HUNGARIAN UNIVERSITY OF AGRICULTURE

AND LIFE SCIENCES

IMPROVEMENT OF KNEE PROSTHESIS GEOMETRY

TÉRDPROTÈZIS GEOMETRIA JAVÍTÁSA

PhD Thesis

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DOI: 10.54598/002110

Gödöllő
2022

Doctoral school

Denomination: Mechanical Engineering PhD School

Science: Biomechanical Engineering Sciences

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CONTENTS

1. INTRODUCTION AND OBJECTIVES

In this chapter, the importance of the research topic is presented along with this research's objectives.

1.1. Introduction

The knee joint is the largest joint in the human body and the joints most commonly affected by arthritis. Fig1.1.The knee joint is a hinge joint, meaning it allows the leg to extend and bend back and forth with a minimal side-to-side motion. It is comprised of bones, cartilage, ligaments, tendons, and other tissues. (Olinski et al., 2016). The human knee is a complex joint located between the leg and the thigh, below the body's center of gravity. It is often considered an organ of biological transmission comparable to a torque converter (Mesfar, 2005). In this context, mechanically, the articular surfaces are considered to support bearings. The muscles are the system's motor or brake organs, and the ligaments provide the link for transmission. The literature includes a multitude of research studies interested in studying the human knee joint. This work covers several aspects, such as the functioning, diagnosis, prevention and treatment of injuries. Their goal is to understand the biomechanics of the joint, predict potentially harmful loads and prescribe rehabilitation techniques. Just like experimental studies, numerical studies help in the prevention of injury and degeneration. In addition, an appropriately developed EF model is a powerful tool to predict the effects of the different parameters involved and provide information complex to obtain from experience. 3D planning of your total knee prosthesis: The new technology allows an ideal preparation and positioning of your knee prosthesis. Traditionally, preoperative planning is based on x-rays to determine the size and positioning of your prosthesis, Optimizing its implementation using 3-dimensional planning by computer and imaging—realization of tailor-made, personalized instruments. The new technology allows an ideal preparation and positioning of your knee prosthesis. Traditionally, preoperative planning has been based on x-rays to determine the size and positioning of your prosthetic knee. These x-rays give a two-dimensional image. The new technology uses MRI or CT scans of your knee to develop specific and unique instruments. These images are three-dimensional and, therefore, exact. The new technology allows the doctor to do a complete preoperative assessment and be more precise in the placement of your prosthesis. This technique also reduces bleeding, the duration of the operation and therefore the risk of intraoperative complications Fig. 1.1.

The human knee joint usually suffers progressive deterioration with time. The conventional cure of this issue is to replace it with an alternate knee by applying the prosthesis implant. The reason is that the process causes the abrasion of the different materials rather than just sliding or rolling. This study aims to develop the numerical measurement of the knee prosthesis's geometry, which fulfils the mechanical requirements of the human knee. The MSC.ADAMS programme was applied to demonstrate the movement of the human knee joint in terms of rotation and flexion. The changes between the condyles of the developed Multibody of the prosthesis related to the flexion angle ranging from 20–120◦ were investigated and presented. The boundary conditions were determined, and simulations performed using the ADAM's programme. An average value of 0.7 was reached for the slip ration, with the maximum getting up to 0.79. An angle between 110–120◦ for the flexion angle was obtained. It can be said that the application of the Multibody model saves

Time as there is no involvement of the tibia and the femur as required for the knee prosthesis. More importantly, as the application of the test machine is omitted in our process, our model's approximations to a human knee are carried out directly. Without cost, several measurements for the knee prosthesis could be made and repaired. The study results provide the necessary insight for future tests regarding the movement of the knee joint.

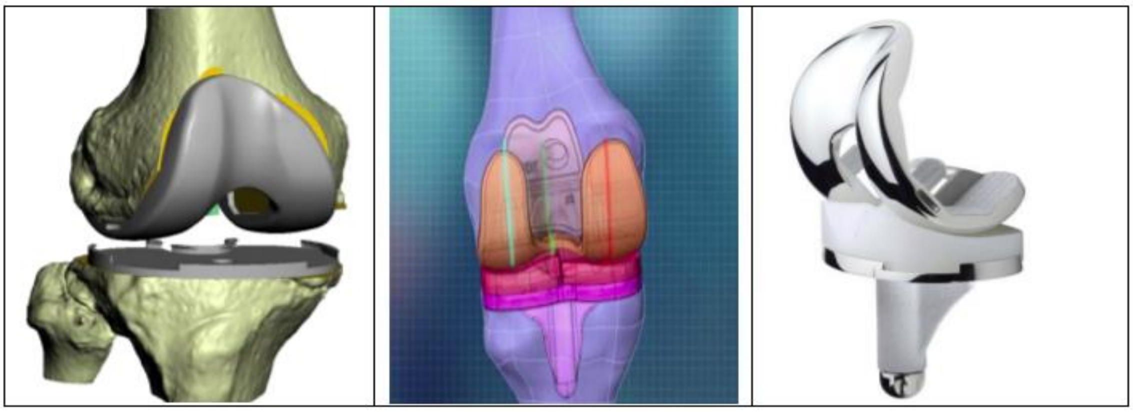


Fig 1.1: Knee prosthesis geometry

1.2. Research objectives

In this research, we will develop the numerical measurement of the knee prosthesis geometry, which fulfils the human knee's requirements mechanically. The objectives of this research can be described as follow:

- To create the new multibody model of the knee prosthesis geometry by using MSC.ADAMS program, within that model to develop the numerical measurement of the knee prosthesis geometry.
- To develop the kinematic motion of the multibody model for the knee prosthesis geometry and this part of the study will be making rotation for Multibody model like Balassa did that with his test machine at MATE university, and we will did the same study to compare our model with his results, with new method with fast result and lower cost.
- To develop the new geometry of the knee prosthesis to reach good results that it can be close to the range the normal human knee motion and will be that great results to reach it.

2. Material and methods

2.1. Femur

The femur is the longest bone in the body, and it alone constitutes the skeleton of the thigh. Extends from the hip to the knee. It presents an oblique direction towards the interior since the distance between the hips is more significant than between the knees. To partially compensate for the approach of the two femurs to the body axis, the tibias separate. The knee thus acquires the appearance of an angular joint outwards in the valgus. (Fig. 2.1).

