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RESEARCH REGARDING CAD MODELING OF THE HUMAN LOWER LIMB BONES

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***Abstract*—** In this study, we will present the importance of the CAD modeling in bioengineering. The objectives of this study are to create 3D models of the lower leg bones, create a reference system and the component assembly. Using the principles of reverse engineering, we will start from the real bone, taken from human cadavers. After scanning it we will obtain three-dimensional images of the bone in various positions. The model that resulted from scanning was "processed" in the program design CatiaV5R20, SurfaceDesign module. After modeling, we will define proper axes and planes corresponding to the assembly (according to the information obtained from the research literature). Regarding the reference system that we used, we proceeded to the election of a primary reference system to which all 3D bones will be reported. Also, for a better management of the assembly and for highlighting the various pathological situations, we will insert Euler Triedre in the assembly area, between the tibia and foot dome, in the center of the knee joint. Giving to the Euler angles different values, we will obtain different bones positions in the assembly. Creating the CAD system, this will be used in studying various diseases of the bones system and joints of the foot, treatment strategies and surgery.

***Keywords*—** bioengineering, femur, reverse engineering, tibia.

I. INTRODUCTION

THE aim of this study is to create a CAD system, used to study diseases of bones, joints of the foot and strategies for treatment and surgery.

Computer aided modeling finds that when it comes to biomechanical research, the study on 3D models is most appropriate, given that the objects studied are body parts, hard real experiments studied as objects that can not be disassembled, studied and then reassembled.

The objectives of this study are creating 3D models of lower limb bones, creating their assembly reference systems considering the mechanical and anatomical axes existing and creating prerequisites for the study of different possible pathological situations.

II. HUMAN LEG BONES MODELING USING REVERSE ENGINEERING

A. 3D Reconstruction, using Reverse Engineering

In many industrial applications, we need to create CAD models of existing objects that do not have such models.

Reverse engineering, in essence, is a discipline that covers a multitude of activities. While conventional engineering transforms bet on concepts and models in real parts and assemblies, in reverse engineering we have an inverse transformation. This means that the parts and the real assemblies are turned into concepts and engineering models.

Reverse engineering involves strict logical stages of functionality, but in reality it may overlap or it may be conducted with more iteration. The reverse engineering on geometric modeling will go trough the following steps [7]:

1) data acquisition
2) data processing
3) delimitation and building surfaces
4) CAD model construction

The data acquisition is the most important step of reverse engineering in geometric modeling. This step produces data files containing organized coordinates measured and analyzed, contained bet on surface physical object.

Data preprocessing stage is done by triangulation networks extrapolation from scanned object shape coordinates, using a process called geometric reconstruction.

The second step, of delimitation and building surfaces, also is of a special importance. In essence, in this step, the shape made of triangulation networks of the scanned area, is delimited using various fonts, delimited on different areas, using geometric criteria, each building area being an appropriate area that seeks to replicate the geometry area. Also in this stage, we make the "join" for all surfaces.

The last step is CAD model construction. Construction stage solid geometric CAD model of the scanned object, requires synergy level surface representation that is made in the previous stage with CAD platforms. Also bet on this stage is done the "solidification" of the geometrical model, "virtual" object by considering the volume bounded by the surfaces of the object and the possibility of associating the volume specific mass of material properties considered.

The most important equipment in this step that permits to realize the data acquisition is the 3D scanner.

The result of the 3D scanning is a file that contains, after the 3D scanning process, the point coordinates of the scanned object. The whole point assembly is used to extrapolate the shape of the solid part analyzed, process which is called geometric reconstruction. If we get also color information for every measure or scanned point, then we can reproduce also the colors for the analyzed object.

All this process was done in the laboratories of the Faculty of Engineering of Sibiu, on tibia and femur. An important and original contribution is the 3D reconstruction of the femur and the tibia, using the reverse engineering principles.

To achieve the 3D models of the tibia and the femur, it was needed to have submitted real scanning elements. We used human bones harvested from cadavers. Harvested bone, which we found appropriate, was prepared prior to the scanning. On its surface a mate powder was applied, in order to avoid the light reflection implied by the laser scanning process, and a series of points that allows matching position for its computerized image reconstruction.

