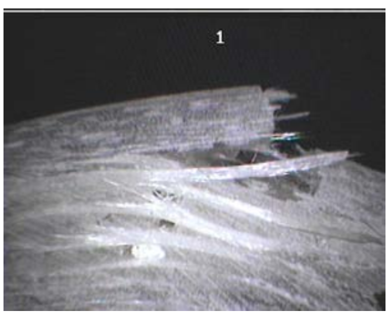


Fig.2.67 Sample 5, magnified 5x [62]

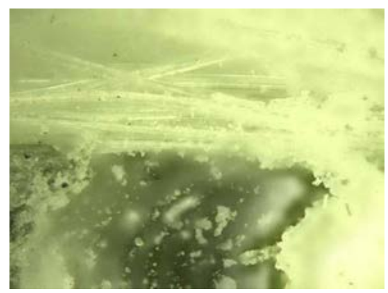


Fig.2.68 Sample 5, magnified 500x [62]

Some interesting results were obtained by studying different types of fabrics, such as the weft fabric and analyze the behaviour during traction and bending. Thus, in fig.2.69 and 2.70 some samples of the material subjected to traction were presented, while in fig.2.71 and 2.72, the sample was subjected to bending.

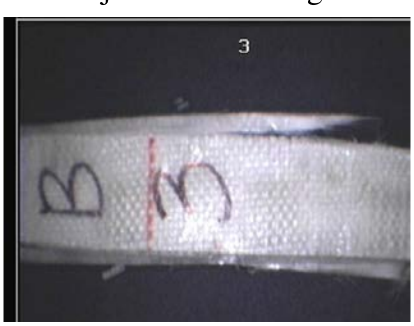


Fig.2.69 Sample 3, traction, 5x [62]

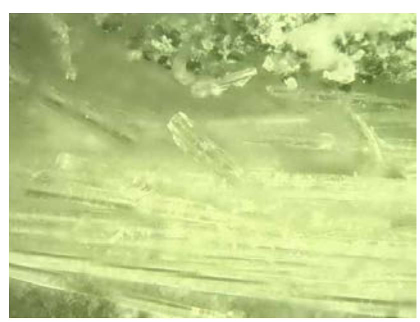


Fig.2.70 Sample 3, traction 500x [62]

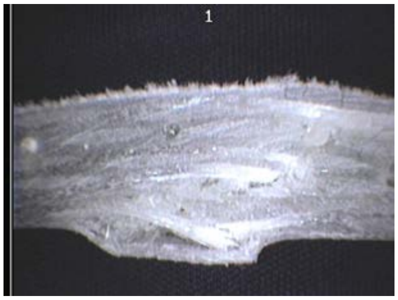


Fig.2.71 Sample 4, bending, 5x [62]

Fig.2.72 Sample 4, bending 500x [62]

According to the visual study, this type of fabric orientation is much more acceptable, as the fibers do not spread significantly after breaking and the matrix structure is only slightly affected.

The next type of fabric that was tested was a warp fabric included in the structure of the composite material, again on a multilayer basis. In fig. 2.73 and 2.74 the results for samples provided with warp fabric, subjected to bending were presented, as these results provide more important details.

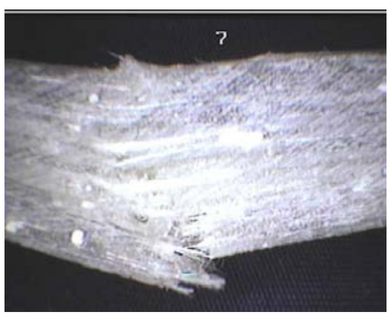


Fig.2.73 Sample 7, bending, 5x [62]

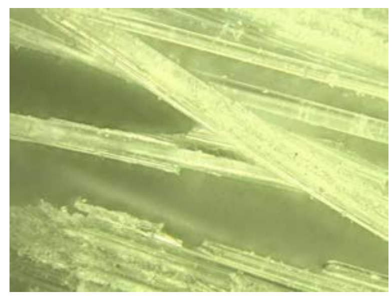


Fig.2.74 Sample 7, bending, 500x [62]

The images show again a dangerous breaking of the fibers but only for high values of stress, that are not likely to be reached in a regular use of an orthopedic device.

After analyzing the studied samples, it was concluded that best results were obtained for the materials provided with layers of weft fabric. For these samples, the breakage proved to be smoother, the fibers are not chaotically spread and the matrix is only slightly affected. For the other types of samples, the breakage produces more damaging results, the fibers push out of the fabric and there is also a delaminating effect of the matrix occurring. Nevertheless, the values of stress required for the material breaking are improbable to be reached during an accident.

As a conclusion, all the tested materials respond to the requirements of withstanding loads of traction and bending but the material provided with weft fabric layers seems to be much safer.

2.2.3. Impact testing of materials for orthopedics devices

In order to be sure that the orthopedics device meets its purpose, the properties it offers should be as close as possible to the ones of the replaced or supported structure and also it should not affect the human body in a negative way. For this reason, the materials used for orthopedics devices manufacturing will be very carefully selected, so that they are biocompatible, preserve the required mechanical and biomechanical properties along the entire use cycle or at least as long as possible and let us not forget the fact they should require reasonable expenses, considering the fact that they need to be individualized according to the psycho-somatic characteristics of each beneficiary. This way they can be made available to a larger target of individuals who require them, contributing to a substantial improvement of their life quality and many times to the smooth readjusting of a person to a normal productive life. [54]

One of the main requirements to meet for an orthopedics device is the impact resistance. They are constantly subjected to dynamical shock stress and impacts during the locomotion or usual activities processes but also due to some accidental phenomena during their entire life-cycle. Also, most of the used materials are obtained by successive layers applied over a basic material in order to be able to benefit of all useful properties of the materials involved. The impact tests also offer us an idea about the adherence degree of the material layers on the basis. For this purpose an equipment provided by INSTRON, model 8200 (fig. 2.75) was used, ideal for testing thin cross-sections of composite and ceramic materials, thin films and also metals. Using this equipment it is possible to obtain the changing values for impact velocities and impact energies. The maximum impact velocity is about 4,4 m/s, while the range of impact energies is somewhere between 1,356J and 132,8J.

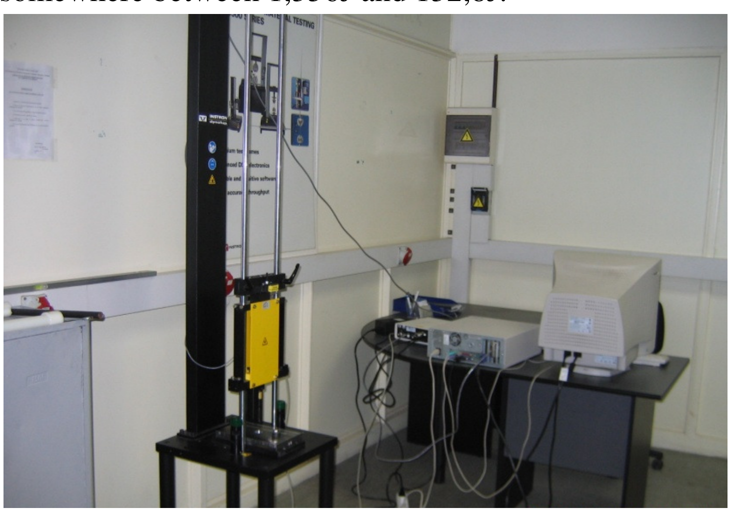


Fig.2.75 Impact testing equipment with acquiring data system [54]

The results are acquired by a computer system with dedicated software, which provides graphical data concerning the impact velocities and energies.

The method used by the testing equipment is based on dropping a certain weight on a vertical direction inside a guiding tube. Knowing the weight dropping height and the value of the weight, the software allows the instantaneous determination of the impact energy, impact velocity, peak load and also other parameters characterizing the studied impact.

The use of this method offers several benefits, the most important for the intended purpose being:

- it is one – directional with no preferential giving in directions. The material gives in through the weakest point of the sample and starts propagating from that point out.
- samples must not be destroyed to be considered failures. Material damage may be defined by deformation, rupture initiation or even complete rupture according to the beneficiary's requirements.

All these factors make this method to represent a better simulation of exposure to functional impact, much closer to the real conditions. The samples used for testing are usually plate shaped manufactured from the basic material and improved with successive layers, as shown in fig.2.76.

The sample is placed in a special groove, designed to allow the central part of the material (subjected to impact) to deflect according to the testing parameters, shown in fig.2.65.

Fig. 2.76 Sample used for impact tests[54]

Fig.2.77 Place for sample positioning[54]

After fixing the sample between the two guiding sleeves, exactly over the groove, tests were performed for different loads between 1 and 5 kg, for impact heights in the range of 25 and 150 mm. Usually the structure resistant element is made of titanium, covered then with different type of acrylates or even with polytetrafluor – ethylene (PTFE) for some prosthesis that require low friction joints in order to be attached to the natural remaining structure. But the expenses are too high for average people so it was decided to use a fiber reinforced composite material instead of the titanium core, and see if it meets the requirements.

The results obtained during the measurements are primarily stored in a table form, where the known parameters such as: type of material, thickness, width, also weight, falling height and the diameter of the falling body chosen for that specific test are introduced (e.g. see Table 2.3). The table also will contain the measured parameters, such as: maximum load, maximum energy, impact velocity, time and some observations concerning the type of test upon the sample (e.g. frontal testing F or both frontal and rear testing B).

Table 2.3 Measured parameters during tests [54]

No	Thickness (mm)	Width (mm)	Weight (Kg.)	Height (mm)	Φ (mm)	Impact measured parameters				
						Max. load (kN)	Max. energy (kg m)	Impact speed (m/s)	Time max (msec.)	Obs.
1	7,75	60,5	3,06	25	20	2,8184	0,1600	0,8550	2,7374	F
2						2,5742	0,1582	0,8585	2,8961	F
3						2,7686	0,1616	0,8577	2,7710	F
4						2,8007	0,1814	0,9243	2,8564	B
5	7,75	60,5	3,06	35	20	3,5199	0,6283	2,6104	2,5848	F
6						3,0752	0,7585	2,8701	2,9633	F
7						3,4281	0,794	3,0244	2,7496	F
8						3,5199	0,8343	3,1896	2,7069	B
9	7,75	60,5	3,06	40	20	4,0646	0,1608	0,8090	2,9877	F
10						4,2351	0,1622	0,8117	2,5238	F
11						4,1062	1,1567	0,8128	2,7161	F
12						4,1432	0,1647	0,8186	2,6520	B
13	7,75	60,5	3,06	50	20	5,0637	0,2000	0,9352	2,4139	F
14						4,8690	0,2016	0,9305	2,8839	F
15						4,6100	0,1997	0,9261	2,6367	F
16						4,6001	0,1999	0,9291	2,8076	B

For each type of impact test, 5 samples were used in order to obtain a result which is as accurate as possible and each sample was tested 3 times, once in the central part and twice towards the lateral sides. The dropping mass value was changed from 1 to 6kg and the height from 100 to 580mm and used samples with thickness between 5 and approx.8mm. The results were obtained as diagrams time versus load and time versus impact energy, with the results table attached providing accurate values for the peak load, deflection at peak load, energy impact at peak load, impact velocity, like shown in fig.2.78 – 2.81.

The diagram in fig.2.78 reveals a 5,07kN peak load, 0,61kg.m impact energy corresponding to the peak load and a 1,36m/s impact velocity, over 4,8s period of time.

The diagram in fig.2.79 shows an 8,53kN peak load, 2,07kg.m impact energy during peak load and 2,8m/s impact velocity over 5,2s period of time.

The diagram in fig.2.80 reveals the following: 4,06kN peak load, 0,16kg. m impact energy for the peak load and 0,8m/s impact velocity over 2,98s period of time.

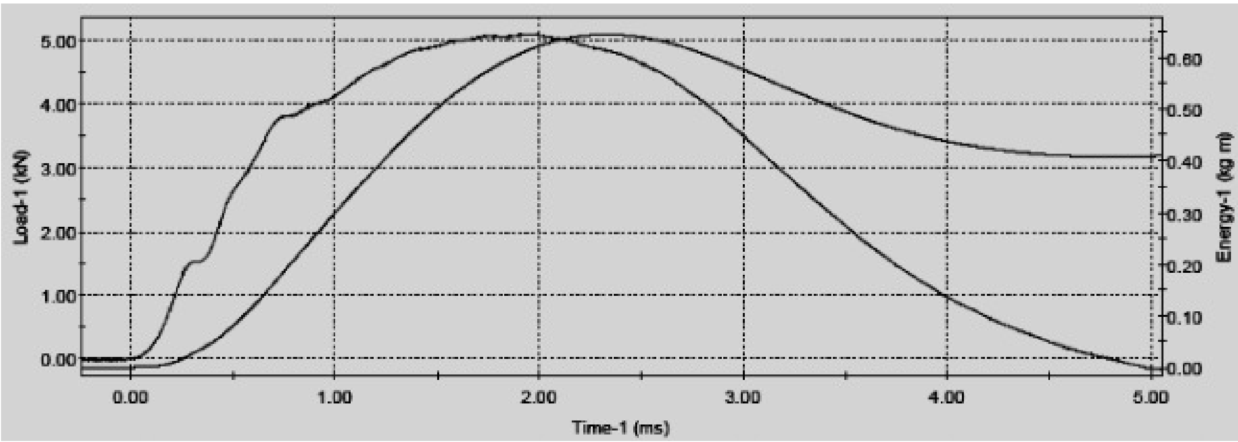


Fig.2.78 Load and energy diagram versus time for a 6,06kg weight mass and 100mm dropping height [54]

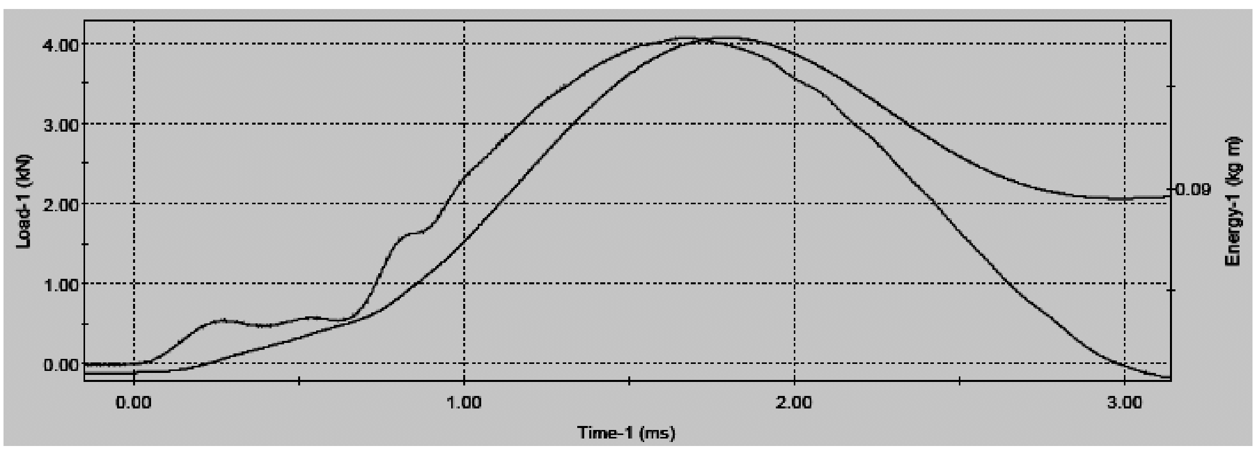


Fig.2.79 Load and energy diagram versus time for a 6,06kg weight mass and 430mm dropping height [54]