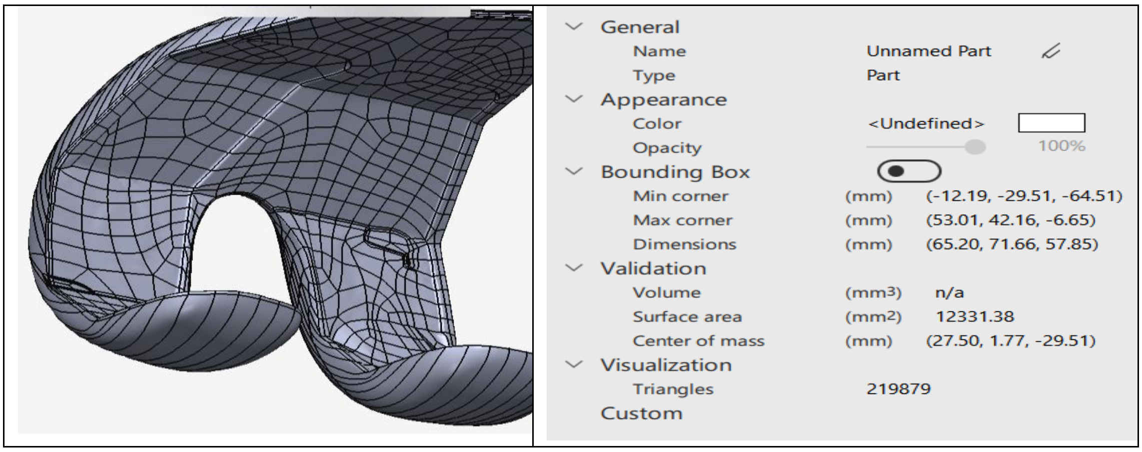


Fig. 2.1 Femur structure in Solidworks.

2.2. Patella

It is a flattened bone, rounded in appearance, or even oval, which extends downwards through its apex or the lower pole. It has two areas (Fig. 2.2):

- Anterior face, convex, which serves as a reflection pulley for the quadriceps and patellar tendons.
- Posterior surface. Oriented towards the joint's interior, it has two facets, internal and external, which contact the corresponding femoral condyles, adapting its concave shape to the convexity of the condyles.

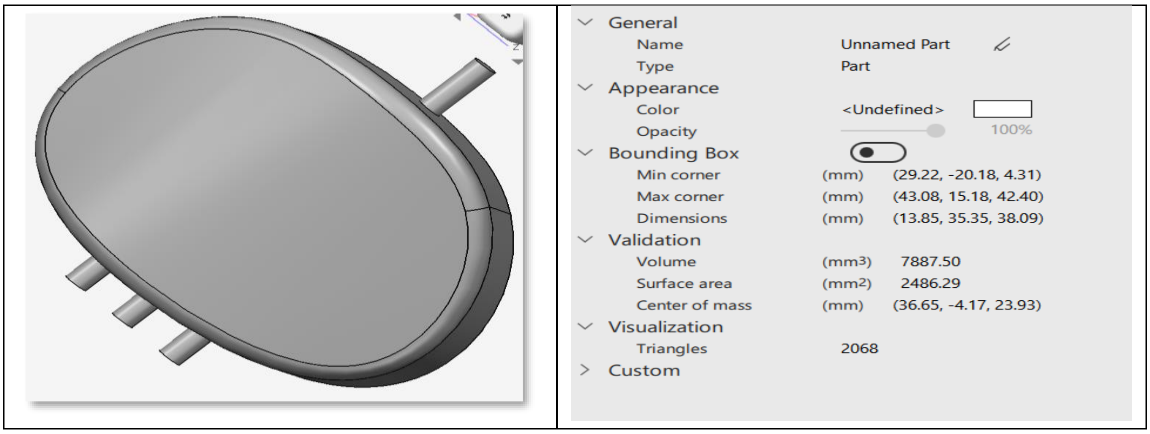


Fig.2.2 Patella structure in Solidworks.

2.3. Tibia

The tibia presents a flat surface that cannot receive the convexity of the condyles of the femur without the menisci which ensure articular congruence. These menisci provide stability and absorb the axial and rotational mechanical stresses of the knee. Together with the fibula, the tibia forms the skeleton of the leg. It supports the body weight and transmits the lines of force from the ankle to the knee.

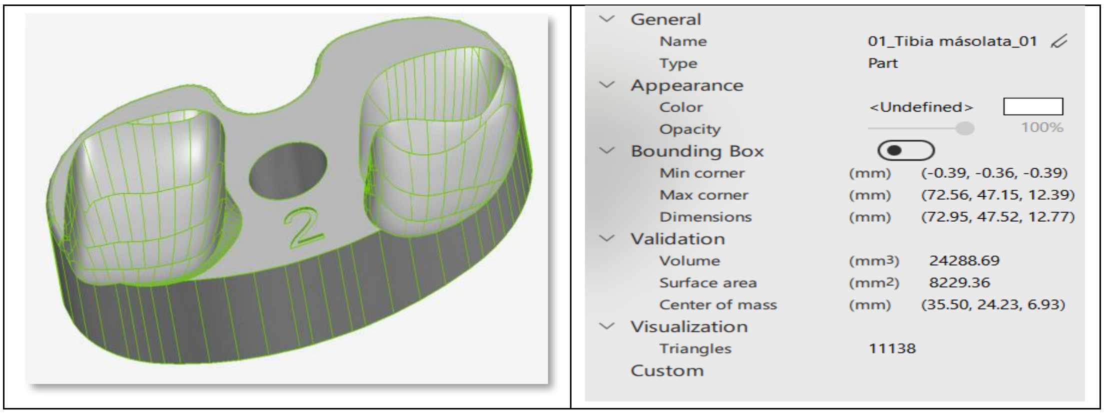


Fig 2.3. Tibia structure in Solidworks.