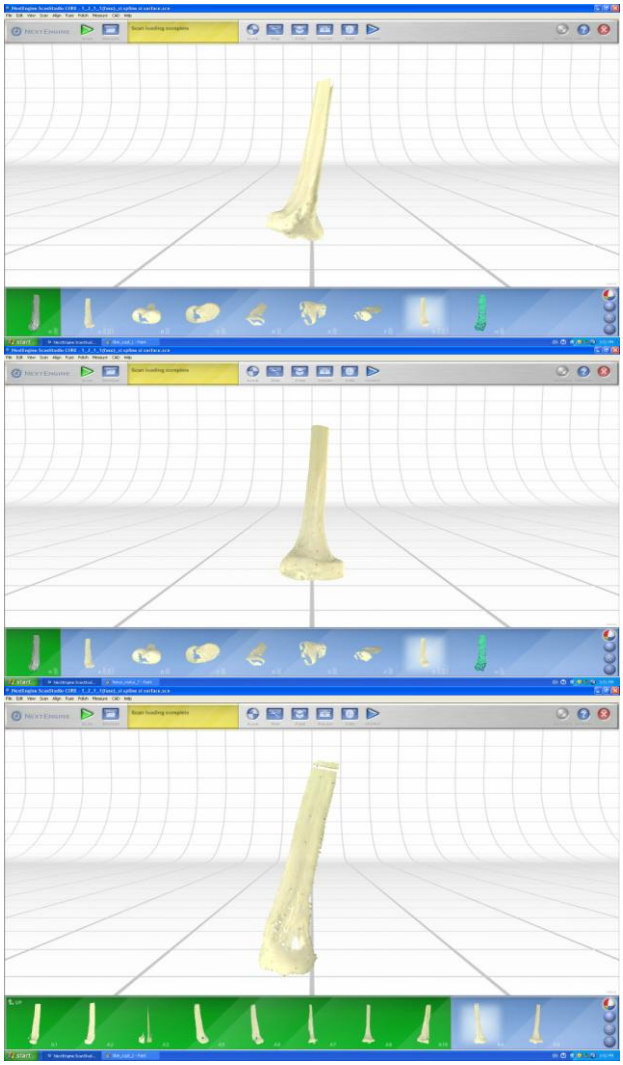

Fig. 1. Pictures of tibia obtained after scanning

The bones were scanned with the NextEngine 3D Scan, which reads the points previously marked on the bone.

Data acquisition was performed using the software package associated. From the scan operation and data acquisition, points that characterize the two bones will result. These files are actually ASCII files and contain spatial coordinates (x, y, z) of the points, in relation to a reference system of the own scanner. Specialized software for image processing allows their views represented in picture 1 (tibia). We can process the raw images obtained with the existing program in the Next Engine scanner, resulting three-dimensional images of the tibia in different positions (Fig. 1.).

As a second step, it is performed a geometric reconstruction of the points, in order to create the surfaces of the bones. Following a specialized algorithm based on the point coordinates, the spline curves, which will actually be the triangulation network that will create spatial surfaces quite accurately, approximates the shape of the outer surface of the bone that will be defined. Models in this phase are stored in files with the extension. STL.

In this phase defects can occur, like intermittently (goals) that should be filled. Using the software's own scanner to do this job, the gaps that appear, will be filled. This procedure is automatic, the only element that should be introduced is the average size of the side facets. Following this initial phase a model quite close to the real model will be obtained (Fig. 2.).

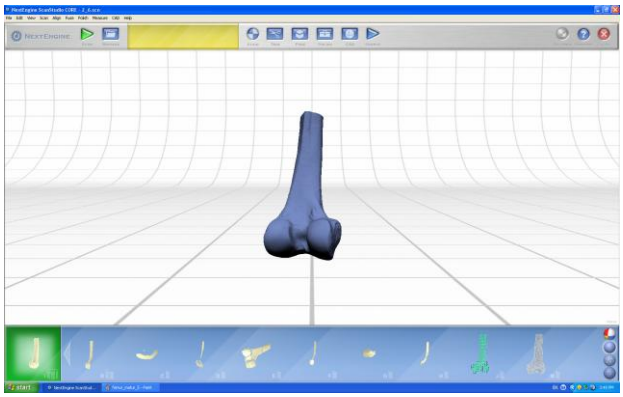

Fig. 2. Femur model scanned

In the construction phase of the surfaces, the initial model obtained is divided into a lot of areas that take into account the variation curves of the real model. The 3D surfaces are Bezier type curves and are generated automatically by the program Studio Core Next Scan Engine. The program allows us to introduce the average number of Bezier surfaces that we want obtained. This number is chosen by repeating successive iterations until it reaches an appropriate level of accuracy. The resulting file is saved in the NextEngine program, with the extension. IGES (Elementary Geometric Surfaces