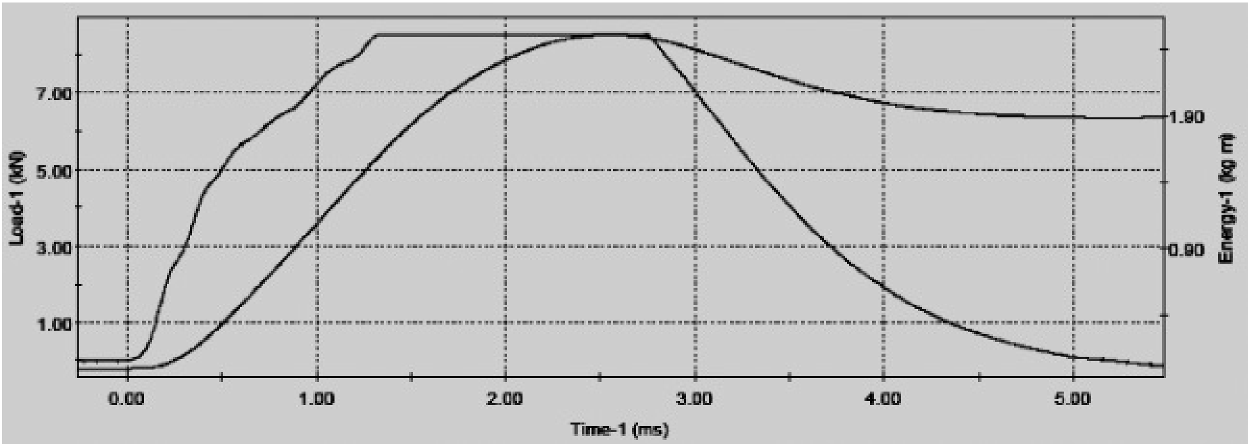


Fig. 2.80 Load and energy diagram for a 3,06kg weight mass and 40mm dropping height [54]

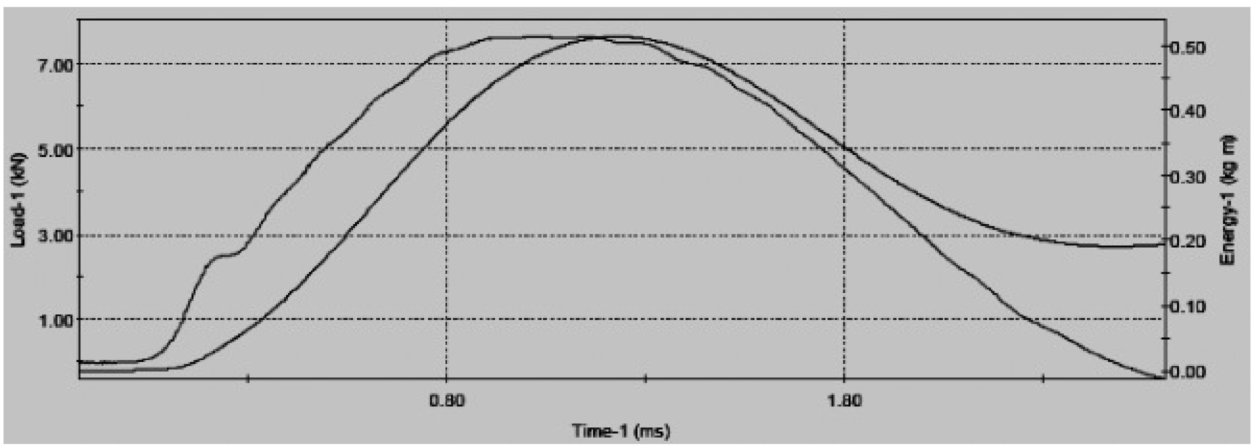


Fig.2.81 Load and energy diagram for a 3,06kg weight mass and 140mm dropping height [54]

Analyzing the diagrams and the tables provided by the equipment software, considering also the initial conditions concerning weight and height, we can conclude that the peak load increases as expected with the weight mass and also with the dropping height. Also the impact velocity is higher with the increase of height and weight. The values obtained for the material deflection are little over 1mm in almost every situation, which is insignificant considering the magnitude of shock. At this rate, the implant is able to resist even at greater loads, provided they are within normal occurring phenomena.

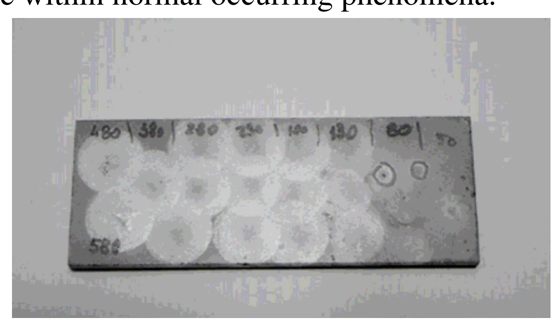


Fig.2.82 Rear part of a sample after testing for various dropping heights [54]

Another interesting issue was the layers adherence after the impacts and it was possible to establish that even the great impacts did not produce any damage upon the material layers, just a small deflection, as shown in fig 2.82.

Only for a height of 580 mm and a maximum weight mass of 6,06 kg, the material shows a bigger deflection, but there is also to consider the small thickness of the sample, around 7 mm.

After analyzing the testing results we might conclude that a fiber reinforced composite material is suitable from the point of view of impact resistance and also can be a good basis for the improving layers to be applied.[54]

Chapter 3. ENVIRONMENTAL INFLUENCES UPON HUMAN BEHAVIOR AND LIFE QUALITY

3.1. Influence of audio and visual stimuli upon human behavior

3.1.1. Theoretical aspects

Living in a rather aggressive environment makes it very important to understand and to coordinate the cooperation and interaction between different perception systems, particularly the mutual influence of seeing and hearing. These two systems cooperate in everyday life in the sense that they can support themselves mutually and draw together more usable information from the situation than one system alone.

The hearing system functions as “early warning system” over the presence of a potential threat, it supplies information about the distance of the threatening object and the remaining time for possible preventive measures. If distance and time are large enough, then a transfer of the auditory to the visual subsystem takes place for controlling the motor function. The visual system can then explore the kind of the object (dimension, color), its position, and direction of motion and speed more exactly. [14]

Like spatial sensitivity, the visual system has a small surface for field of view (fovea), where acuity and color distinction are maximum. With increasing distance from this point (fovea centralis) to the periphery both acuity and color distinction become worse, but movements can be recognized more easily. The visual field is however altogether limited to approximately half of the environment which lies in front of our nose and with good visibility people are able to see several kilometers far. In addition we steer the eyes arbitrarily around so that they can examine fields of the surrounding area more exactly.

Another sensory system of the human body cannot be comparable with the visual system from organization point of view. When hearing, the human subject can perceive spatial information from the environment which surrounds his body, when smelling something similar happens at shorter distance, pressure and temperature are felt at close range by the whole body surface (at skin level).

Like temporal selectivity there are a lot of differences like: human subject can close his eyes, which temporarily stops working the visual information channel, but he cannot seal the ears, the nose and the skin.

Hearing, smelling and feeling take place all the time – even during sleep. The temporarily complete suppression of information other than visual is not possible. The visual system can catch fine and small details from the enormous information offered; on the other hand it misses all the available information which lies outside the field of view. A condition for the survival of an organism equipped with so different systems is the close cooperation and mutual control between these subsystems.

There are many implications because in everyday life human subject has multimodal information about the place of an object or an event: if telephones ring, cars race, humans talk, then the visible place of the sound agrees with the audible, and he is informed both by the visual and by the hearing system about the place of object or event. The senses cooperate here in the way that they analyze corresponding information (fig.3.1).

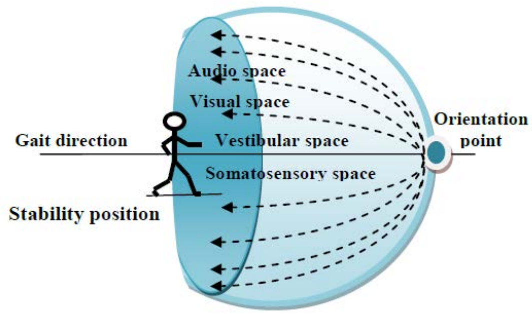


Fig.3.1 Cooperation of senses for orientation [14]

Some other researches had demonstrated that the key to robust perception is the combination and integration of multiple sources of sensory information and they suggest that humans combine the available information using following two strategies: sensory combination and sensory integration.

First strategy – **sensory combination** - tries to maximize information delivered from the different sensory modalities and the incoming information streams of the environment are processed by the human brain to reconstruct and update a mental image of the scene, with object, event or human subjects.

The second strategy is **sensory integration** and describes interactions between redundant signals. If there is more than one sensory estimate available for perceiving some environmental property, the information has to be integrated so that a coherent multisensory percept is formed.

To come up with the most reliable (meaning unbiased) estimate, the variance of the final estimate should be as low as possible. If the system made 10 estimates of the same environmental property, all 10 would be slightly different due to the fact that every sensory signal is noisy.

The external aspects of the human factor's mobility, posture and style of displacement may indicate certain instabilities due to sensorial systems.

3.1.2. Analysis of noise effect upon human body stability

The ear can be divided into three distinct regions based on their function and location in the peripheral auditory system. The acoustic signals manifested as pressure fluctuations in the air are collected by the external ear and transmitted through the middle ear towards the inner ear for transduction into electrical neural impulses to the brain.

A lot of sounds, many of them considered as noises, from the environment determine changes of the human behavior, and if they are combined by visual stimuli, they may finally affect the stability, balance, gait or jumps performed by the human factor.

All these manifestations may become in time, activity discomfort or may even transform in occupational pathologies if the causes, manifestation forms, their evolution and values remain unknown. Hearing loss can be due to aging, exposure to loud noise, medications, infections, head or ear trauma, congenital or hereditary factors, disease processes and many other causes.[12]

Human hearing is at its most sensitive around speech frequencies (200 Hz – 3.5 kHz). The full hearing range for a fit young person runs from about 20 Hz (20 cycles per second) to almost 20 kHz (20,000 cps). However, the high frequency response falls off rapidly with age, most adults can't hear much above 8 – 10 kHz. Below 20 Hz, sound is referred to as Infrasound, as it is really sensed as a vibration rather than heard by the ear.[103]

The stability stance as well as the integral balance around the equilibrium position are determined by the health level of the entire human body and may constitute clear informational sources for the human behavior evaluation in any situation.

The small deviations of the human body posture around the vertical direction determine the occurrence of a torsion moment, which acts upon the entire structure and may unbalance the human body or may create a vibration state.

However, this process of corrective torque generation is not fully understood and controversy remains regarding the organization of sensory and motor systems contributing to the postural stability of the entire human body.

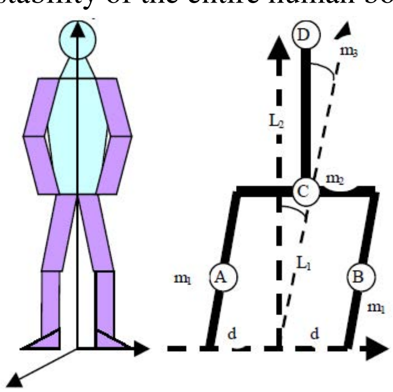


Fig.3.2 Pelvic structural model [89]

Balanced state of postural sway is controlled by central nervous system, and the upright stance cannot be sustained without this control. It is widely accepted that the corrective torque is generated through the action of feedback control system; the input sources include visual, proprioceptive and vestibular system.[89]

Fig. 3.2 shows a simplified pelvic structural model during static upright stance. A, B are the masses of legs, C is the mass of pelvis and D is the mass of upper trunk.

Because the lumbar-sacral always sways in reversed direction about the ankle joint with the same value of θ, the upper trunk is kept perpendicular to the horizontal.

In order to locate the center of mass it is necessary to establish some main principles:
- its precise location depending on individual's anatomical structure;
- habitual standing posture;
- current position;
- external support;
- location in human body;
- variations with body build, posture, age, and gender
- infant > child > adult (in % of body height from the floor);
- generally accepted that it is located at ~57% of standing height in males, and ~ 55% of standing height in females;

Location of COM remains fixed as long as the body does NOT change its shape.

Maintaining balance in standing position is one of the most important activities for two main reasons: firstly, the center of mass must be located in the support area; secondly, for a major period of the standing action, the body is supported first by two legs and after a short time by a single limb with the center of mass inside the base of support but with the tendency of going outside it. In elder people especially, up to 70% falls occur during standing and of course, locomotion action. [12]

Static stability limit means the distance of the GCOM from the edge of the support polygon, measured along a current vector of motion of the gravity center, where:

$$x_{GCOM} = \frac{\sum_{i=1}^{n} x_i G_i}{\sum_{i=1}^{n} G_i} = \frac{\sum_{i=1}^{n} x_i m_i}{\sum_{i=1}^{n} m_i} \tag{3.1}$$

$$y_{GCOM} = \frac{\sum_{i=1}^{n} y_i G_i}{\sum_{i=1}^{n} G_i} = \frac{\sum_{i=1}^{n} y_i m_i}{\sum_{i=1}^{n} m_i} \tag{3.2}$$

mi being the mass of the *i*-th body, while *xci* , *yci* denote the location of the center of mass of the *i*-th body.[60]

The motion of the first link was on ankle and the second link was on lumbar-sacral. [46] The angular sway of the first link can be measured as the average value of the two legs and the angular sway of the second link can be calculated indirectly as shown in fig. 3.3, where point O is the ankle joint, point A is the lumbar-sacral joint, point P_1 represents the marker of legs and P_2 represents the marker of the subject's back. [89]

Angular sway θ_2 of lumbar-sacral joint is expressed as

$$\theta_2 = \left(\frac{x_2}{L_1 + l_2} - \frac{x_1}{l_1} \right) \left(1 + \frac{L_1}{l_2} \right) \tag{3.3}$$

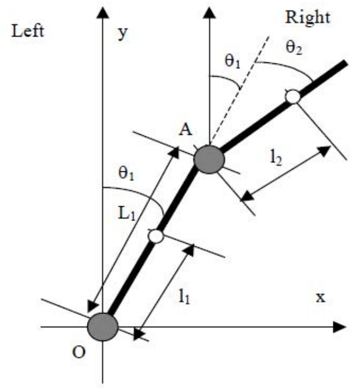


Fig.3.3 Determining the angular sway angle [51]

The data acquisition structure is based on an assembly of measuring human physiological parameters controlled by a computer unit (fig.3.4).

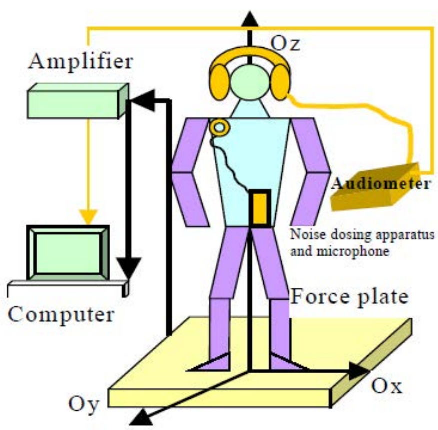


Fig.3.4 Experimental setup [51]

The main measuring element is the Kistler force platform, which records the values acquired for the forces and moments developed by the human body, along the three directions (X, Y and Z), during an established period of time according to the experiment requirements. The analysis performed upon the subjects started by establishing an investigation protocol, which aimed at a large range of measuring the bipedal stability (big base of support with different polygons, small base trapeze shaped, open eyes and arms along the body, in the same moments of the day – morning) and with different levels and sort of noises or acoustic stimulus.