2.4. The movements of the knee

They are expressed above all in the profile plane (sagittal): flexion-extension, the amplitude of which goes from 0 to 140° of flexion. In extension, however, very flexible subjects called hyper axes can exceed 0° and go up to 15° of hyperextension, another movement is possible: rotation. The tibia can rotate on its axis by 30 to 60° in external rotation (mostly) and in internal rotation but only when the knee is in flexion.

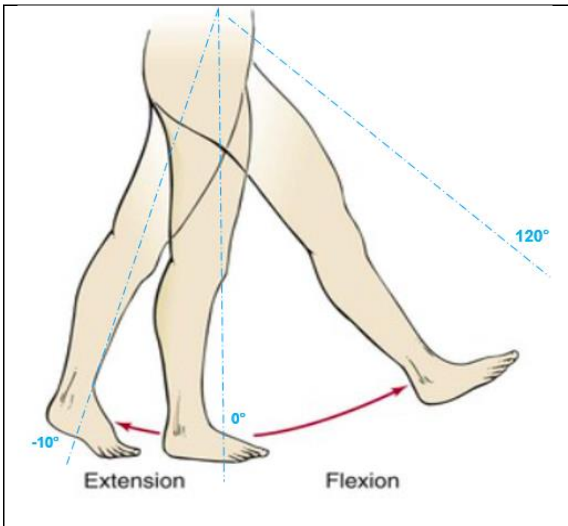


Fig 2.4 Flexion movements from 0° to 120°

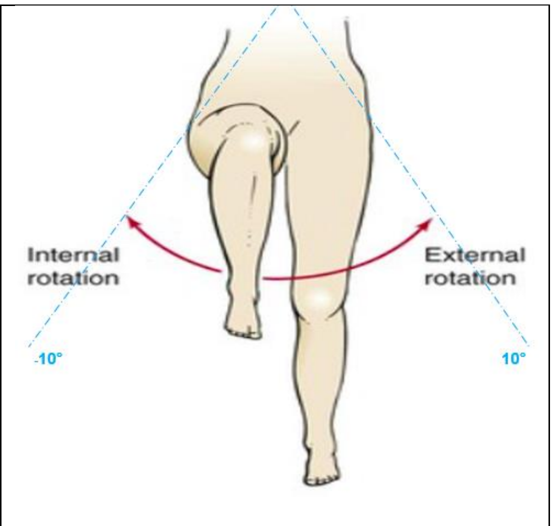


Fig 2.5 Rotation of the knee between -10° to 10°

2.4.1 Knee flexion

It requires the instantaneous combination of two movements: sliding rolling. Flexion causes the condyles to roll on the tibial plateau. However, the unfolding of the condyles is twice as long as that of the tibial plateaus. The succession of events takes place in several phases: rolling from 10 to 15° of flexion then association of sliding with rolling then at the end of the flexion only the sliding makes it possible to achieve the last degrees of flexion in thin and flexible people (140 to 160 °).

2.4.2 Knee rotation

When the knee is flexed the posterior part of the condyles is in contact with the middle portion of the glenoid. The massif of thorns is cleared of the indentation and therefore unblocked. The rotation causes one condyle to advance and the other to retreat on the tibial glenoid.

2.5. Ligaments (springs)

We create the springs between the femur and tibia by using the part of patella to replace the ligaments in the normal knee, so we add springs to fix the patella at the middle between the femur and tibia.

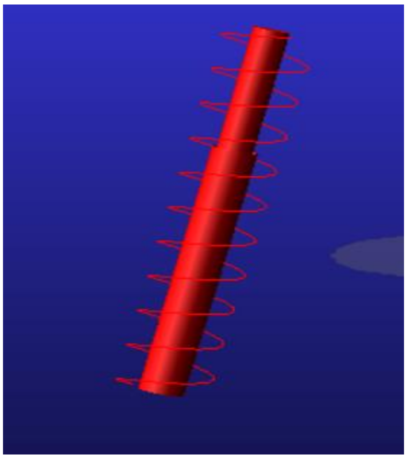


Fig.2.6 Spring in ADAMS program

2.6. Machines

2.6.1. Machine for measurement of the knee prosthesis

The test machine for measuring the prosthesis was created by the Biomechanical Research Group of MATE University (designed by Gabor Balassa). With this machine (Fig 2.7), they made many different prosthesis sizes by using the 3D model of knee prosthesis. The developed prosthesis model was produced by CNC milling technology.

The test machine is multipurpose, making it ideal for evaluating the knee pros-theses. Its suitability for different types of loads is also significant.

Unfortunately, in using the method of machine milling with 3D printing, designing and developing the knee prosthesis is time-consuming, and a high cost is incurred. Furthermore, since it is a try and error method, and there is no predefined procedure, a significant quantity of knee prosthesis model material will be lost with these measurements.

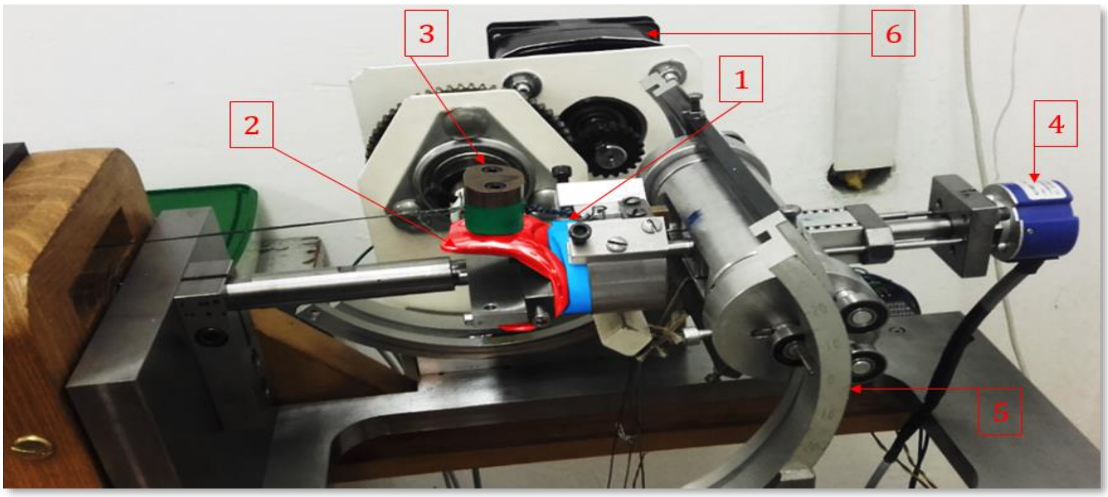


Fig 2.7. Machine for measurement of the knee prosthesis

1: Tibia, 2: Femur, 3: Patella, 4: Rotation sensor, 5: T-section guide track (-10 ° -+ 120 ° flexion range), 6: Stepper motor and gear transmission.