Interface). Such a graphic file has a very good level of compatibility with CAD programs and can then be exported to any graphic modeling software (Catia, Solid Works, etc.)

In the last stage of the construction of the solid geometric CAD model, the IGS export file is practically realized and afterwards it is loaded into Catia V5R20 software. Also in this phase: the so-called "solidification" of the model, consisting in taking into account the volume defined by the outer surfaces and the association of this volume of mass-specific material characteristics. In the case of the tibia and also of the femur, more part bodies will be created, with several different characteristics that take into account in the actual structure of the bone.

Catia V5R20 models obtained are presented in Fig. 3. and Fig. 4.

Fig. 3. Model of the femur in CatiaV5R20

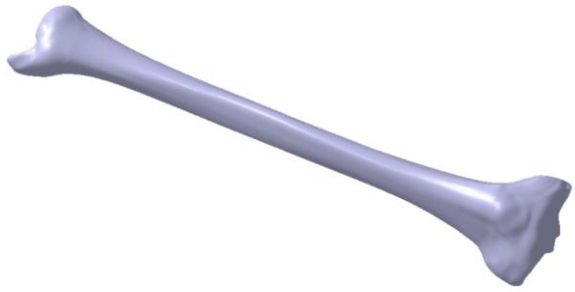

Fig. 4. Model of the tibia in Catia V5R20

B. Reference Geometry Elements

An important aspect is the reciprocal positioning axes that make up the leg bones.

At one leg in anatomical position, we can observe three axes. First axis align joint centers of the hip, knee and ankle, and is determined of three points: the center of the femoral head, center interlining femurotibiale and center interlining astragaliene. This is the mechanical axis of the lower limb [1].

This axis is not vertical, it makes an angle of 3 degrees to the vertical (V) in normal position. Being on balance on only one leg, this angle increases in order to fulfill the necessity to have on the same axis the center of gravity of the body with the one of the foot.

Mechanics axis (Fig. 5.) makes angles of 90 degrees with its extremities, considered as the upper horizontal planes, passing through the center of the femoral head and the tip of the great trocanter (hip orientation line) and the lower is tangent to the dome of the talus (hip orientation line). The angle between this last plane and the mechanics axis, slightly differs from a person to another person, but conventionally is considered to be an 90 degrees angle [3].