Temperature into laboratory was 25^0C, air humidity 80% and atmospheric pressure 755 mmHg. In the second stage the physiological parameters of the human subjects were measured (weight, height, age, pulse, blood pressure) in relaxed stance, without any health problems and with a good metabolism (example: blood pressure 155/82mmHg, pulse 91, face temperature $36,7^0$C, height 175 cm, weight from 50-125 kg). All these parameters are necessary to establish a common modeling base to measure and to evaluate the human body stability behavior in the same noisy conditions.

The subjects were subjected to various sounds perturbations, continuous or briskly, with different intensities and along various time intervals, with or without hearing protection (fig.3.5). [51]

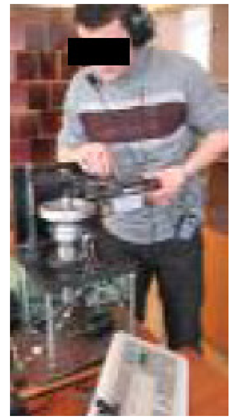


Fig.3.5 Person subjected to noise perturbations without hearing protection (left) and with hearing protection (right) [51]

In fig.3.6 data acquisition concerning the stability of a human subject, female, height 1,7m, age 53, no health problems, wearing far sighted glasses, weight 80kg, were presented. The stability area and the moments of forces evolution along axes Ox and Oy were analyzed at morning time, without any source of additional effort induced to the organism.[51]

As it can be noticed from the diagrams analysis in fig.3.6, the evolution of the stability area in this case presents a compact and asymmetrical surface, for the recorded human subject reactions subjected to an unilateral acoustic stimulus, of short duration (5 sec) coming from the left side. Thus, the human subject try to self re-balance by changing and extending the area of stability of center of mass (COM) projection on the right side (the opposite side of the acoustic stimulus), increasing in this manner the support surface, but setting off through small oscillations the instability rate of the whole human body.

In the diagram from fig.3.7 a similar situation is presented for the same human subject (standing on a big base of support-BOS), when using an acoustic stimulus coming from the right side, having the same duration and amplitude. The same sort of instability occurred (manifested to the opposite side of the stimulus direction), the area of stability having now a much more compact shape and being compensated by a sustaining support of the right leg, having a higher level of instability (the selected areas are more dense).

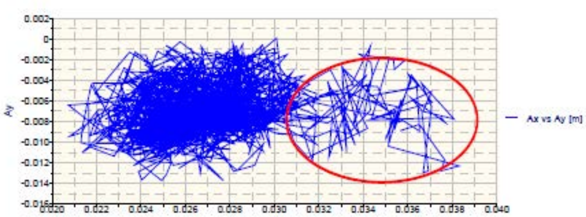


Fig.3.6 Area of stability for acoustic stimulus from the left side [51]

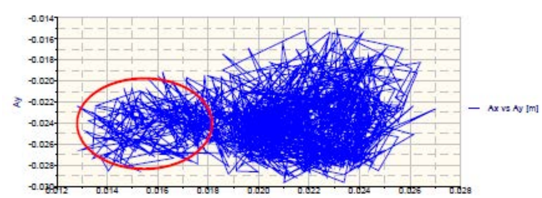


Fig.3.7 Area of stability for acoustic stimulus from the right side [51]

These manifestations can be found in all the analyses performed on the selected subjects allowing a unitary evaluation of the stability area.

The recordings presented in fig.3.8 and 3.9 represent the evolution of the moments of forces, measured on *Ox* and Oy axis for the same human subject, in the two variants of acoustic stimulation. After the analysis performed on the diagrams presented in fig.3.8 the following can be observed: the stimulus coming from left side establishes a much equilibrated behavior of the human body along the axes Ox and Oy, and the instability can be induced only if the appearance of the acoustic stimulus is random, the human subject having a good and natural capacity for recovering the standing position on this side (right leg).

Opposed to this situation, when the acoustic stimulus is coming from the right side, this develops a strong balance of the human body on the opposite side (left), on both directions Ox and Oy, at the moment of appearance and during acoustic stimulus (selected zone on fig.3.9).

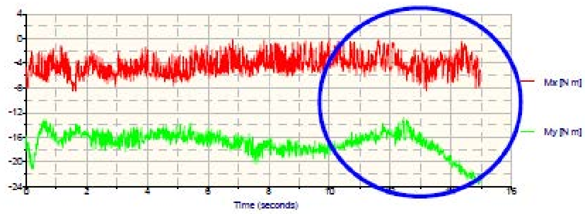


Fig.3.8 Moments on Ox and Oy axis for big BOS, with acoustic stimulus on left side[51]

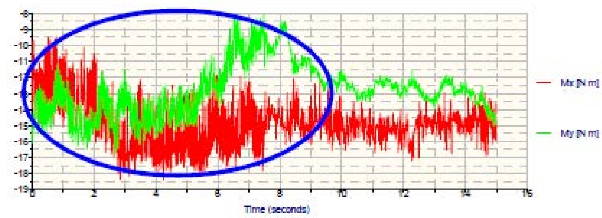


Fig.3.9 Moments on Ox and Oy axis for big BOS, with acoustic stimulus on right side[51]

The recording time was each time the same – 15 sec and the data set was stored in the measurements database used for evaluation. In the case of force evolution analysis the same type of manifestation was observed for the recording performed in the evening, emphasized by an increase of the variation limits of the force along Oz, but also by a higher frequency of their occurrence, values that indicate an increased instability of the human body and a fatigue state at the inferior limbs level.

In this situation and correlating with the age and the influence of the poor sensorial system we may confirm that the installation of the fatigue state or an instability behavior of the human body as a follow of a normal daily activity takes place in the second part of the day determining a motor activity deficit and the diminishing of the orientation perception increasing the balance and the sway at different acoustic stimulus.

3.2. Influence of solid particles pollution upon human health

The entire human activity unfolding within the environment interacts with it, producing a wide range of changes. As long as these changes do not cross a certain threshold, nature by means of its cyclic process is able to compensate the transformations. When this threshold is passed, the unbalance cannot be compensated anymore and irreversible transformations occur.

3.2.1. Types of aerosols

According to their location there are:

Outdoor aerosols. They have a high influence upon wide populations and wide environments as they can spread fast according to atmospheric conditions. Their concentrations are typically low but in some environmental calamity situation concentration may become hazardous for human health.

Indoor / work aerosols. They usually influence workers, often they reach higher concentrations due to some industry specific processes that may generate specific aerosols (with known composition) leading to specific health effects, like pneumoconiosis in mine industry (due to insoluble mineral dusts), asbestosis, lung cancer, mesothelioma in asbestos industry, nasal cancer in wood (furniture) industry (due to hard wood dusts).
Measurements can be done in these specific areas in order to describe the possible human exposure.
Aerosol types:
-dust: solid, mechanically produced particles, size from sub-micron to approx. 100 μm
-spray: large liquid droplets, mechanically produced, from few μm up
-mist: liquid droplets, produced by condensation processes, size up to few μm
-fume: solid particles, produced by condensation processes, often aggregates, size from few nm to about 1μm
-smoke: incomplete combustion produces solid/liquid particles, often aggregates, size below 1μm
-bio-aerosols: liquid/solid particles containing biologically viable organisms [49]

3.2.2. Example of working environment with fine solid particles charge in the atmosphere

The study was developed within a fiber glass composites workshop, where around 20 workers perform their daily activity. Many solid particles coming from processing fiber glass reinforced composites are visible in the atmosphere and covered all the equipments and furniture in the workshop rooms. (fig. 3.10, fig.3.11)

Fig.3.10 Worker and equipment surrounded by solid aerosols [49]

Fig.3.11 Furniture covered in glass fiber particles [49]

Most of the technological operations are performed manually or using simple devices like grinding wheels or mechanical saws. (fig.3.12 and 3.13).

Fig.3.12 Manual cutting operation[49]

Fig.3.13 Manually assembling [49]

Some of the most affected human senses due to a productive activity in an environment of glass fiber wastes, proved to be the cutaneous inflammatory process, the thermal adjustment, the respiratory function and also the visual function.

Workers skin and clothing come permanently in contact to the solid particles resulting from the manufacturing process of the fiber glass reinforced composites, particles that have the tendency of clinging to the skin and textiles (fig.3.14 and 3.15).

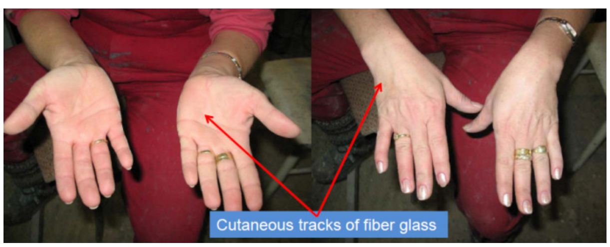


Fig.3.14 Fiber glass attached to skin [49]

Fig.3.15 Fiber glass attached to clothing[49]

3.2.3. Statistical evaluation of visual behavior

In order to accomplish the statistical evaluation of the adult worker people visual behavior, a software, dedicated to these investigations, was used with the possibility of building a database useful to the caring doctor or to the statistical researches. This software, called OPTIKL ver.1.0 is realized in a Delphi programming language for the statistical processing of the data recorded during the optometric investigations using VISIOTEST and unfolded within the project initiated in Brasov area, named VEDERE 2020RO.

The investigations were done by taking into consideration several factors that might influence the results and also allow the design of a comprehensive database: gender, age, wearing or not wearing glasses, time of day, etc.

Some examples of the investigations performed upon the workshop employees are presented in fig.3.16 1nd 3.17.

Fig.3.16 Male, early fifties, wearing glasses [49]

Fig.3.17 Female, early thirties, not wearing glasses [49]

The recordings are done for each subject in a new window as shown in fig.3.18 and finally the statistics are created by the software. Based upon these statistics the analysis and interpretation of the results was possible (fig.3.19).

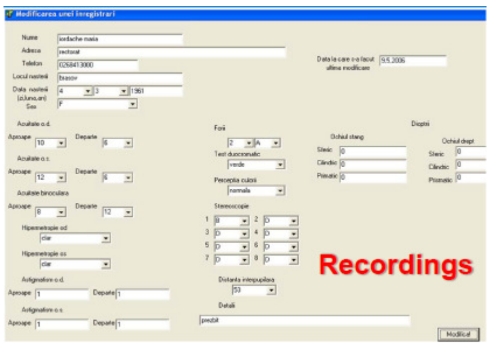


Fig.3.18 Recordings window [49]

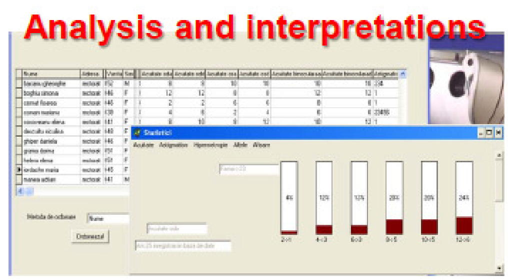


Fig.3.19 Data analysis and interpretation[49]

3.2.4. Assessment of thermal adjustment

The aspects concerning the cutaneous thermal adjustment of the workers were analyzed using a thermo-vision camera, emphasizing a series of different manifestations of the human body temperature with respect to the working environment, quantity of handled glass fiber, length of contact and work volume.

Thermography or thermo-vision is a non-destructive and non-contact method used to measure the thermal field by recording infrared radiations and visualizing the temperature distribution upon the observed surfaces.

Comparisons were made between the temperatures of different body parts: face, hands, feet, between face temperature at the beginning of the work day and towards the final time of work, between male and female workers, etc.

Some of the results obtained by help of the thermo-vision camera FLIR 7 are presented in fig.3.20 – 3.25.

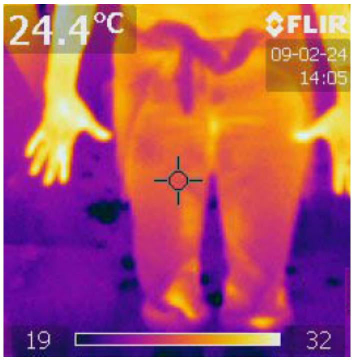


Fig.3.20 Arm temperature at the end of work day, female subject [49]

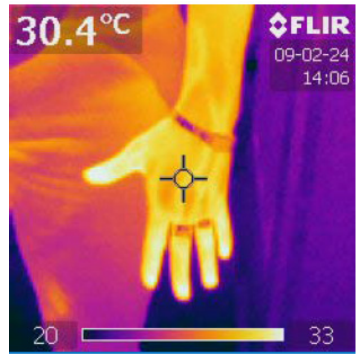


Fig.3.21 Hand temperature at the end of work day, female subject [49]

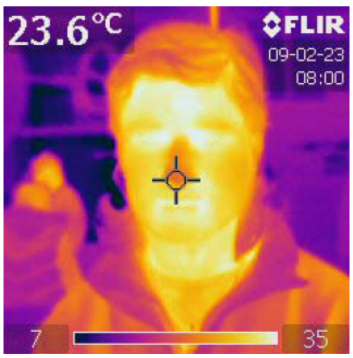


Fig.3.22 Face temperature at the beginning of work day [49]

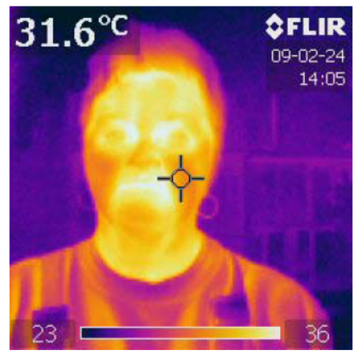


Fig.3.23 Face temperature at the end of the work day [49]

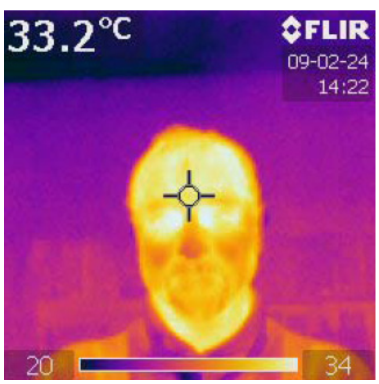


Fig.3.24 Face temperature at the end of the work day, male subject [49]

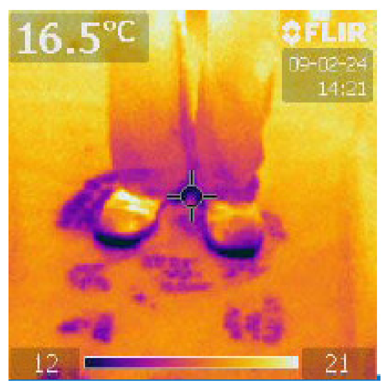


Fig.3.25 Feet temperature at the end of the work day, male subject [49]

During the performed analysis the following short term the following phenomena were identified: physiological phenomena but with possible pathological repercussions due to the prolonged contact to solid type substances wastes, upon the persons subjected to the screening:

-Increase of the cutaneous temperature, especially in the hands, face-forehead and eyes area, also around the neck and torso level;

-Diminishing of the visual acuity along the 8 hours work by at least one level;

-Diminishing the colors perception capacity;

-Decreasing of the accommodation skill of the visual function from close vision to far vision;
-Increasing the cutaneous irritability at hands, face, nasal and mouth mucous membrane level;
-Decreasing of the speech sound volume and occurrence of a swallowing discomfort;
-Decreasing of the organism hydration.