2.6.2. A graph of Rotation against Flexion for the prosthesis developed with a test machine.

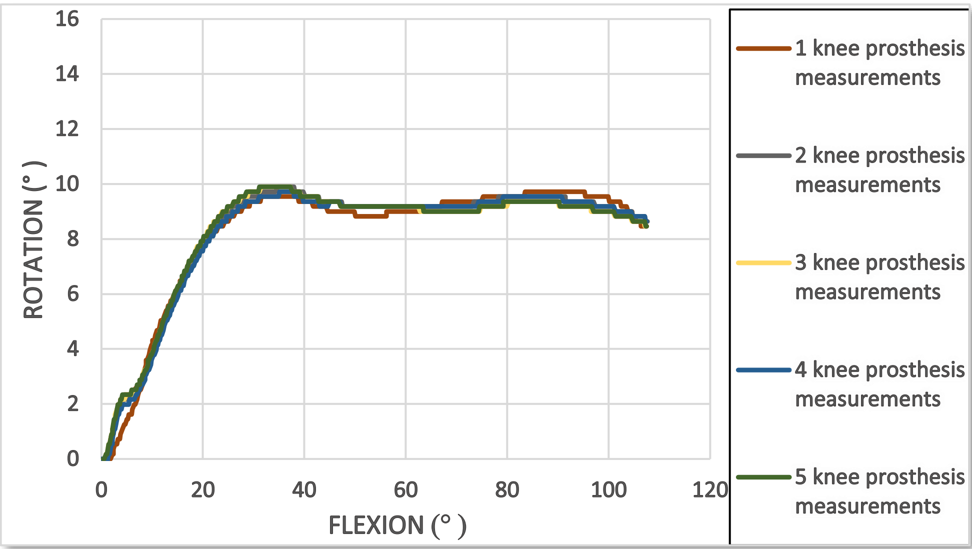


Fig 2.8 A graph of rotation against Flexion for the knee prosthesis was designed by Balassa and tested with their machine compared with the regular movement of the human knee (Balassa, 2019).

These diagrams present a measurement of the test machine for the knee prosthesis geometry movements, and it is a good method, but unfortunately with this method, we will lose our time and money for creating the models and try it at the machine, that way we will replace this method with the new method by using a new virtual model method. Without losing money and time we can make the measurement of the knee prosthesis geometry and the results better than the test machine.

2.7. ADAMS Program

Adams is the most widely used multibody dynamics and motion analysis software in the world. Adams helps engineers study the dynamics of moving parts, how loads and forces are distributed throughout mechanical systems, and improve and optimize their products' performance (Hroncová et al., 2014). Utilizing multibody dynamics solution technology, Adams runs nonlinear dynamics in a fraction of the time required by FEA (Finite Element Analysis) solutions. In addition, loads and forces computed by Adams simulations improve the accuracy of FEA by providing a better assessment of how they vary throughout a full range of motion and operating environments. We used the MSC. Adams software environment to create a model (Fig. 4.1) for modelling and error analysis of the gear transmission mechanism. The model consists of solid bodies, the shaft is modelled by a geometric element "femur" "tibia" "patella" "springs" and the spur gearing is imported from the 3D parametric modelling software.

2.8. The Virtual Multibody Model

The virtual multibody model was created by applying the following procedures

- The general point motion was used to stabilize the distal femur, where all the coordinates are shown (Fig 2.10). This enables the distal femur to make a transitional movement along the y-axis.
- The cylindrical joint model was used to restrict the knee part to allow rotation around all axes (Fig 2.10). This enables the shin bone to conduct a natural rotation.
- We only considered the patellar tendon and the rectus femur in the numerical-kinematical model. Therefore, we create both of them as simple linear springs, as shown in (Fig 2.10).
- According to the literature, the rectal femoral stiffness modulus was determined between 25 and 100 N/mm, according to the literature (Frigo et al., 2010; Thelen et al., 2005). As an average value, we set it to 80 N/mm. With the stabilization factor set at 0.15 Ns/mm, for all the strings to prevent oscillations in the system, the patellar tendon was set to inextensible (Fig 2.10).
- According to Coulomb's law, contact restrictions are established concerning static and low dynamic friction coefficient ($\mu s = 0.1$ $\mu d = 0.085$) between the femur, tibia and patella, similarly to real joints (Fig 2.10). The kinetic relationship between systemic forces, frictional forces (Fn, Fs), and flexion angle is analyzed using this constraint.

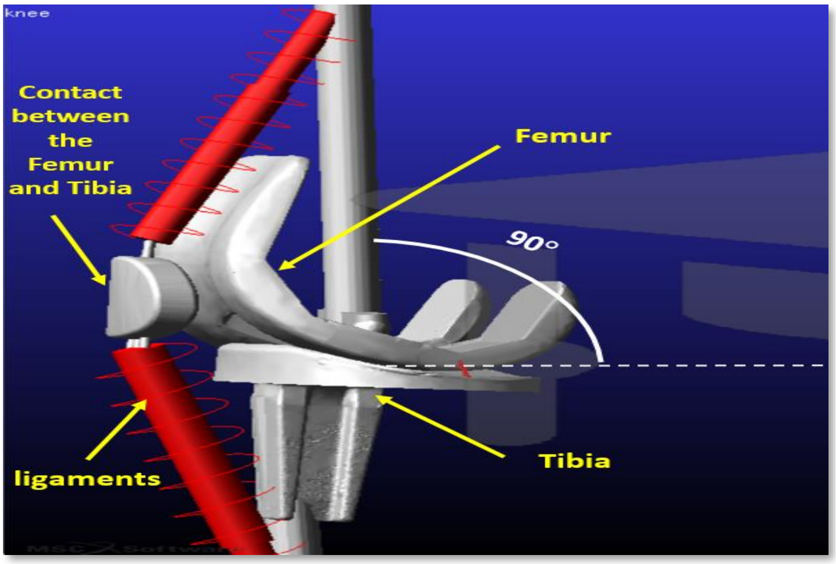


Fig 2.10. Our Multibody model in the MSC.ADAMS.