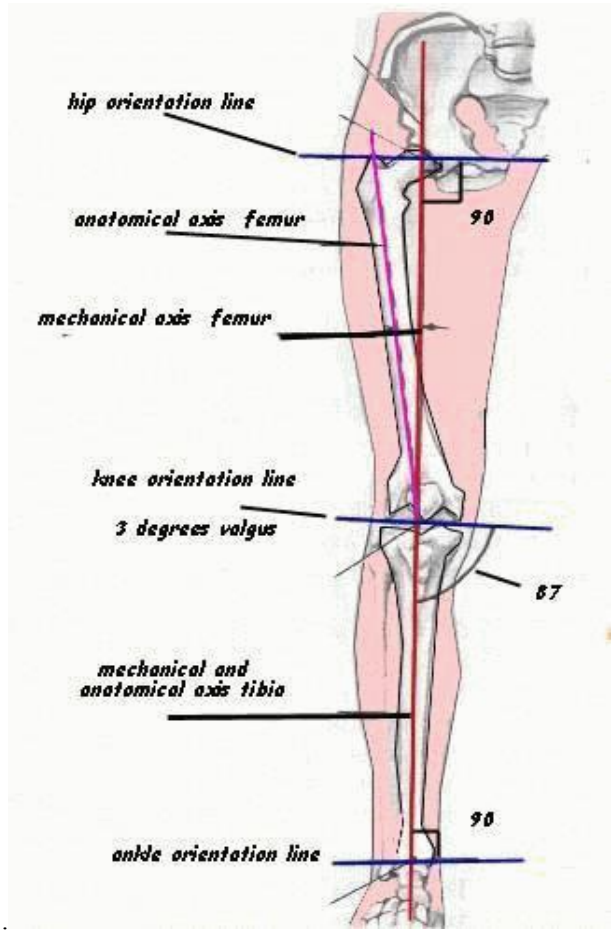

Fig. 5. Foot axis in the frontal plane

Considering the third plane of the knee joint, which is tangent to the two femoral condyles and with the tibial glenoid contact cavities, we find that it has an inclination of 87 degrees of the mechanic axis, resulting in a physiological valgus knee of 3 degrees, toward the mechanic axis [2].

In conclusion, the mechanical axis of the lower limb frontal plane is defined as a line passing through the center of the femoral head and the center of the ankle joint. At an healthy person, this line normally has to cross the center of the knee joint in the frontal plane [4].

The other two axis (Fig. 6.) are anatomical axes femoral axis situated in the long area of the body of the femur and tibia.

Anatomic axis of the tibia coincides with the mechanic axis.

Anatomic axis of the femur starts at the point of intersection between the mechanic axis, and the transverse plane of the knee joint, and goes in the direction of the femur and ends in the area of the great trocanter. The two axes are not aligned, making an angle of 170-175 °.

In the sagital plane, the mechanic axis that passes through the center of gravity of the leg joins a point from the great trocanter, behind the femoral head, because it is "thrown" by 15 ° prior to the femur axis, with another point which is situates at the center of symmetry the ankle [5]. This axis intersects the area of the knee joint, close to the anterior area. (Fig. 6.)

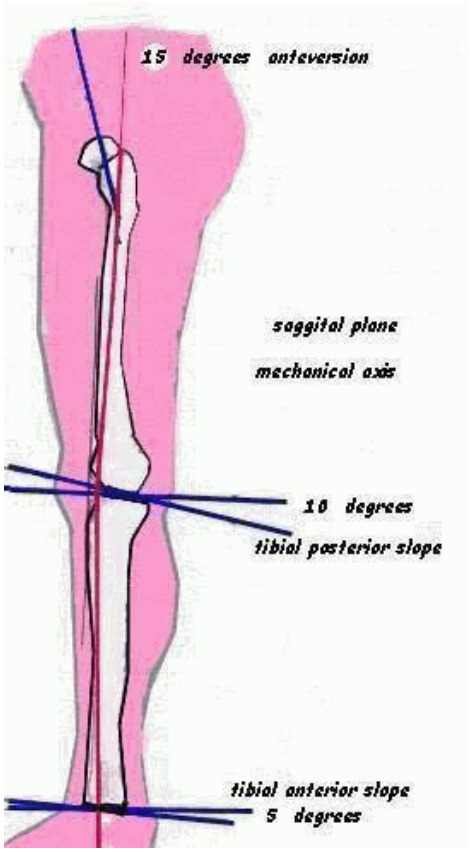

Fig. 6. Foot axis is sagittal plane

It is considered to be a correct position, that bet on practically exists a collinear position between the ankle, knee and hip. A good position is when the central femoral head axis intersects the center of the knee, and a deviation or a bad alignment is when the knee deviates from this axis.

The line orientation of the hip is defined by the center of the femoral head and the top of the great trocanter, and makes an angle of about 90 ° with the mechanical axis of the leg. The guidance line of the ankle is a line that crosses the ankle talus dome (probably tangent in areas II and III as in Fig. 6.). Between this line and the mechanical axis, is also an angle of 90 °.

Medial line is posterior inclined in the knee area, with an angle of 10 °. Anterior cortex of the tibia and the femur are collinear in the sagittal plane with the knee in full extension.

In relation to the reference systems used, it was chosen a primary reference system to which virtually all bones models will be reported. This reference system is triortogonal and it is placed on the ground projection of the center of gravity of the body. In Fig. 7. are shown the corresponding axes of the femur with the corresponding assembly axis.