The improper working conditions might lead to professional illnesses representing a gradual worsening of the workers health due to the systematic action of some noxious factors (noise, radiations, high frequency voltage, chemical factors, etc.).[49]

3.3. Influence of heat losses in buildings upon quality of life

3.3.1. General considerations

All of the important cities in Europe consist of a mixture of old and new buildings representing different types of structures and construction materials according to the time interval they were built. Some of them are huge, impressive, historical buildings with thick stone or brick walls; others are new modern constructions of concrete, steel and glass but we also need to think about individual residences each having its own specific features.[40]

Regardless of the construction characteristics, one of the major problems nowadays is related to the high energy costs and consumption required for their heating, for assuring the comfort of people living or working inside. Of course, specialists approached it from different point of views, some of them concerning the type of heating or the type of fuel used for heating but there is an important issue that still can be researched and improved, and we mean by that the uncontrollable energy losses. Their occurrence is more frequent in older buildings, usually due to a lack of tightness around windows and doors but also due to losses through the walls material itself. Heat is usually transferred from one fluid (in our case air) to another through a separating wall, made of various materials.[63]

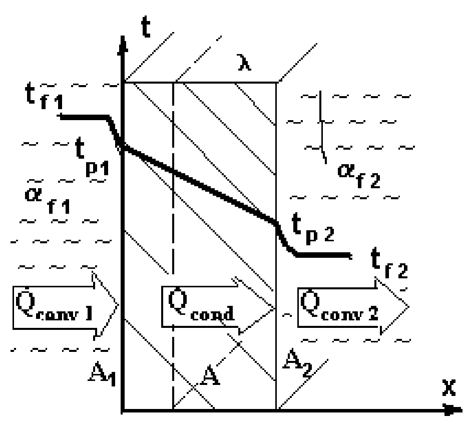


Fig.3.26 Heat transfer process [7]

A complex process of heat transfer involves concurrently proceeding processes of conduction, convection, and thermal radiation. In practical applications heat is usually transferred from one fluid to another through a partition or separating wall. Three stages can be distinguished here, during which heat is transferred (fig.3.26): [7]

- from a fluid with a higher temperature ***tf1*** to a separating wall which is at a lower temperature ***tp1***, by thermal radiation and/or **convection**
- in the wall, by **conduction** at a temperature difference (***tp1—tp2***)
- from the surface with the temperature ***tp2*** to a fluid with a lower temperature ***tf2***, by thermal radiation and/or **convection**

Under steady-state conditions the rate of heat flow $\boldsymbol{Q}$ is the same through each cross section made at right angle to the direction of flow.

$$\dot{\boldsymbol{Q}}_{conv1} = \dot{\boldsymbol{Q}}_{cond} = \dot{\boldsymbol{Q}}_{conv2} = \dot{\boldsymbol{Q}}_{1-2} \quad (3.4)$$

And the heat transfer will be:

$$\dot{Q} = \frac{t_{f1} - t_{f2}}{\frac{1}{\alpha_{f1}} + \frac{\delta}{\lambda} + \frac{1}{\alpha_{f2}}} \cdot A = k_p \cdot (t_{f1} - t_{f2}) \cdot A \quad (3.5)$$

To derive the heat-transfer equation for composite walls, the thermal resistance of a plane wall **δ/λ** should be replaced in above equation with the thermal resistance of a composite wall, then

$$\dot{Q} = k_{pn} \cdot (t_{f1} - t_{f2}) \cdot A \quad (3.6)$$

Where

$$k_{pn} = \frac{1}{\frac{1}{\alpha_{f1}} + \sum_i \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_{f2}}} \quad (3.7)$$

is the global heat transfer coefficient.

Heat transfer by convection is a very complicated process, depending on many factors: the origin and conditions of motion; the velocity of motion ***w***; the chemical and physical properties of the fluid involved; the shape of the wall; its geometric dimensions; roughness of the wall surface; the temperatures of the fluid ***tf*** and wall ***tp***.

The amount of heat transferred by convection is, therefore, a function of the following main parameters:

$$\dot{Q} = F(\rho, c_p, \lambda, \eta, p, t, \mathrm{Re}, ...) \quad (3.8)$$

where **ρ** = fluid density, m^3/kg;

λ = fluid thermal conductivity, W/m.deg.

η = kinematics' viscosity, m^2/sec;

$\boldsymbol{c_p}$ = heat capacity at constant pressure, kJ/kg-deg.

The intensity of heat transfer by convection depends mainly on the thickness of the fluid boundary layer at the wall and on the temperature gradient in this layer. It is rather difficult to determine the relation between these two factors. Practical calculations of convection heat transfer are, therefore, based on Newton's formula:

$$\dot{Q} = \alpha \cdot A \cdot |t_f - t_p| = \alpha \cdot A \cdot \Delta t \qquad [W] \quad (3.9)$$

where α is the local heat-transfer coefficient which shows the rate of heat flow per 1 m^2 of surface at a temperature difference Δt of 1°C between the wall and fluid.

It is very difficult to determine the convection coefficients for the two fluids (α_{f1} for the interior and α_{f2} for the exterior) and also the overall heat transfer coefficient k.

In accordance with Fourier's investigations devoted to heat conduction in solids, the quantity of heat q flowing per unit time through unit of isothermal area is proportional to the temperature gradient:

$$q = \frac{d\dot{Q}}{dA} = -\lambda \cdot \frac{\partial t}{\partial n} \tag{3.10}$$

where ***λ*** is the thermal conductivity which represents the physical property of the substance.

Considering a plane homogeneous wall (see fig.3.27) with an area ***A*** (m2) and ***δ*** (m) thick. The boundary surfaces of the wall are at temperatures ***t1*** and ***t2***. Then, to determine the total heat flux the rate of heat flow ***q*** per unit area by the wall area ***A*** shall be multiplied and then the Fourier's equation will be integrated in the direction of flow from ***0*** to ***δ*** and with respect to temperatures ***t1*** to ***t2***

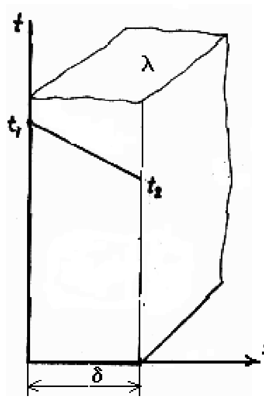


Fig.3.27 Plane homogeneous wall [63]

$$\frac{Q}{A} \cdot \int_0^{\delta} dx = -\int_{t_1}^{t_2} \lambda \cdot dt \tag{3.11}$$

Hence,

$$q_s = \frac{\dot{Q}}{A} = \frac{\lambda}{\delta} \cdot (t_1 - t_2) = \frac{\Delta t}{\frac{\delta}{\lambda}} \tag{3.12}$$

Based upon the electrical analogy the concept of ***thermal resistance*** which is the reciprocal of conductivity may be introduced:[8]

$$R_{cond} = \frac{\delta}{\lambda} \tag{3.13}$$

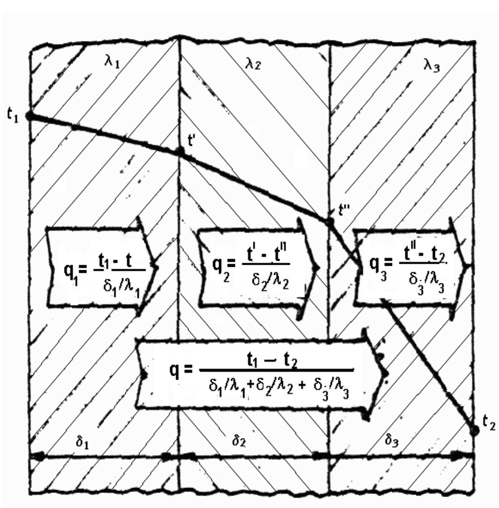


Fig.3.28 Cross section of a three layers wall[7]

The simplest way to drive the equation for heat conduction through a composite wall is to apply the concept of *thermal resistance*. The most valuable property of thermal resistance is the fact that individual thermal resistances are summed up in the direction of flow. So the quantity of heat per unit time through unit of isothermal area, using the total thermal resistance of a multilayer wall becomes: (3.28)

$$\frac{t_1 - t'}{\frac{\delta_1}{\lambda_1}} = \frac{t' - t''}{\frac{\delta_2}{\lambda_2}} = \frac{t'' - t_2}{\frac{\delta_1}{\lambda_3}} = \frac{t_1 - t_2}{\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}} = q \tag{3.14}$$

3.3.2. Using thermography for assessing heat losses

The images obtained by help of a thermo-vision camera (fig.3.29) allow the determination of the unknown temperatures of the walls both interior and exterior and thus the conduction heat flow by applying Fourier's law.

Fig.3.29 Thermo-vision camera FLIR 7[63]

Thermo-vision (thermography) is a non-destructive and non-contact method used to measure the thermal field by recording infrared radiations and visualizing the temperature distribution upon the observed surfaces. The thermal contrast of the building is displayed, meaning the difference of intensity of the radiations produced by the building by comparison to the environment.

The dedicated software allows acquiring the values of temperatures in any chosen area upon the building, inside or outside, values that will be further used for determining the heat flow.

In order to perform the study an old building of the university, consisting of several laboratories and classrooms was selected then the thermo-vision camera was used upon the same area (near a window), both inside and outside. The measurements were made during a very cold winter day, while the environmental outside temperature was about -15^{0}C, while the inside environmental temperature was around 18^{0}C.

After downloading the pictures from the thermo-vision camera, the cursor position may indicate the precise temperature in a certain point that seems more interesting (fig.3.30) or several temperatures scattered around a studied area (fig.3.31).

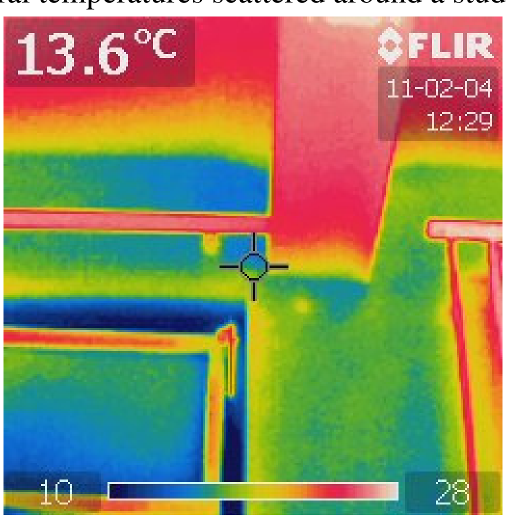


Fig.3.30 Inside image (single temperature)[63]

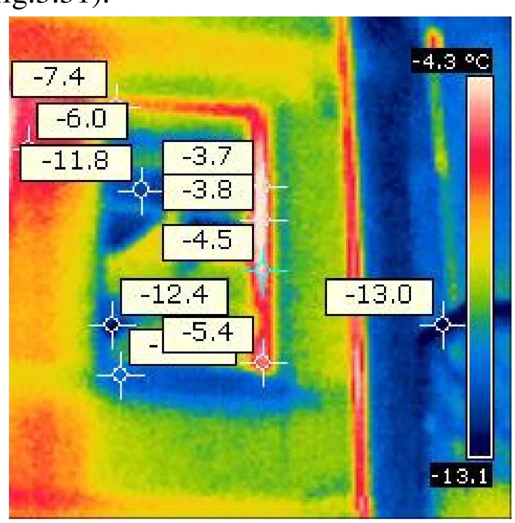


Fig.3.31 Outside image (several temperatures)[63]

In both figures there is a legend of the colours indicating the range of temperatures, measured upon a certain surface. They are also recorded entirely in an Excel file, both for the outside and the inside of the studied part.

A random part of the studied surface was considered in order to highlight the method and evaluate a critical surface from the point of view of energy losses, namely the surface in the vicinity of the window. The inside and outside temperatures distributions were represented in a 3D graphical representation (fig.3.32 and fig.3.33), for the considered area.

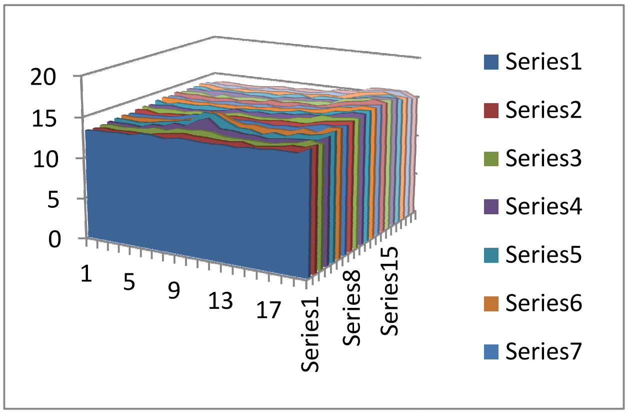


Fig.3.32 Temperatures distribution inside[63]

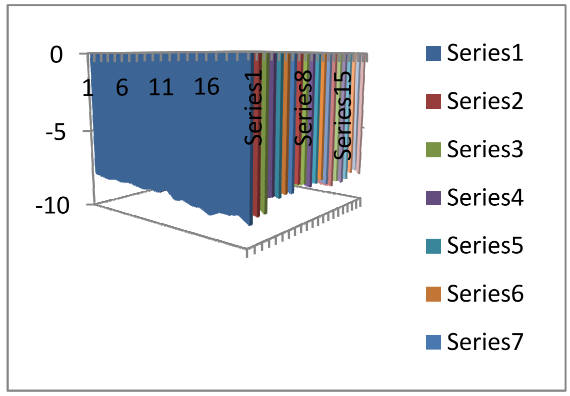


Fig.3.33 Temperatures distribution outside[63]

The temperatures range on the inside wall start from 13,2^{0}C up to 16,4^{0}C, while the temperatures on the external wall are between -8,8^{0}C and -5,5^{0}C.

The data gathered for 20 x 20 pairs of cells (one outside and the corresponding inside one) were selected and a constant thermal resistance of the wall was considered, determined like a sum of ratios between thickness and conductivity coefficient of different layers in the wall. Then the heat losses were determined for each cell with respect to the area and they were added to find the entire heat loss corresponding to all considered 400 cells to find a total value of 52,915 W/m^2, which is as high as expected, considering the fact that the studied building is a 100 years old building. The distribution of the unit heat flow for the considered cells was presented in the 3D representation shown in fig.3.34.