2.9. Boundary conditions for the simulation

After the geometrical model is obtained, the MSC.ADAMS program was used to build the multibody model. But, first, the following boundary conditions were applied to our model (prosthesis geometry):

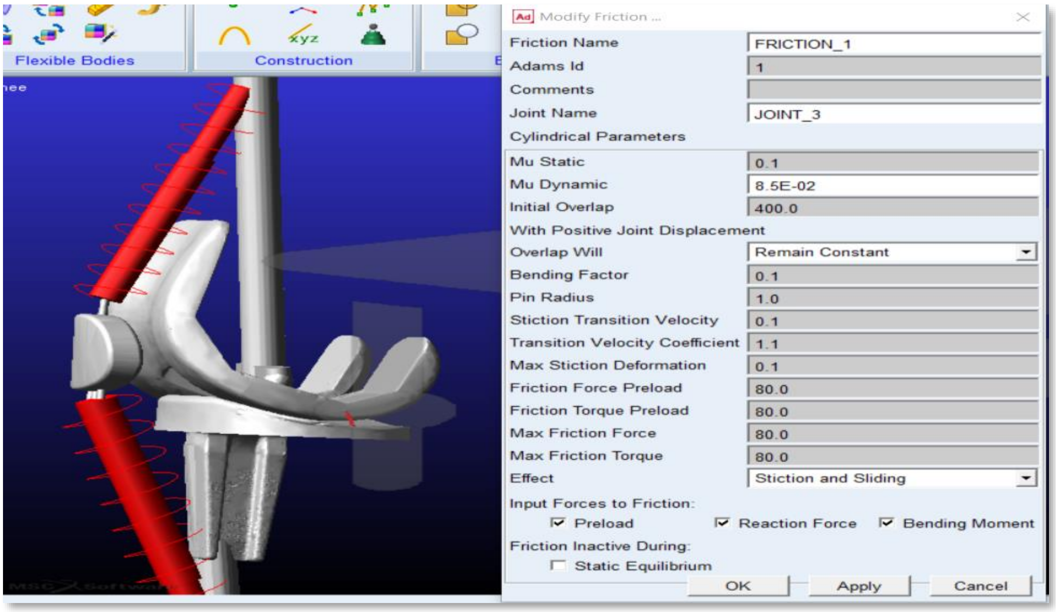


Fig 2.18. Parameters for friction Multibody model

2.10. Block diagram showing the applied steps of the multibody virtual model created in the ADAMS software.

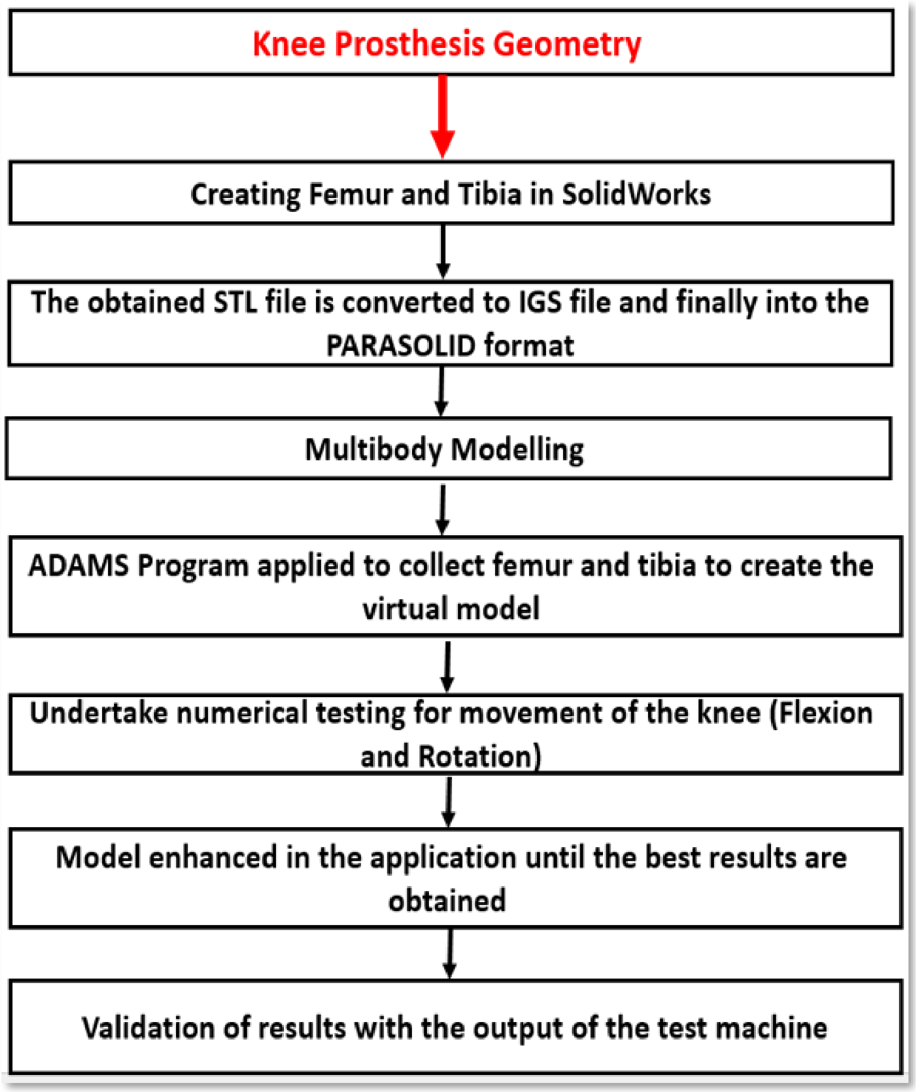


Fig 2.19. Block diagram showing the applied s

3. RESULTS And Discussion

This section presents the results and the accompanying discussions for the study

3.1. The Virtual Multibody M1

The ADAMS programme could compute the forces directly. At first, we saved it as PARASOLID, and we imported it into the MSC.ADAMS. The flexion angle was derived by combining the femur and tibia's angular velocities about the x-axis. This was done considering that the model was at 20° for the sliding and rolling at the start of the movement. The angles were divided into three to tackle the three-dimensional movement. The results are summarized in Fig. 3.1.