Also for proper management of assembly and highlight the pathological situations, is inserted Euler triedre in the assembly area, between the tibia and foot dome in the center of the knee joint. Giving different values to the Euler angles, different positions of the bones in the assembly are obtained.

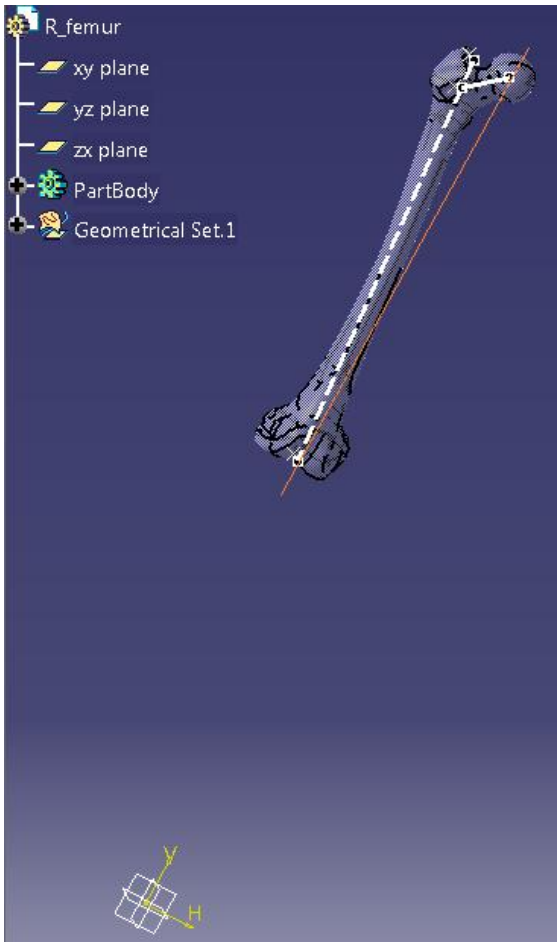

Fig. 7. Femur axis

C. Axial Deviation of the Lower Limb

Mechanical axis deviation bet on the legs, presents a particular interest in orthopedic practice, both in pediatrics and in adults medicine, so studying these deviations and their measurement methods are very important.

There are two main sources of misalignment. A first source is due to the structural elements of bone that

undergoes changes in shape, due to aging. The most important are the cartilage wear, causing gonarthroses, with axial assembly deviation, without a change in bones shape [6].

Next we propose a study of these deviations by creating dedicated computer applications.

Assembling the leg bones was performed in Catia V5R20, Assembly design module.

After creating 3D models of the bones, in which were defined the axes and planes that needed for the assembly [8]: mechanical axis of the tibia, femur mechanical axis planes contact between the tibia and femur, meniscus, femur, tibia-meniscus, was performed the assembly.

In Fig. 8. it is the image of the tibia in which it was defined the mechanical axis and the contact plane between the tibia and meniscus.

The contact plane between femur and tibia was defined in accordance to the theory presented in the first chapter.

Also, to achieve the bone geometry, the body planes were also considered.

As we have the leg bone geometry, we proceeded to assemble the bones.

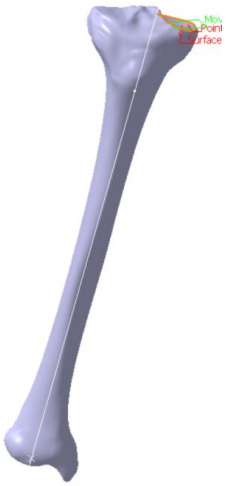

Fig. 8. Tibial mechanical axis representation

For the beginning, we considered two triortogonal axis systems, which we called "Skeleton tibia-femur" and "Skeleton tibia-foot." We used this axis system for the bones assembly. It was considered Z axis mechanical axis, YOZ plan accordingly the foreground plane of the human body, the XOZ sagittal plane of the body plan. The XOY plane in "Skeleton tibia-femur" will correspond to the contact plane between the tibia and the femur, respectively "Skeleton tibia-foot" which will correspond the plan contact of the tibia and foot. In Fig. 9 we can see the tibia after the two “Skeleton” assembly.

This axis system was defined as a system of axes Euler , angles that can change the grid, in the desire to analyze different situations of the position of the tibia.