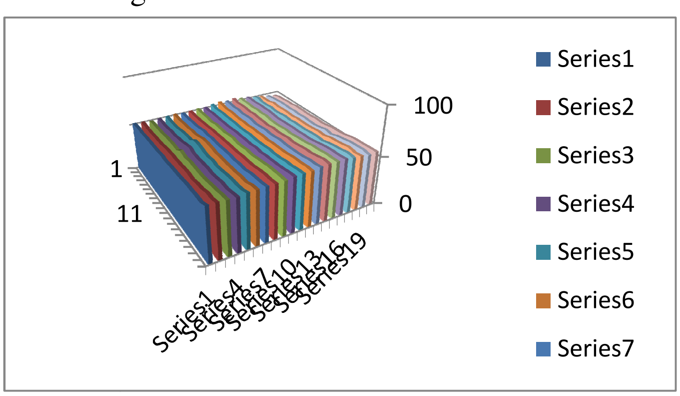


Fig.3.34 Distribution of heat flow in the considered area [63]

By help of the results obtained from the thermo-vision camera it becomes possible to determine the average temperatures of the walls (inside t_{im} and exterior or outside t_{em}) as weighted average of the isothermal surfaces temperatures (surfaces corresponding to the same colours).

If the isothermal surfaces of the same colour A_i, with the corresponding temperatures t_i, are found, the average temperature of a wall will be determined using the following relations:

$$t_{im} = \frac{\sum_i A_i * t_i}{A_i} = 14{,}5^0 C \qquad (3.15)$$

$$t_{em} = \frac{\sum_e A_e * t_e}{A_e} = -7{,}54^0 C \qquad (3.16)$$

Knowing the structure of the non-homogeneous wall (consisting of several homogeneous layers) it is possible to determine the thermal resistance of each layer and finally the entire thermal resistance of the wall, respectively the unit heat flow (per unit area).

The method based upon thermography offers reliable information related to the temperature distribution, both outside and inside the building walls, highlights the problem areas, processes the results, avoiding complicated calculus and errors. By providing the exact positions of the problem areas, contractors will know exactly where to apply the insulation materials. By applying the correct insulation materials, the thermal resistance increases according to the insulation thickness and physical properties, leading to a decrease of the heat transfer coefficient and thus of the heat losses.

The activities of energy conservation, including the optimal use of primary and secondary energy resources, represent the most urgent and efficient objectives for the development of a healthy social and economical life. These activities require correct and reliable information upon the energy losses of different structures. Based upon this information, specialists are able to perform energy balances or analyzes with scientific support. This way, according to the new regulations, the studied buildings may obtain an energy certificate stating the insulation efficiency.[63]

3.3.3. Assessing insulation efficiency

Usually there is certain reluctance in most communities to invest in costly high technology house equipments meant to decrease energy consumption, which will payback in a longer time, most of them in about 6 to 7 years. So the solution of improving the building insulation seems more acceptable from the average citizen's point of view.

Of course the idea of insulation has to be considered in two ways, especially due to the drastic climate changes in the last few years, meaning significant differences of temperature between winter and summer. This is why a good insulation should not only provide a comfortable temperature inside when outside it drops below zero (in order to avoid permanently increased heating needs), but also an acceptable interior environment when the exterior is governed by tropical temperature values (leading to energy consumption for ventilation or air conditioning).

On the other hand, this solution requires a careful study of the optimal possibilities to be used for buildings insulation, taking several factors into consideration, such as: type of insulation, thickness, building orientation and so on. Their action should be correlated in order to obtain the optimal choice.

In order to observe the influence of insulation upon the quantity of heat transferred through buildings walls, the modern method based on the use of a thermo-vision camera from FLIR systems with dedicated software was used.

Three types of buildings were studied:

→ Old, non-insulated building
→ Partial insulated building, insulation thickness 5cm
→ Building with finalized insulation, thickness 12cm

The images were captured from the outside and also from the inside of the building (mirror-like), both during summer and winter. Of course the phenomenon of heat transfer goes from inside towards outside in winter and becomes reversed in summer.

By help of FLIR software it was possible to extract from the captured images the entire set of temperature values, for each 1cm^2 and select a certain surface for study. In the following images some of the captures for different situations are presented (fig.3.35 – 3.38).

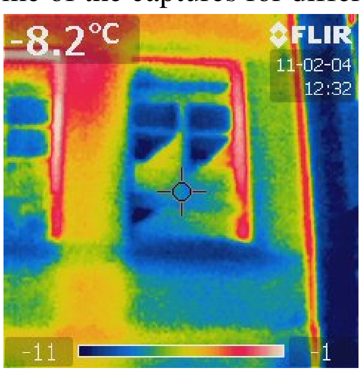


Fig.3.35 Non-insulated building, outside, winter [64]

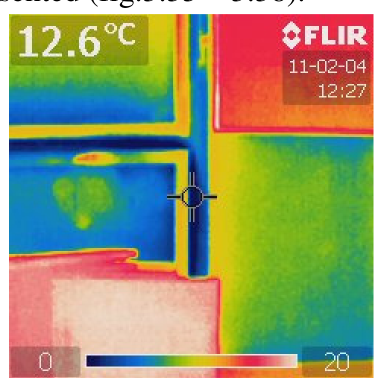


Fig.3.36 Non-insulated building, inside, winter [64]

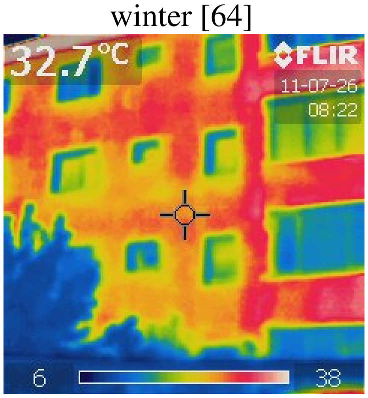


Fig.3.37 Insulated building, outside, summer[64]

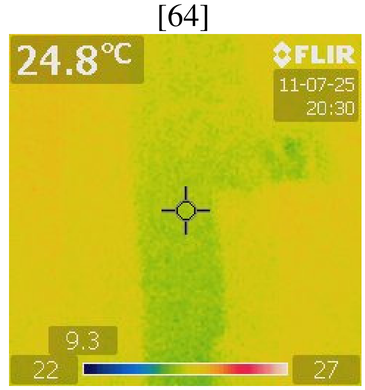


Fig.3.38 Insulated building, inside, summer[64]

Using the temperature values provided by the software, it was possible to determine the heat loss for the non-insulated building in winter at about 52,91W/m^2. The values for the partial insulated building were obtained around 38,32W/m^2, while for the building with finalized insulation, 28,06W/m^2.

In summer, the direction of the heat flow is reversed and the goal of the insulation is keeping as much as possible heat outside in order to avoid energy consumption required for intensive use of air-conditioning.

Following the same procedure as in winter it was possible to determine the heat flow through a certain surface for the three types of studied buildings. Thus, for the insulated building there was 14,6W/m^2, for the partial insulated building 16,55W/m^2, while for the non-insulated building the heat flow was obtained about 28,4 W/m^2.

Another interesting development might be determined based upon the temperature values offered by FLIR system. For example, analyzing the image of a partial insulated building (fig.3.39) and creating the 3D temperature diagram in a proper position we find exactly the mirror image of the building façade, with the possibility of observing the uniformity of the temperatures in the insulated areas (fig.3.40).

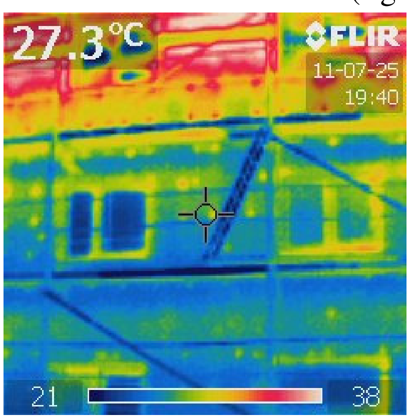


Fig.3.39 Partial insulated building with scaffolding [64]

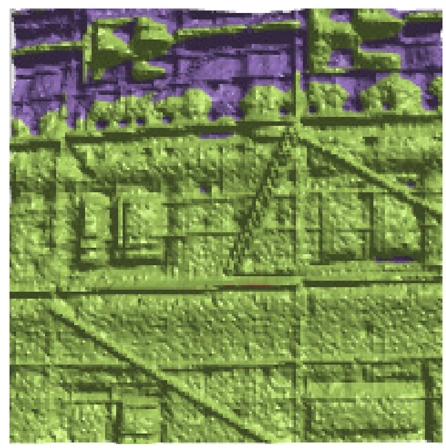


Fig.3.40 3D temperature diagram of the façade [64]

It is obvious that the insulated areas maintain a constant temperature; the insulation looks uniform providing an isothermal surface.

The magnitude of the heat flow is directly influenced by the thickness of the insulation, the smaller the thickness the higher is the heat flow. Also the environmental temperature plays a critical part, as far as the direction of the heat flow is concerned (from inside to outside in winter and reversed in summer) and also the magnitude of the heat flow, considering the fact that the difference between the comfort temperature inside and the environmental exterior temperature is much higher in winter.

The idea of energy conservation seems to appeal more to the average citizens as far as their residences are concerned. This is not only due to fewer costs but also due to the faster payback of the investments (2 to 3 years).

This is the reason why the optimization of these types of activities presents an utmost importance. Using the simple methodology of a thermo-vision camera associated with the dedicated software allows the determination of heat flow through various types of walls or around openings (doors, windows). This determination will not only pinpoint the problem areas but also provide the optimal possibilities concerning the insulation (thickness, type of material, number of layers etc.) in a very accurate way.[64]

3.3.4. Using multi-criteria analysis for selecting the optimal choice of heating for people's life quality

An extremely important issue in analyzing the residential heating sources is represented by the correlation between the temperature of the thermal agent and the climate factors. In the functioning of such system, the correlation mechanism is based upon the buildings heating process (walls, roof, foundation) and criteria analysis highlights the quality-quantity adjustment of the primary thermal agent related to the external temperature, as well as accomplishing interior comfort conditions by a rational selection of the insulation material and thickness.

Multi-criteria analysis can be successfully used in various situations in order to perform rankings or to evaluate several options in order to highlight the optimal one according to some proposed criteria. The benefit of this analysis is the fact that its results offer us an objective choice in a very high proportion, providing a scientific basis for our decisions.

Our goal is to identify the best choice of heating for residential buildings from the point of view of its efficiency. We are going to compare the most used types of heating provided in our country such as: methane gas heating (G), electric based heating (radiant panels) (E), solar power based heating (S), combined heating (solar + methane gas) (SG).[35]

The most important part of the analysis is the criteria selection, as this is the condition in obtaining objective and solid results. According to the studies performed at global level, we decided to select the following criteria: type of fuel used for heating (FT); type of insulation (materials) (IM); insulation thickness (IT); costs (CO); geographic area (GA); type of residence (RT); inhabitants' opinion (IO). We establish the weight of each criterion by awarding a value chosen from 3 possible values: 0; 0.5; 1, in comparing each criterion with the other one. The following table allows us to determine the weight of each criterion (γ_i) based upon FRISCO formula: [38]

$$\gamma_i = \frac{p + \Delta p + m + 0.5}{-\Delta p' + \frac{N_{crt}}{2}} \tag{3.17}$$

where

p - sum of the points obtained by the considered element;

Δp - difference between the score obtained by the considered element and the last level element;

m - number of surpassed criteria;

N_{crt} - number of considered criteria;

Δp'- difference between the score of the considered element and the first level element (negative value).

For each heating option a certain grade will be given according to each criterion, as shown in the following table and consequently the grade is multiplied to the weight determined for the studied criterion, finally obtaining the score for each type of heating, helping us to make the optimal choice (table no.3.1)

Table no.3.1

	FT	IM	IT	CO	GA	RT	IO	Score	Level	Weight
FT	0.5	1	1	1	1	1	1	6.5	1	5.428
IM	0	0.5	1	0	1	1	1	4.5	3	2.363
IT	0	0	0.5	0	0	0	0	0.5	7	0.105
CO	0	1	1	0.5	1	1	1	5.5	2	3.555
GA	0	0	1	0	0.5	1	0	2.5	5	0.933
RT	0	0	1	0	0	0.5	0	1.5	6	0.470
IO	0	0	1	0	1	1	0.5	3.5	4	1.538

Table no.3.2 provides the final scores obtained by each type of considered heating and represents a reliable tool used to establish the optimal choice, according to the resident's requirements.

Table 3.2

	G		**E**		**S**		**SG**	
Criterion	**Ni**	**Niγi**	**Ni**	**Niγi**	**Ni**	**Niγi**	**Ni**	**Niγi**
FT	7	38.00	8	43.43	10	54.29	9	48.86
IM	6	14.18	6	14.18	7	16.55	7	16.55
IT	5	0.53	5	0.53	8	0.84	8	0.84
CO	4	14.22	3	10.67	7	24.89	8	28.44
GA	5	4.67	7	6.53	9	8.40	8	7.47
RT	5	2.35	4	1.88	6	2.82	6	2.82
IO	8	12.31	7	10.77	5	7.69	8	12.31
FINAL SCORES		**86.26**		**87.99**		**115.48**		**117.29**
RANKING	**4**		**3**		**2**		**1**	

Analyzing the results it becomes obvious that for the time being and existing records, the combined type of heating, using both solar energy and methane gas is the optimal choice for residential buildings heating. There is though a very small difference between this and solar power heating, proving the fact that the future tendencies are towards sustainable and renewable sources of energy.

The method based upon thermo-graphics offers reliable information related to the temperature distribution, both outside and inside the building walls, highlights the problem areas, processes the results, avoiding complicated calculus and errors. By providing the exact positions of the problem areas, contractors will know exactly where to apply the insulation materials. By applying the correct insulation materials, the thermal resistance increases according to the insulation thickness and physical properties, leading to a decrease of the heat transfer coefficient and thus of the heat losses.

Also the method can be used to compare several buildings that where renovated and insulated with different types of materials in order to identify the optimal choice of material, also considering the best quality-cost ratio.

Chapter 4. FINAL CONCLUSIONS AND ORIGINAL CONTRIBUTIONS

Considering the exponential involvement of technology and engineering in medical care and human life quality during the last decades, there is an obvious need of interdisciplinary research in order to gain as much benefit as possible from the contributions of each scientific domain. Based upon these considerations, research should be more and more directed towards priority areas centered on the human being welfare in a sustainable and less aggressive environment.

The research developed along this thesis followed three main directions: biomechanical analysis of human balance and motion in order to assess and contribute to the rehabilitation and recovery of people with kinetic dysfunctions, studies upon the properties of materials for biomedical use and studies of the environmental influences upon the human behavior and consequently upon the life quality.