To be able to describe all the coordinates, we have restricted the distal femur by the general point motion, as shown in Fig 3.1. The knee model was restricted by a cylindrical joint, which allows the flexion process between a femur and tibia. Simple linear springs are designed as the boundary between the rectus femur and the patellar tendon as in (Frigo et al., 2010; Thelen et al., 2005).

According to Coulomb's law, the contact limitations between the femur and the patella tibia are established for low static and dynamic friction coefficients ($\mu s = 0.1$ $\mu d = 0.085$), similar to human joints (Merkher et al., 2006). On the femur distal, a force vector was created, as shown in Figure.3.1, and the value is set at 400 N. Whiles define it by a step function (A, x0, h0, x1, h1).

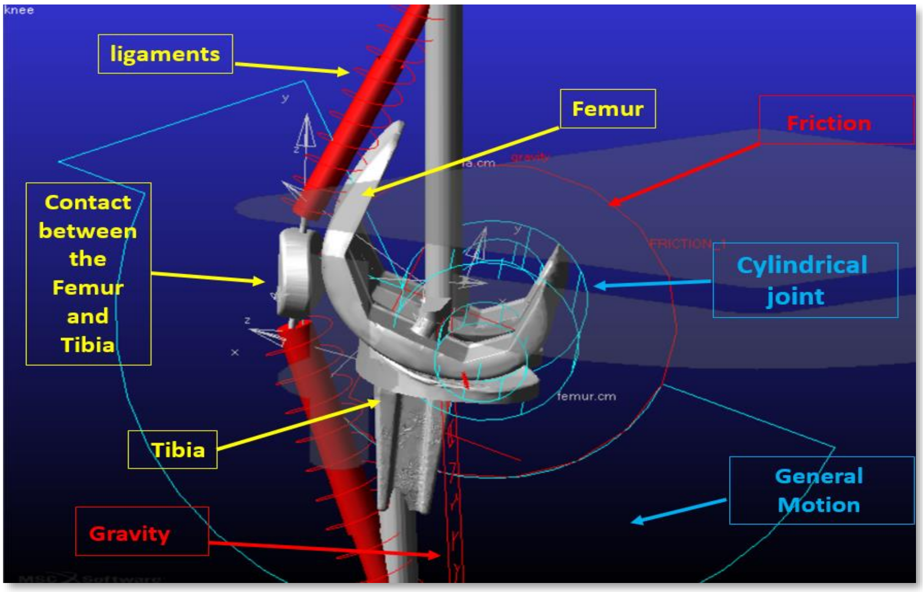


Fig 3.1. Our Multibody M1 in the MSC.ADAMS.

3.1.1. Simulation of the multibody M1 in different range of rotation

The pictorial representations of the model at the angles of 0° and 100° of Flexion are shown in Figs 3.6 and 3.3. The relationship between the angles of rotation and flexion is illustrated in Fig 3.4. It is observed that the sudden increase in the rotational angle was offset by an increase in the angle of curvature. A sharp rise in the flexion angle till 35º was seen beyond the rotational angle of 20º, which indicates the onset of sliding between the tibia and the femur in the knee. Similarly, the flexion angle in the range of 20°-30˚ originates the joint prone to rolling. In contrast, the rotational angle's stability for the flexion angle lies in the range of 30° to 110°. The increasing flexion angle indicates that the tendency of sliding is predominant.

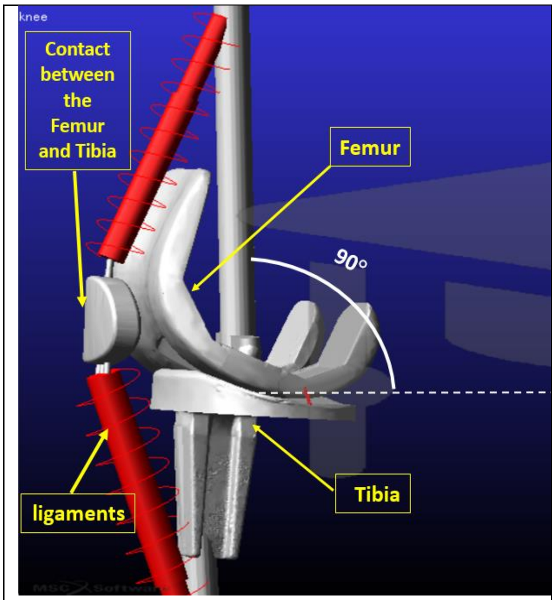


Fig 3.2: Multibody M1 at the position 0°.

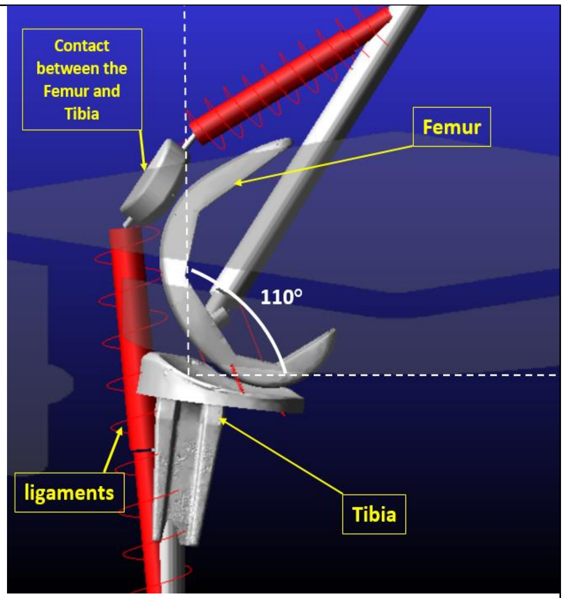


Fig 3.3: Multibody M1 at the position 100°.