Assembly constraints applied were:

1) Skeleton was fixed;

2) coincidence between the mechanical axis and the 'skeleton'Z axis;

3) coincidence between the planes of contact and corresponding planes;

4) plane-parallelism between human body plane and corresponding plan of the "skeleton".

Fig. 9. Tibia after two "Skeleton” assembly

In Fig. 10. is the image of the leg bones assembly.

Fig. 10. Leg bones assembly

D. Situation that may reside the Leg Bones

One of the situations the leg bones can be, is presented in Fig. 11. The “Skeleton” of the tibia-foot leg is rotated with 10 degrees.

In Fig. 12. is the image of the ”Skeleton” tibia-femur rotated with 10 degrees.

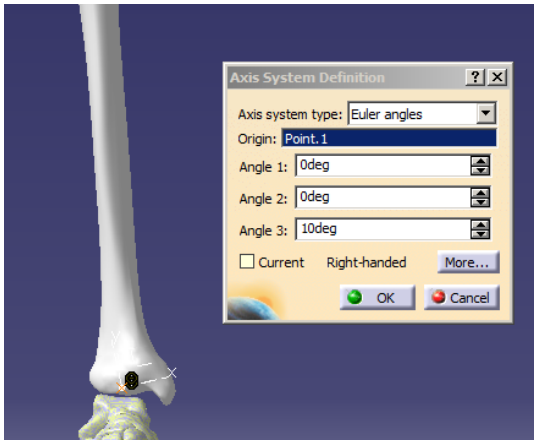

Fig. 11. "Skeleton " tibia-foot leg rotated with 10 degrees

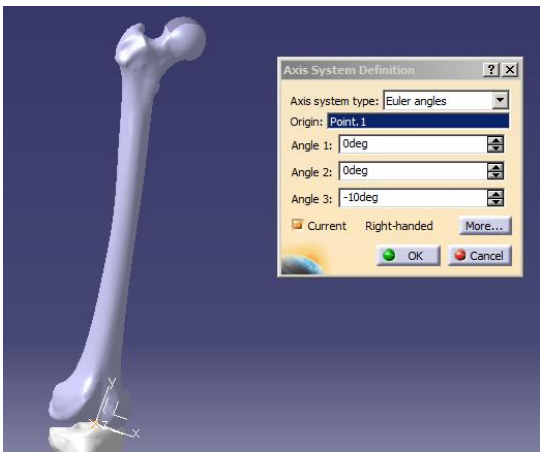

Fig. 12. "Skeleton" tibia-femur rotated with 10 degrees

By this "Skeleton" systems, described in this paper, we can create an assisted biomechanical system, which can study a wide variety of existing diseases of the lower limbs.

For example, if we consider only the frontal plane misalignment of the leg (perfect achievable by changing the angles of the "Skeleton"), we can simulate, evaluate and verify the knee pathological situations, such as:

1) genu varum
2) genu valgum
3) dislocations
4) osteoarthrits
5) establishing responsibilities for misalignment on the tibia, femur, or both of them, on geometrical criteria
6) establishing treatment strategies depending on the angles of simulated elements, elements of great importance both in terms of preoperative and teaching
7) possible checks of deformations and and tension over a situation resulting in the assembly (editing Euler angles).We can establish how can we modify the geometric values.

III. CONCLUSION

This study treats the general problems of modeling and assembly in the lower leg biomechanics bones.

Creating the CAD system is very important because it can be used to study the osteoarticular system, treatment strategies and related surgery.

For modeling human foot bone a 3D scan reconstruction was made, applying known stages: data acquisition, data preprocessing, delimitation of effective construction and building surfaces and geometric CAD model.

After the scanning procedures, it resulted a CAD model in Catia V5R20, software that offers more superior possibilities for processing the information. Another important element is the incorporation of geometric and dimensional references. These are points axes important planes, trieders and Euler angles, that are necessary for modeling and assembling.

Foot bones assembly was done for healthy subjects and also for pathological situations. A 3D system, on which different pathological situations can be simulated, was realized.

Given that there are two knee planes (sagital and transverse) with birth and wear and in that way was made the assembly, allows all these approaches and other joints of the foot (ankle and hip), it results the complexity of the system and justify the implementation assembly in the manner shown.

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