4.1. Final conclusions

- The occurrence of a locomotor disease or trauma will lead unfortunately to motion and stability limitations that influence in a negative manner people's life and activity.
- The collaboration between medical staff and engineers may lead to faster results on the way of recovery and rehabilitation and also of designing and manufacturing devices meant to support and improve life of people with motor disabilities.
- Testing people using force platforms (Kistler, FootScan) or devices like ArmTutor or LegTutor, in friendly and parametrical stable environments (research laboratories) will provide accurate and reliable results concerning their stability, mobility degrees and balance that will represent valuable information for their situation before and after a medical procedure
- Research upon mobility degrees will pinpoint the problem areas and create a foundation for the design of rehabilitation procedures to be followed
- Subjects can be monitored along the entire recovery process and adjustments can be made to their exercise according to the obtained results

- Healthy people can be also monitored during their working activities in order to avoid occurrence of professional diseases or simply to improve their performances
- Dedicated software are used in order to create statistics and databases that are valuable information for future challenges
- Correlative analysis using different experimental procedures can provide enhanced results and accurate solutions for motion and balance improvement
- Modeling and simulation by help of software like LifeMode and AnyBody could provide valuable data concerning forces and displacements in joints and body members making possible to predict the evolution in a certain medical procedure
- There is always a high demand for newer, better and if possible cheaper materials to be used for dental purposes or orthopedic devices
- Fiber reinforced composite materials became a strong alternative for manufacturing orthopedic orthotic and prosthetic devices, as their mechanical properties are far better than those required for the purpose and the costs lower than existing metallic choices
- Composite materials are also a suitable and mostly used option for dental materials, both for restoration works and for prosthetics
- There are possibilities of comparing the properties of dental materials by multi-criteria analysis, considering mechanical properties, chemical resistance and thermal resistance, together with other criteria that may interest the users and beneficiaries
- Microscopic breakage of materials for orthopedic devices is critical as they come in contact with human tissues
- Environmental factors like visual and audio stimuli influence the stability and balance of the human beings subjected to them in a negative manner so they should be considered as potential disturbing factors in a working environment
- Thermal comfort highly influences human life quality so finding the best option for heating residential buildings or institutions represents a priority
- By harmonizing the activity of mechanical engineers, medical staff, medical engineers, kineto-therapists, environmental engineers and other professionals there are distinct possibilities of creating innovative ways of improving life quality and maintaining a healthy environment for human beings, according to the priorities set by the new research programmes of the EU.

4.2. Original contributions

The main original contributions presented in the thesis are the following:

- ➢ Creating methodologies and procedures for testing people with locomotion impairments according to their individual situation
- ➢ Creating testing protocols to monitor patients before and after surgical orthopedic interventions

- Designing correlative procedures for static and dynamic testing of locomotor disabled subjects
- Assessment of healthy subjects performances and designing exercises for their improvement
- Assessment of subjects suffering of professional locomotor diseases and designing a monitoring procedure
- Creating databases and statistic analysis of the processed data and recordings for further use
- Assessment of existing dental materials properties from mechanical, chemical and thermal point of view in order to identify best choices
- Study of composite materials properties in order to promote their use for orthopedic devices or other biomedical use
- Microscopic analysis and image processing for determining roughness of dental materials and microscopic failures as follow of mechanical, chemical and thermal aggressions
- Designing methodologies of experimental testing for people subjected to sensorial stimuli during various situations
- Using thermo-vision camera for measuring human temperature variations in affected areas of their body
- Designing procedure for analyzing people subjected to a working environment polluted with solid particles
- Using multi criteria analysis for determining the best option in multiple decision and comparison situations.

Part II. The evolution and development plans of scientific and academic career

I. Evolution of scientific and academic career

In 1986 the author graduated from University Transilvania of Brasov, Faculty of Machine Construction Technology, finally graded 9,92. For 5 years, until 1991 she has worked as technological engineer at Romanian Aeronautical Enterprises from Ghimbav – Brasov.

The first stage of the academic activity started in 1991 when the author became assistant professor at University Transilvania of Brasov, Department of Mechanics. In 1997 she was promoted lecturer and in 1998 she obtained her Ph.D. with the thesis entitled "Contributions to the Theory, Calculus and Construction of Directional Gyros from their Stability Point of View".

In 2001 she was promoted Associate Professor within the same department.

The teaching activities within the Department of Mechanics involved in the beginning seminars and laboratories for multiple engineering study programs whose curricula mandatory includes the subject "Theoretical Mechanics". After three years, lectures started in the same subject of "Theoretical Mechanics" and later "Dynamics of Rigid Bodies". Being a certified English-Romanian translator she was assigned to teach the subject of Theoretical Mechanics in English language, as the new study programs in foreign languages emerged, offering opportunities for European students to access Erasmus exchanges with Romania. As the master programs started to develop in Transilvania University, she started teaching lectures and laboratories in "C++ Programming" for Computational Mechanics master students.

In order to support teaching activities she published applications handbooks in collaboration with the other colleagues in the department and also lecture notes and courses, both with the university publishing house and with other publishers, including an English Mechanics book for the students in English study programs.

Obviously teaching activity should harmoniously blend with research activity in order to assure technology and know-how transfer towards the economic agents and to contribute to the financial support of future researches. Also the contact with other academic partners helps strengthening connections between high education institutions and with various economic partners, thus creating an excellence environment that will bring beneficial influences for the young future professionals.

In this respect, the author was involved in around 20 research projects, in 5 of them as project manager contributing not only to the endowment of the research departments of the university but also to the development of the research network by publishing and presenting numerous papers in national and international conferences and by publishing journal articles. Students were involved in some of the research activities resulting in presentations within the students scientific manifestations. Ph.D. students and master students were also involved in carrying out specific tasks of the research projects, which helped them finish their graduation assessment.

Between 2004 and 2007 the author acted as scientific responsible of the Department of Mechanics, being in charge with the monitoring of research and scientific activities. During this time she initiated in 2005 the International Conference “Computational Mechanics and Virtual Engineering”, still ongoing every two years, starting from a Module III research project. Also as a result of a Module III project she organized the International workshop „Trends and Research in Composite Materials Recycling”, gathering important personalities in this area of research. As a consequence she was invited as a partner in an international project ASO 4-23-2008, „Environmentally Usage of Power” sponsored by Austrian Science and Liaison Office.

In October 2008 she organized the workshop „Computer Science Applied in Mechanics and Biomechanics” reuniting several academics from Japan, United Kingdom, Croatia and Bulgaria and starting a new network of research. She also was part of the organizing committee for a number of other scientific manifestations like:

- 2nd National Conference with International Participation: Optometry and Medical Engineering,
- Applied and Theoretical Mechanics, Cairo, Egypt.

She was invited to be chairperson in several international conferences like:

- International Conference on Continuum Mechanics (CM'07), Portoroz, Slovenia, 2007;
- Annual International Conference for Academic Disciplines, Austria, 2011;
- IEEE conference on E-Health and Bioengineering, Iasi, 2015.

The author is member of IAENG (International Association of Engineers) and was invited to review papers for Engineering Review, indexed in Cambridge Scientific Abstracts and Viniti, International Journal of Computer Aided Engineering and Technology, World Scientific and Engineering Society, etc.

Having the permanent wish of learning about new subjects, the author attended specialization courses at International Centre of Mechanical Sciences, Udine, Italy in 2007 - Simulation Techniques in Applied Dynamics and in 2009 - Dynamical Inverse Problems: Theory and Application.

Around 2008 a second stage of the academic and scientific career began with new interests and involvements in other research areas. The author’s interest was aroused by studies related to medical engineering and optometry, mechatronic engineering, biomechanics and environmental influences upon the human body, composite materials for biomedical use, etc. As a consequence she started researching with new departments (became member of the Advanced Mechatronic Systems research department) and published a high number of articles and papers related to the new research interests. The author won by competition a research grant regarding computerized methods used to study rigid implants and finalized it successfully involving a young team of Ph.D. students, who managed to finalize their thesis in the same domain.

In 2009 she was invited by the Medical Engineering Department from Anglia Ruskin University, Chelmsford branch, to present some of the researches performed within the project “Computerized Method for Correlative Biomechanical Modeling of Rigid Implants”, as the subject aroused the interest of the English academics.

Since 2011 the author works with a new teaching department, Product Design, Mechatronics and Environment and has the great opportunity of teaching new subjects like: Medical Devices Ergonomics and Databases and Statistical Processing. These new subjects and the involvement in other study programs opened the opportunity of supervising degree projects and master dissertations and of course continuing the students training for research activities.

Ever since she started the academic career, the author was involved every year in the enrollment commission for new students and tried to promote and acknowledge the applicants about the opportunities of studying at Transilvania University.

To summarize the author's most important achievements during the professional and scientific career, the following results should be highlighted:

- Project manager for Transilvania University of the international project:
  - ENVIRONMENTALLY USAGE OF POWER, during 2008-2009, financed by Austrian Science and Liaison Office, Contract no.4-23-2008, value 10000 Euro
- Project manager of the following research grants won by competition:
  - "Computerized method of correlative biomechanical modeling of rigid implants" during 2009-2011, financed by UEFISCSU, value 222844 lei
  - "Identification by modeling and experimental analysis of nano-composites properties to be used in antifriction bearings. Application for directional gyros", during 2006-2008 financed by AMCSIT, value 405000 lei
  - "Promotion and support of Romanian research participation in transnational programs in the field of new and composite materials ecological recycling wastes", during 2006-2008, financed by ANCS, 85000 lei
  - "Advanced researches in computational mechanics and virtual engineering", during 2006-2007, financed by CNMP, 100000 lei
- team member in over 10 research projects won by national competition
- over 10 citations of the scientific papers in articles published at international level, some of them in journals with impact factor, the most important being:

→ D. C. Anghel, A. Ene, N. Belu, *A Matlab Neural Network Application for the Study of Working Conditions*, Advanced Materials Research, Vol. 837, pp. 310-315, Nov. 2013

→ Lewandowski, W., *The external walls of a passive building: A classification and description of their thermal and optical properties,* Energy and Buildings 69, 2014 (IF 2,88)

→ Porumbeanu Madge O.L., *Evaluation of usage patterns and promotion of electronic resources in academic medical libraries: the case of the Central Library of the "Carol Davila" University of Medicine and Pharmacy in Bucharest, Romania*, Qualitative and Quantitative Methods in Libraries (QQML) 4: 387 – 392, 2013

→ N.S. Souza, A.C.G. Martins, D.C.D. Machado, *A Influência do Eixo Visuo-Podal na Regulação do Equilíbrio Morfoestático em Idosos,* Rev Neurocienc 2012;20(2):320-327

→ Boobalan V, Omkar S N, Ramesh D V, Shankar S., *Simulation of Muscle Activation Patterns in the Hip Joint During Normal Level Walking Followed by Sit-to-stand*

Movement Between Two Hip Implants, Trends in Biomaterials and Artificial Organs, vol.28, 2014

→ Rajendran, J.; Arutprakasam, S.S.; Warrier, A.M. "Stability and bifurcation analysis of a pupillary light reflex model", *Control and Decision Conference (CCDC), 2015 27th Chinese,* On page(s): 1765 – 1771

→ Kardi Teknomo, Maria Regina Estuar, *Visualizing Gait Patterns of Able bodied Individuals and Transtibial Amputees with the Use of Accelerometry in Smart Phones*, Revista Colombiana de Estadística Current Topics in Statistical Graphics, 2014, vol. 37, no. 2, pp. 471 – 488

→ G. Campitelli, G Macbeth, *Hierarchical Graphical Bayesian Models in Psychology,* Revista Colombiana de Estadística Current Topics in Statistical Graphics, vol.37, no.2, 2014, pp.319-339

→ Egoyan, A.E., *Equilibrium and Stability of the Upright Human Body*, The General Science Journal, ISSN 1916-5382, 2013

→ P. Čech, J. Junger, *Monitoring the Level of Postural Stability after Modification of Size of Support Surface,* Physical Activity in Science and Practice pp. 189–199 Presov University, Prague 2013

→ L. Ghazaleh, M. Anbarian, M.T. Karimi, *Dynamics Study of Ankle Joint during Quiet Standing Balance Control with Emphasis on Dominant and Non-dominant Lower Limb,* Physical Treatments, vol.4, no.3, 2014

→ J. Apolinar Munoz Rodriguez, *Improving the Modeling of the Plantar Surface via Bezier Networks and Laser Projection,* Information Technology And Control, T43, nr.4, 2014 (IF 0,623)

- reviews of papers for journals like Engineering Review indexed in Cambridge Scientific Abstracts, International Journal of Computer Aided Engineering and Technology, World Scientific and Engineering Society
- authorized translator from technical English to Romanian
- graduated training courses at International Centre of Mechanical Sciences, Udine, Italy:
    - ♦ Simulation Techniques in Applied Dynamics (2007)
    - ♦ Dynamical Inverse Problems: Theory and Application (2009)

- Ph.D. thesis in Mechanical Engineering: „*Contributions to the Theory, Calculus and Construction of Directional Gyros from their Stability Point of View*”, 1998;
- Number of chapters published in international publishing houses like Springer, Elsevier, InTech, etc. - 9
- 11 books published in national publishing houses
- 60 ISI indexed papers according to ISI Web of Science)
- 41 papers indexed in various databases like: EBSCO, ProQuest, Index Copernicus, Google Scholar, Ulrich, etc.
- 98 papers published in various conference proceedings
- 1 patent

II. Development plans of scientific and academic career

Scientific and academic career will develop in a harmonious blending together, as teaching should be based upon solid applicative knowledge and keep track of the newest researches and developments in the targeted scientific area. Only by being permanently active and involved in the actual research tendencies and priorities of the European and even non-European developed countries, academics are able to deliver solid, meaningful and reliable knowledge to their students. Therefore, a careful future planning should be determined.

Development of academic career

The main directions that are planned for the development of the academic career are the following:

- using and developing new and modern methods of teaching, based on computer aided lectures, video presentations, experimental laboratories;
- delivering new, original and up-to-date course and laboratory supports for all the subjects to be taught, for both undergraduate and master students, mostly on electronic support in order to make them accessible to all targeted groups;
- developing new course and laboratory subjects according to the scientific advancements in the field;
- identifying new and modern possibilities of examination in order to valorize as much as possible the students' skills;
- developing opportunities and possibilities of better communication between students and teaching staff in order to get the necessary feed-back regarding the efficiency and attractiveness of the taught subjects;
- identifying intriguing and economical based subjects for the master dissertations and degree diplomas of the supervised students;
- contributions to the development of new study programs required by the labor market in order to provide highly trained professionals in niche areas;
- meeting the requirements for the rank of full university professor;
- enhancing the existing collaborations with other universities both from Romania and other countries in the world and starting new working contacts;
- contributions to the improvement of existing courses curricula in order to meet the employers' requirements and assure a suitable training to the future professionals attending the study programs coordinated by the Department of Product Design, Mechatronics and Environment, especially Medical Engineering, Optometry and Mechatronics

- keeping track of the evolutions in the teaching process developed by other national or European universities in the same study programs.

Development of scientific career

The main directions of the scientific career development are related to:

- meeting the requirements for becoming a Ph.D. supervisor in order to access the opportunity of working with young professionals at a higher level
- involving more undergraduates, master students in scientific research according to their interests and the author's research directions
- encouraging young researchers to benefit and use the high tech equipment existing at the Research Institute of Transilvania University laboratories
- publishing papers in scientific journals with an impact factor over 1
- identifying opportunities of winning research grants at national or international level in order to access appropriate funding for future research, for up-to-date experimental equipment and offer possibilities to the Ph.D. students to present their researches in high level international conferences
- enhancing collaborations with national and international universities in order to find opportunities of exchanging expertise in the countless directions of research offered by mechanical engineering
- applying for international projects under Horizon 2020, either as project manager or as team member according to the requirements
- identifying new research themes and running applicative experiments in the area of Medical Engineering, Optometry and Mechatronics, simultaneously attracting young researchers in the scientific activities and training them for starting their own line of research interest
- developing new collaborations with economic agents in order to approach research priorities that may help their development and innovation trends
- developing collaborations with academics from other study programs that may benefit from applicative engineering research, like medicine, environmental engineering, sports, computer science, etc.