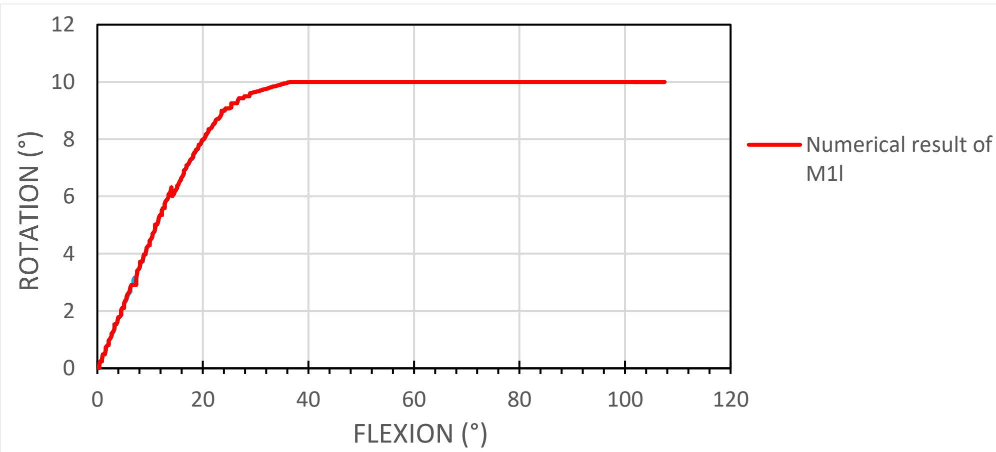


Fig 3.4. A graph of rotation against flexion of our virtual M1.

3.1.2. Experimental measurement result for test machine of The Hungarian University of Agriculture Engineering and Life Science.

The result shown in Fig 3.4 is essential as it is the bases for our numerical experimentation. The Hungarian University of Agriculture Engineering and Life Science research team developed several pros-thesis design methods initiated by (Balassa, 2019) by using the test machine they developed, as shown in Fig 2.7. It was mentioned by (Balassa, 2019) that the presented results (Figs 2.8) in his study was actually the best with respect to the closeness to the natural knee movement.

3.1.3.. Comparing the results of the current study of the numerical measurement method and the experimental measurement result for the Hungarian University of Agriculture Engineering and Life Science test machine.

In order to validate the results from the numerical studies, we compared our virtual numerical model with the prostheses joints that have been tested using with the test machine in the Hungarian University of agriculture engineering and life science. The average values are plotted together against the virtual numerical model, as shown in Fig 3.5. The close similarity between the two curves indicates that this virtual model can replace the measurement by the test machine of the Hungarian University of Agriculture Engineering and Life Science. It was also found that there was a rise in the angle of rotation as the flexion angle varied from 0° to 30°. Thus, a good agreement of value obtained from our model with other prosthetic joints is established in the flexion range of 30° to 110°. We noticed there are the close results between the proposed model and other prostheses. In this case, we were able to create a new model that enables us to make multiple measurements of a new model. As a result, we can change the materials made of artificial joints, more accessible, and obtain faster results without many calculations.

Table 1. Comparison between the virtual model procedure and the test machine.

Virtual model	**Test machine**
It saves time and material	Time-consuming and involves wastage of material.
It saves money because it is objectively focused	High cost incurred because it is a procedure of try and error
The Lack of transition in flection and rotation is used to simplify the geometry and diversity in motion, allowing our new virtual model to be more realistic.	This process cannot be applied with a test machine hence the inefficiency of the procedure.

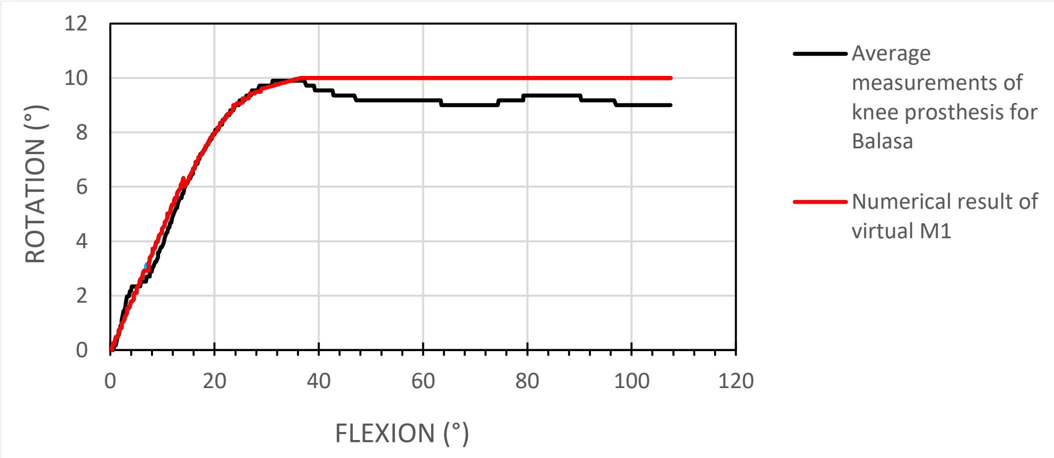


Fig 3.5. Verification results of our virtual M1 with the prosthesis developed with a test machine.

3.2. The Virtual Multibody M2

In this part of study we change the geometry of the model M1 with new geometry to create new model M2, so we change the cylindrical joint with spherical joint, trying to get deferent results maybe it will be better.