Directions of scientific research

After the years spent at the Department of Mechanics, the fundamental knowledge regarding Theoretical Mechanics was thoroughly set. Feeling the need of more applicative and human related research, the author started redirecting interest towards Applied Mechanics in areas like Medical Engineering, Optometry and Mechatronics. In this respect, the following directions of scientific research are to be continued or approached in the future:

- study the mechanical behavior of biomedical materials, especially for dental and orthopedical use

- improving skills in using FEM analysis for preclinical evaluation of rigid implants in dentistry and orthopedics and for assessing the mechanical properties of orthotic devices
- improving skills in using modeling and simulation software like LifeMode and AnyBody in order to create new models and improve the existing ones or adjust them to the current research needs
- design and validate new methodologies for testing properties of biomaterials and create databases to support medical staff and patients to select the optimal choice
- identify new materials with suitable properties and biocompatibility to be used for medical rigid implants
- study the biomechanics of various human motion impairments in order to offer reliable means of rehabilitation for temporarily disabled persons
- design of new rehabilitation methods for motion impaired patients in collaboration with the medical staff
- design of new mechatronic devices to support medical impaired people or special categories like elderly people or disabled children
- study of environmental influence upon human sensorial systems, especially upon vision and hearing, and identify means of protecting people against environmental aggressions
- ergonomic studies upon people performing various repetitive working activities and identifying means for improving their working position
- biomechanical studies upon athletes in order to improve their performances and provide information for sportive equipment optimization
- statistical analysis of the experimental tests run during various types of researches, processing of databases and recordings
- using more computer methods in biomechanics and medical engineering
- creating and processing surveys regarding the use of the existing composite materials for biomedical use in order to accurately identify the shortcomings and benefits

Additionally, the future researches will follow the possible trends occurred at national, European and global level in order to maintain the high research standards set by Transilvania University and contribute to the effort of putting science and technology to work for improving human life quality.

REFERENCES

[1] Andersen M.S., Damsgaard M., Rasmussen J., *Scaling and local marker coordinate determination of musculoskeletal systems*, Digital Human Modeling for Design and Engineering Conference, Seattle, USA, 2007.

[2] Anderson F., Pandy M., *Individual muscle contributions to support in normal walking*, Gait and Posture 17, 2003, pp.159-169

[3] Antonescu, D., Buga, M., Constantinescu, I., Iliesu, N., *Metode de calcul şi tehnici experimentale de analiza tensiunilor în biomecanică*, Ed. Tehnică, Bucureşti, 1986

[4] Arnold A., et.al. - Muscular Coordination of Knee Motion during the Terminal Swing Phase of Normal Gait, Journal of Biomechanics 40, 2007, p. 3314-3324

[5] Au, A.G., et al., *Contribution of loading conditions and material properties to stress shielding near the tibial component of total knee replacements*, Journal of biomechanics, 2007

[6] Avramescu E.T., „Bazele anatomice ale mişcării" – curs practic pentru studenţii facultăţilor de kinetoterapie, Craiova

[7] Băcanu, Gh., "*Termodinamică, transfer de căldură şi de masă*", Editura "Dealul Melcilor", Braşov, 1998, ISBN 973-98014-0-4

[8] Băcanu Gh., *Thermal Rehabilitation of Multi-Flats Buildings*, Proceedings of the 1st WSEAS International Conference on "Urban Rehabilitation and Sustainability (URES'08)", Bucharest, Romania, 2008

[9] Balazic, M., Kopac, J., Jackson, J. M., Ahmed, W., *Review: titanium and titanium alloy applications in medicine*, International Journal of Nano and Biomaterials, vol. 1, no. 1, pp. 3-34, 2007

[10] Barbu D., Cotoros D**.**, *Assessment of the Occupational Effects of Vibrations on the Human Body*, Applied Mechanics and Materials, Vol. 801, pp. 290-294, Oct. 2015

[11] Baritz, M., Cristea, L., Cotoros, D., Danaila, C., Rogozea, L., *Eyeball Retinal Image and Oculo-Motor Equilibrium Analyze by Human Body Stability Recordings*, Mecatronica, 2007, Issue 1, pp.22-26

[12] Baritz M., Cotoros D., Cristea L., Balcu I., *Analyses of noise effects on standing human body stability*, Recent Advances in Signals and Systems, 2009, p.168-173

[13] Baritz, M., Cotoros D., Cristea L., Rogozea L., *Assessment of Human Bio-Behavior during Gait Process Using Lifemod Software*, Broad Research in Artificial Intelligence and Neuroscience, ISSN 2067-3957, Volume 1, 2010

[14] Baritz M., Todor V., *Some Considerations about Pedestrian Biomechanical Behavior Affected by Audio and Visual Stimuli Perception*, Proceedings of International Conference

on Innovations, Recent Trends and Challenges in Mechatronics, Mechanical Engineering and New High-Tech Products Development – MECAHITECH'10, vol. 2, 2010

[15] Baritz, M., Cotoros, D., *Advanced Technologies in Biomechanics Investigations for the Analysis of Human Behaviour in Working Activities*, ISBN 978-953-307-141-1, Scyio, Rijeka, Croatia, 2010

[16] Baritz, M., **C**otoros, D., *Education of Arms' Users in Dealing with Technological Activities*, Chapter International Conference on Advancements of Medicine and Health Care through Technology, Volume 36 of the series IFMBE Proceedings, Springer Verlag, 2011, pp. 114-119

[17] Baritz, M., Cotoros, D., *Digital Microscopy Used in Synthetic Structures Analysis of Dental Prosthesis*, Chapter International Conference on Advancements of Medicine and Health Care through Technology, Volume 36 of the series IFMBE Proceedings, Springer Verlag, 2011, pp.230-233

[18] Baritz M., Cotoros D., *Analysis of plantar pressures developed during gait for hollow foot and flat foot shapes with bio-behavioral implications*, EHB, Iasi, 2011

[19] Baritz M., Cotoros D., *Modeling and simulation of human locomotion system structure and behavior by dedicated software –LifeMode*, EHB, Iasi, 2011

[20] Baritz M., Cotoros D., *Anthropometrical Studies for Human Hand Rehabilitation Procedures*, IFMBE proceedings, vol.36, ISBN: 978-3-642-22585-7, Springer Publishing House, 2011

[21] Baritz M., Cotoros D., *The Influence of Plantar Surface Shape and Height Upon the Support Basis and Bipodal Stability*, CORTEP, Sinaia, 2012

[22] Baritz, M., Cotoros, D., *Human Gait Analysis for Hip Implanted Persons before and after Implant Procedure*, Chapter 5th European Conference of the International Federation for Medical and Biological Engineering, Volume 37 of the series IFMBE Proceedings, Springer Verlag, 2012, pp 880-883

[23] Baritz M., Cotoros D**.** L., Braun B. C., *Eye Tracking Used to Evaluate the Human Behavior*, Applied Mechanics and Materials, Vol. 186, pp. 260-265, Jun. 2012

[24] Baritz M., Cotoros D., *Correlative analysis of the influence on human behavior and working comfort due to repetitive technological processes*, International Journal of Modern Manufacturing Technologies, ISSN 2067–3604, Vol. IV, No. 1 / 2012, pp. 15-20

[25] Baritz M., Cotoros D., Cristea L., Braun B., *Analysis of Stability Asymmetries and of Gait Cycle Used to Determine the Recovery Degree for Subjects with Traumatic Locomotion Disorder*, Applied Mechanics and Materials, Vol. 332, pp. 534-539, Jul. 2013

[26] Baritz M., Cotoros D., *Oscillatory Movements Analysis at Knee Level*, Applied Mechanics and Materials, Vol. 436, pp. 271-276, Oct. 2013

[27] Baritz, M., Cotoros, D**.,** *Reactive Postural Response in Bipodal Balance Analysis*, Applied Mechanics and Materials, Elsevier, 2013, pp. 842-847

[28] Baritz M., Cotoros D., *Evaluation of postural stability associated to lifting/lowering motions*, Applied Mechanics and Materials, Vol. Modeling and Optimization of the

Aerospace, Robotics, Mechatronics, Machines-Tools, Mechanical Engineering and Human Motricity Fields, OPTIROB 2014, 26 June 2014 - 29 June 2014, Elsevier, pp. 646-651

[29] Baritz M., Cotoros D., Balcu I., *Evaluation of Comfort Degree for Pushing/Pulling Motions under the Influence of Controlled Induced Vibrations in the FingersHand–Arm Assembly*, Applied Mechanics and Materials 658, 2014, pp.413-416

[30] Baritz M., Cotoros D., Barbu D., *Analysis and Simulation of Gait Types with Blocked Joints*, Applied Mechanics and Materials 658, 2014, pp.407-412

[31] Baritz M., Cotoros D., *Development of correlative investigation technique (CIT) of human performances in specific conditions of postural malfunctions*, Advanced Materials Research, Elsevier, 2014, pp.531-534

[32] Baritz, M., Cotoros, D., Muntean, R., Ciobanu, I., *Forces distribution analysis developed in the plantar surface in simulation case of controlled blocking of joints*, Applied Mechanics and Materials, Volume 656, 2014, Elsevier, pp. 642-649

[33] Baritz M., Cotoros D., Dumitrescu L., *Microscopic Analyze of Insoles Composite Structures Behavior under Water Immersion, Temperature Variation and Saline*, Applied Mechanics and Materials, Vol. 760, pp. 287-292, May. 2015

[34] Baritz M., Balcu I., Cotoros D., Stanciu A., *The Automotive Vibrations Effect on the Comfort Degree Determined at the Level of Foot-Shoe Composite Structure*, Applied Mechanics and Materials, Vol. 760, pp. 305-310, May. 2015

[35] Baritz M., Cotoros D., Barbu D., *Criteria Analysis for Optimal Choice of Efficient Energy Use in Residential Buildings*, Springer Proceedings in Energy, 2014, p.39-47

[36] Baritz, M., Cotoros, D., Barbu D., *Use of Thermo-Vision for Early Detection of Heat Losses, Inside and Outside Buildings with Mixed Heating*, Chapter Sustainable Energy in the Built Environment - Steps Towards nZEB, Part of the series Springer Proceedings in Energy, Springer Verlag, 2014, pp 31-37, ISBN: 978-3-319-09706-0

[37] BioWare software analysis system (2006) - Operating manual for version 3.2.6, type 2812A1-3

[38] Bobancu, S. *Creativitate și inventică.* s.l. : Curs şcoala doctorală, 2013.

[39] Bowen RL., *Use of epoxy resins in restorative materials*, J Dent Res 1956, 35(3), pp.360-369

[40] Bradley J., *Heat Loss*, School of the Built Environment, Leeds Metropolitan University

[41] Bratu D.,et.al. *Materiale dentare-Materiale utilizate în cabinetul de stomatologie*; Editura Helicon, 1994

[42] Braun B., Baritz M., Cotoros D., *Research on Correlation between any Plantar Diseases and Stability*, Applied Mechanics and Materials, Vol. 186, pp. 254-259, Jun. 2012

[43] Brown W.S., Dewey W.A., Jacobs H.R., *Thermal Properties of Teeth*, J Dent Res, 1970, 49(4), p. 751

[44] Bulancea V., Lacatusu St., Alexandru I., Biomateriale, Bucureşti, 2006

[45] Cenci, M.S., Pereira-Cenci, T., Donassollo, T.A., Sommer, L., Strapasson, A., Demarco, F.F., 2008. Influence of thermal stress on marginal integrity of restorative materials. Journal of Applied Oral Sciences 16, 106–110.

[46] Chaffin D., Andersson G., Martin B., Occupational Biomechanics, John Wiley&Sons, 1999

[47] Cheung, W., “A review of the management of endodontically treated teeth: post, core and the final restoration,” Journal of the American Dental Association, vol. 136, no. 5, pp. 611–619, 2005

[48] Combe E.C., Burke F.J.T., Douglas W.H., *Dental biomaterials*, Boston, Kluwer Acad. Publ., 1999

[49] Cotoros D., et.al., *Solid particles influence upon human body behavior - reason for a better management of wastes*, Proceedings of the C&SEE International Solid Waste Management Symposium, Vienna, 2009, p.67-78

[50] Cotoros D., Baritz M., Albu A.G., Cristea L., *Modeling the Human Gait and Standing Stability by Lifemode Software*, COMEC, Brasov, 2009

[51] Cotoros D., Baritz M., *Aspects concerning the Human Body Stability in Acoustical Perturbations Conditions*, Proceedings of the Xth Symposium “Acoustics and Vibration of Mechanical Structures AVMS 2009, p. 58-63.

[52] Cotoros D., Baritz M., *Some Considerations Concerning the Modelling of the Human Body Locomotor Recovery System*, European Conference on Modelling and Simulation, ECMS, Madrid, 2009

[53] Cotoros D., Baritz M., *Human Gait Analysis for Hip Implanted Persons*, European Conference on Modelling and Simulation, ECMS, Madrid, 2009

[54] Cotoros D., et.al. *Aspects Concerning Impact Tests on Composites for Rigid Implants*, World Congress on Engineering, London, 2009

[55] Cotoros D., Baritz M., *Biomechanical Analyzes of Human Body Stability and Equilibrium*, World Congress on Engineering, London, 2010

[56] Cotoros D., Stanciu A., *Experimental Research Concerning Mechanical Properties of Materials for Biomedical Use*, World Congress on Engineering, London, 2010

[57] Cotoros D., *Analysis of skeletal prosthesis component elements at structural level*, Metalurgia International, 2010

[58] Cotoros D., Baritz M., Serban I., *Applied computer science to establish active correlation for improving the handling skills*, International Conference on Applied Computer Science, Elsevier, Malta, 2010, pp.504-507

[59] Cotoros D., *Analysis of Skeletal Prosthesis Component Elements at Structural Level*, Metalurgia International, Vol: 15, Special Issue: 7, pp.116-120, 2010

[60] Cotoros D., *Mechanics for Students*, Lux Libris Publishers, Brasov, 2005

[61] Cotoros D. et. al. *Advanced Methodology of Heat Losses Assessment in Buildings*, Bad Hofgastein, 2011

[62] Cotoros D., et.al., *Microscopic Analysis of Breakage in Materials for Hard Implants*, World Congress on Engineering, London, 2011

[63] Cotoros D., Băcanu Gh., Baritz M., *Advanced Methodology of Heat Losses Assessment in Buildings*, International Journal of Arts & Sciences 4.19, pp. 307-314, ISSN 1944-6934

[64] Cotoros D., et.al., *Correlative Analysis of Energy Efficiency in Urban Buildings*, Proceedings of the 2nd International Conference USCUDAR, Prague, 2011, p.111-114.

[65] Cotoros D., Baritz M., *Combined-correlated methods applied to the analysis of dental prostheses materials quality*, Ch.10 in New technologies, trends, innovations and research, InTech Publications, 2012, p.209-239

[66] Cotoros D., Baritz M., Stanciu A., *Conceptual Analysis of Correspondence between Plantar Pressure and Corrective Insoles*, World Academy of Science, Engineering and Technology 59, 2011, pp.155-158

[67] Cotoros, D., Stanciu, A., Baritz, M., *Some Mechanical Characteristics of Materials for Dental Prosthetics*, Proceedings 26th European Conference on Modeling and Simulation ECMS, Koblenz, 2012, pp.212-215

[68] Cotoros D**.**, Baritz M., *Implementing Rapid Prototyping Technologies for Corrective Insoles*, International Journal of Modern Manufacturing Technologies, vol.IV, no.4/2012, ISSN 2067-3604, pp.41-46

[69] Cotoros D., Stanciu A., Baritz M., Cristea L., *Experimental Approaches Regarding the Elastic Properties Bending of Roving*, Applied Mechanics and Materials, Vol. 760, pp. 335-340, May. 2015

[70] Cotoros D., Stanciu A., Baritz M., Cristea L., *Microscopic Analysis Following Bending of Roving Type Composite Material*, Applied Mechanics and Materials, Vol. 760, pp. 341-346, May. 2015

[71] Cotoros D., et.al., *Correlative Assessment of Patient's Progress Subjected to a Hip Implant Procedure. Case Study*, 5th IEEE - EHB 2015, p.98

[72] Cotoros D., et.al. , *Modeling and Simulation of Gait by Anybody Software before and after Hip Arthroplasty*, 5th IEEE -EHB 2015, p.101

[73] Cotoros D., Baritz M., Stanciu A., *Influence of Carpal Tunnel Syndrome induced by Vibratory Actions upon Fingers Mobility*, AVMS 2015, Applied Mechanics and Materials, Timisoara

[74] Craig RG, Powers JM., *Restorative dental materials*, 11th ed. St. Louis, Mosby, 2002

[75] Damsgaard M., Rasmussen J., Christensen S. T., de Zee E. M.**,** *Analysis of musculoskeletal systems in the AnyBody Modelling System,* Elsevier, 2006.

[76] Darvell BW., *Materials science for dentistry*, Hong Kong: B.W. Darvell, 2000

[77] Dewaele M, Truffier-Boutry D, Devaux J, Leloup G., *Volume contraction in photocured dental resins: The shrinkage-conversion relationship revisited*, Dent Mater 2006, 22(4), pp.359-365

[78] Diaconu M.P., *Optimizarea prin metode fizice a biocompatibilităţii materialelor dentare*, Teza de doctorat, Iasi, 2012

[79] Dikbas I, Tanalp J, Ozel E, Koksal T, Ersoy M., *Evaluation of the effect of different ferrule designs on the fracture resistance of endodontically treated maxillary central incisors incorporating fiber posts, composite cores and crown restorations*, J.Contemp.Dent.Pract.2007,8, pp.62-69

[80] Dufek, J.S., Schot, P.K., Bates, B.T., *Dynamic lower extremity evaluation of males and females during walking running*, Journal of Human Movement Studies, 18, 1990

[81] Ferracane J.L., *Current trends in dental composites. Critical Reviews in Oral Biology & Medicine,* 1995, 6(4), pp.302-318

[82] Fokkinga W.A., Kreulen C.M.,Vallittu P.K., Creugers n.H., A structured analysis of in vitro failure loads and failure modes of fiber, metal and ceramic post and core systems.Int.J.Prosthodont.2004;17:476-482

[83] Gabbard, C., Goncalves, V., Santos, D., *Visual-motor integration problems in low birth weight infants*, Journal of Clinical Psychology in Medical Settings, vol. 8, no. 3, 2001

[84] Gross M., A critique of the methodologies used in clinical studies of hip-joint arthroplasty published in the English-language orthopaedic literature, *J Bone Joint Surg Am*, 1988 Oct; 70 (9), 1364 -1371

[85] Grosu L., s.a. (1983) *Biosistemul orofacial*, Cluj- Napoca, Ed.Dacia

[86] Hamilton, N., Luttgens, K., *Kinesiology. Scientific basis of human motion*, McGraw-Hill, New York, 2002

[87] Heydecke G, Peters M C., *The restoration of endodontically treated, single-rooted teeth with cast or direct posts and cores: a systematic review*. J Prosthet Dent 2002; 87, pp.380–386

[88] Hollins, Carole. *Basic Guide to Anatomy and Physiology for Dental Care Professionals.* Oxford, UK : John Wiley & Sons, Ltd, 2012.

[89] Jiang Y., Nagasaki S., You M., Zhou J., *Dynamic studies on human body sway by using a simple model with special concerns on pelvic and muscles roles*, Asian Journal of Control, Vol. 8, No. 3, pp. 297-306, September 2006.

[90] Jotkowitz1 A., Samet N, Rethinking ferrule –a new approach to an old dilemma, British Dental Journal 2010; 209: 25–33

[91] Kennedy D.M., Stratford P.W., Hanna S.E., Wessel J. and Gollish J.D., Modeling early recovery of physical function following hip and knee arthroplasty, *BMC Musculoskeletal Disorders* 2006, **7**/100

[92] Kishen A., Asundi A., *Investigations of thermal property gradients in the human dentine*, J Biomed Mater Res, 2001,55, pp.121-130

[93] Klasson, L. B., *Carbon fibre and fibre lamination in prosthetics and orthotics: some basic theory and practical advice for the practitioner*, Prosthetics and Orthotics International, no. 19, pp. 74-91, 1995

[94] Li, J., *Development of integrated process design environment and statistical analysis of RTM process*, The Florida State University, 2003

[95] Lu H., Roder L.B., Lei L., Powers J.M., *Effect of surface roughness on stain resistance of dental resin composites*, J Esthet Restor Dent, 2005, 17, pp. 102-109

[96] Lussi A., *Dental Erosion From Diagnosis to Therapy*, Copyright 2006 by S. Karger AG www.karger.com, ISSN 0077–0892 ; ISBN 3–8055–8097–5, 2006

[97] Medved V., Measurement of Human Locomotion, CRC Press LLC, USA, 2001

[98] Meyer G., Ayalon M., *Biomechanical aspects of dynamic stability* (Book style with paper title and editor), in *Eur Rev Aging Phys Act* , 2006

[99] F. Moldoveanu, *Advanced computer system based on medical imaging of personalized implants dedicated to hip arthroplasty*, Bucharest, 2013.

[100] Morresia A.L., D'Amario M., Capogreco M., Gatto R., Marzo G., D'Arcangelo C., Monaco A., "*Thermal cycling for restorative materials: Does a standardized protocol exist in laboratory testing? A literature review*", Journal of the Mechanical Behavior of Biomedical Materials 29 (2014) 295 – 308

[101] Murariu C., *Cercetări în domeniul materialelor compozite*, Raport de activitate, Universitatea "Gh. Asachi", Iaşi, 2008

[102] Murphy F, McDonald A, Petrie A, Palmer G, Setchell D., *Coronal tooth structure in root-treated teeth prepared for complete and partial coverage restorations*, J Oral Rehabil 2009; 36, pp. 451-461.

[103] Nakashima A.M., *The effect of vibration on human performance and health: A review of recent literature*, Technical Report DRDC Toronto TR 2004-089 July 2004

[104] Neumann, D.A., *Kinesiology of the musculoskeletal system: foundations for rehabilitation*, Mosby Inc., St. Louis, Missouri, 2002, USA, ISBN 0–8151–6349–5

[105] Nica I, Cimpoeşu N, Rusu V, Andronache M, Ştefănescu C., *Structural properties of nanofilled and microfilled restorative composites*, Materiale Plastice, 2012, 49, pp.176-180

[106] Nica I, Aluculesei A, Baciu C, Rusu V, Agop M., *Characterization of some dental composites*, Metalurgia International, 2011, XVI, pp. 38-42

[107] O'Brien W., *Dental Materials and Their Selection*, Quintessence Publishing Co, Inc, 2002

[108] Olariu, V., Roşca, I., Radu, N. Gh., Baritz, M., Barbu, D., *Biomecanica*, vol.1, Bazele biomecanicii, ISBN 973-9372-01-5, Ed. „Macarie", Colecţia, „Universitaria", Târgovişte, 1998

[109] Opran, C.., Baritz, M., Cotoros, D., *The effects of some liquids of general use upon the shape and structure of the monthly worn contact lenses used for visual comfort*, Optoelectronics and Advanced Materials-Rapid Communications, Vol.4, Issue: 7, pp. 1052-1059, Jul. 2010

[110] Ōunpuu, S., *The biomechanics of walking and running*, Clinics in sport medicine, vol. 13, nr. 3, 1994

[111] Papilian, V., *Anatomia omului*, vol. 1, Aparatul locomotor, Editura Didactica si Pedagogica, Bucuresti, 1982

[112] Paravina R.D., Roeder L., Lu H., Vogel K. & Powers J.M., *Effect of finishing and polishing procedures on surface roughness, gloss and color of resin-based composites*, Am. J Dent, 2004, 17(4), pp. 262-266

[113] Park, J. B., Bronzino, J. D., (Eds.) *Biomaterials: Principles and applications*, ISBN 078-0-8493-7888-1, CRC Press, Boca Raton, FL, 2007

[114] Petrasincu N., Fara L., *Bioclimatic Elements for Traditional Romanian Houses*, Conference PLEA2006, Geneva, Switzerland, 6-8 September 2006.

[115] Radu C., *Some theoretical aspects about normal cycle gait*, TMT 2007, Hammamet, Tunisia, ISBN 978-9958-617-34-8.

[116] Radu, C., *Determination of knee joint reaction forces in static conditions using inverse dynamic method*, COMEFIM 8, Seria: Applied Mathematics and Mechanics 49, Vol II, Cluj-Napoca, 2006, ISSN 1221-5872

[117] Radu C., Rosca I., Cotoros D., *The Design of an Adapted Osteosynthesis Implant for Fibula' Fracture*, Chapter International Conference on Advancements of Medicine and Health Care through Technology, Volume 26 of the series IFMBE Proceedings, Springer Verlag, 2009, pp 299-302

[118] Regenio M, et al., *Stress distribution of an internal connection implant prostheses set*, Stomatologija, Baltic Dental and Maxillofacial Journal, 11, 2009

[119] Roşca, Ileana, C., Radu, C.: *On the design of an experimental installation to determine the kinematic parameters during human locomotion*, the 19th International DAAAM Symposium "Intelligent Manufacturing & Automation: Focus on Next Generation of Intelligent Systems and Solutions", DAAAM 2008, Trnava, Slovacia, ISSN 1726-9679

[120] Saltzman, M. W., *Biomedical engineering. Bridging medicine and technology*, ISBN 978-0- 521-84099-6, Cambridge University Press, Cambridge, 2009

[121] Schache A.G., Baker R., Vaughan C.L., *Differences in lower limb transverse plane joint moments during gait when expressed in two alternative reference frames,* Journal of Biomechanics 40, 2007, pp. 9–19

[122] Serban I, Rosca IC, Braun BC, Druga C, *Environmental effects on the center's offset of the Kistler force plate,* International Conference on Advancements of Medicine and Health Care through Technology, 2011, pp.100-105

[123] Serban, I., Baritz, M., Rosca, I. C., Cotoros D., *Statistical Analysis of Anthropometric and Physiologic Performance of the Hand*, Chapter International Conference on Advancements of Medicine and Health Care through Technology, Volume 36 of the series IFMBE Proceedings, Springer Verlag, 2011, pp.380-383

[124] Sherfudhin H., Hobeich J., Carvalho C.A., Aboushelib M.N., Sadig W.,Salameh Z. Effect of different ferrule designs on the fracture resistance and failure pattern of endodontically treated teeth restored with fiber posts and all-ceramic crowns Journal of Applied Oral Science,2011, 19(1):28-33

[125] Singh, R., Dahotre N.B., *Corrosion degradation and prevention by surface modification of biometallic materials*, Journal of Materials Science: Materials in Medicine, 2007

[126] Slutzky-Goldberg I, Slutzky H, Gorfil C, Smidt A., *Restoration of endodontically treated teeth review and treatment recommendations*, International Journal of Dentistry Volume 2009 (2009), Article ID 150251, 9 pages

[127] Spiller, Martin S., *Dental Composites.* New York : Academy of Dental Learning & OSHA Training, 2012.

[128] Stanciu A., Cotoros D., *Study Concerning the Mechanical Tests of MAT&ROVING Fiber Reinforced Laminated Composites*, WSEAS, Puerto de la Cruz, Spain, 2009.

[129] Stanciu, A., Cotoros, D., Baritz, M., *Researches upon composite materials for prosthetic and orthetic devices*, Optoelectronics and Advanced Materials- Rapid Communications Vol. 6 Issue: 1-2, pp. 335-338, Jan-Feb 2012

[130] Stanciu, A.E., Cotoros, D.L., Cristea, L., Baritz, M., *Determination of stress and strains of a composite tank used for liquid medical products*, Journal of optoelectronics and advanced materials / v.17 no.7/8, 2015년, pp.1146-1151, ISSN 1454-4164

[131] Taylor D.F., Kalachandra S., Sankarapandian M., McGrath J.E., *Relationship between filler and matrix resin characteristics and the properties of uncured pastes*, Biomaterials 1998, 19, pp. 197-204

[132] Tözeren A., Human *Body Dynamics Classical Mechanics and Human Movement*, ISBN 0-387-98801-7, Springer-Verlag, New York

[133] ***- User guide Hand Rehabilitation System, (2010), operation manual for sensory gloves

[134] Van de Graaff K., Human Anatomy, McGraw-Hill Companies, 2001

[135] Vaughan C., Davis B., O'Connor J., - Dynamics of Human Gait, 2nd edition, Kiboho Publishers, Cape Town, South Africa, 1999

[136] Vaughan, C.L.(1987) - *Biomechanics of human gait*. 2nd edition Champaign, Ill.: Human Kinetics Publishers

[137] Versluis A., Douglas W.H., Sakaguchi R.L., *Thermal expansion coefficient of dental composites measured with strain gauges*, Dent Mater, 1996,12(5), pp. 290-4

[138] Williams, D.F., *An Introduction to Medical and Dental Materials*, Concise Encyclopedia of Medical & Dental Materials, Pergamon Press and The MIT Press, 1990

[139] Winter, D.A. (1995) - *Anatomy, biomechanics and control of balance during standing and walking*. Waterloo, Ont.: Waterloo Biomechanics;

[140] Huei-Ming Chai (2013) *Stance and stability*, [online], available: http://www.pt.ntu.edu.tw/hmchai/BM03/BMClinic/Stance.htm, [accessed 23 November 2015]

[141] http://www.ninds.nih.gov/disorders/carpal_tunnel/detail_carpal_tunnel.htm#282133049 [accessed 3 October 2015]

[142] Medi Touch (2015) *Physical Therapy Solutions*, available: http://www.meditouch.co.il/en, [accessed 13 November 2015]

[143] HKed City (2015) available: http://resources.edb.gov.hk/~s1sci/R_S1Science/sp/en/syllabus/unit14/new/egmain1.htm [in Chinese] [accessed 3 November 2015]

[144] Business solutions for a sustainable world (2015), available: http://www.wbcsd.org/web/eeb [accessed 3 November 2015]
[145] The World Bank Group (2015), available: http://www.worldbank.org/, [accessed 3 March 2015]
[146] Dudescu, E. (2013) *Biomecanica generală*, [online], available: http://www.scribd.com/doc/290986549/Emil-Dudescu-Biomecanica-Generala, [accessed 23 March 2015]
[147] Drosescu, P. (2014) *Medicina sportivă*, available: http://www.medicinasportiva.ro/dr.drosescu/curs_2014/16.%20Biomecanica%20mersului.pdf [accessed 12 October 2015]
[148] Universitatea din Craiova (2015) *Biomecanică*, available: http://cis01.central.ucv.ro/educatie_fizica-kineto/pdf/studenti/cursuri%20master/Curs_IV.pdf [accessed 23 April 2015]
[149] *** Research project report, ID744, "Computerized method of correlative biomechanical modeling for rigid implants", 2009-2011, Project manager: Cotoros D.