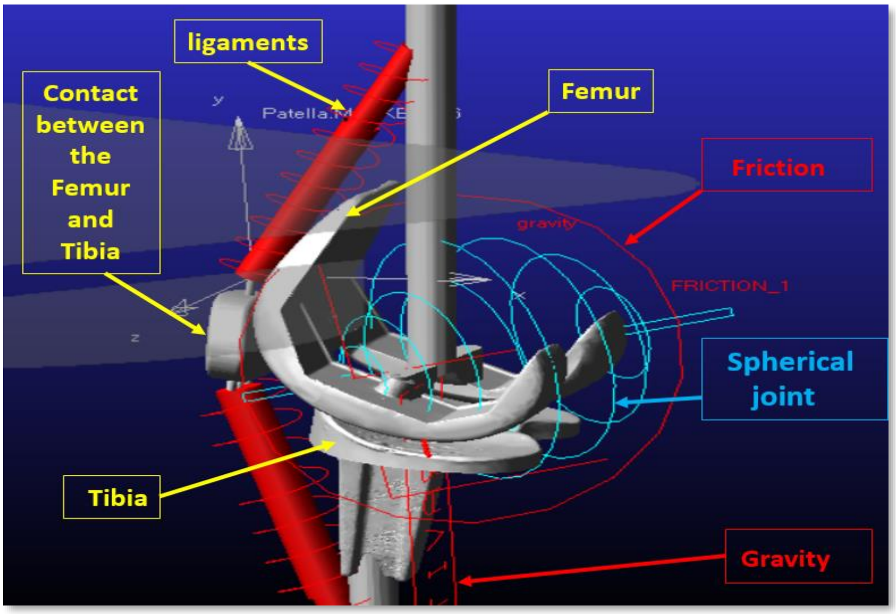


Fig 3.6. Our multibody M2 in the MSC.ADAMS.

After simulated model (M2) is shown in Fig 3.6. The graph of rotation against flexion is illustrated in Fig. 3.7. It was noticed that the angle of rotation varies linearly with respect to the flexion. It was observed that the sudden increase in the rotational angle was offset by an increase in the angle of curvature. A sharp rise in the flexion angle till

120º was seen beyond the rotational angle of 9º. The maximum elevation of flexion against the angle of rotation was found to be 120°.

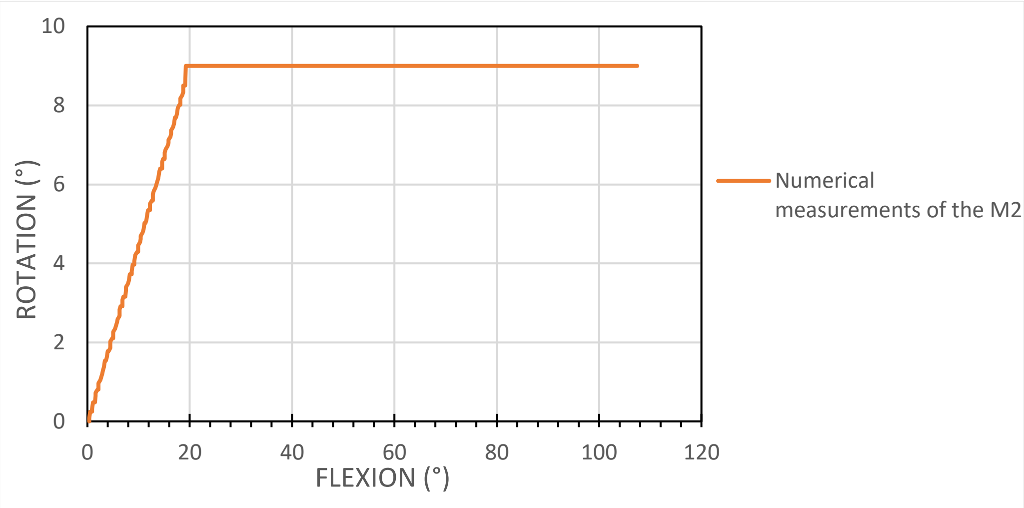


Fig 3.7. A graph of rotation against flexion of our virtual M2.

In order to validate the results from the numerical studies, we compared our virtual numerical model (M2) with the prostheses joints that have been tested using with the test machine in the Hungarian University of agriculture engineering and life science. The average values are plotted together against the virtual numerical model, as shown in Fig 3.8. The close similarity between the two curves indicates that this virtual model can replace the measurement by the test machine of the Hungarian University of Agriculture Engineering and Life Science.

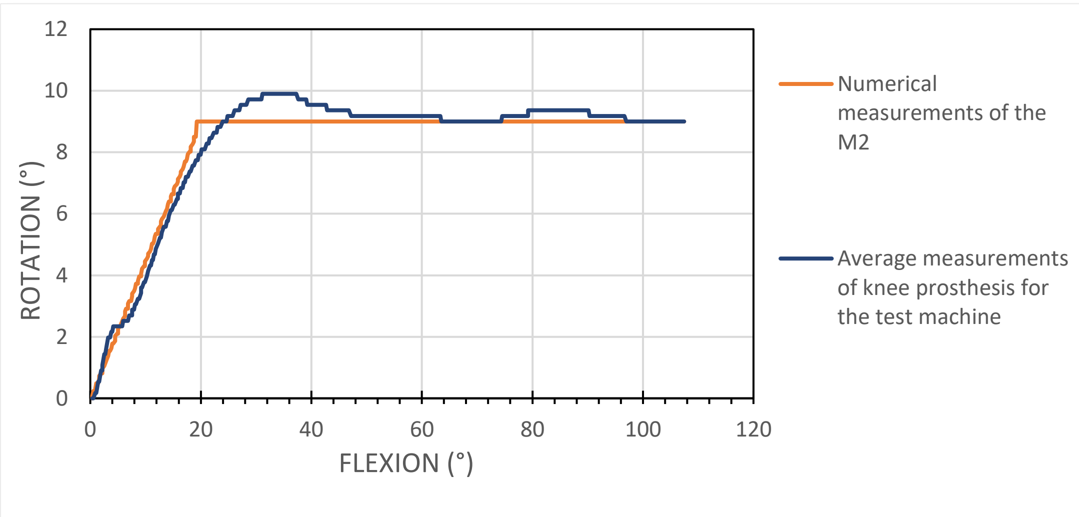


Fig 3.8. Verification results of our virtual M2 with the prosthesis developed with a test machine.

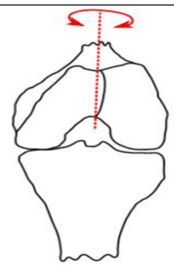
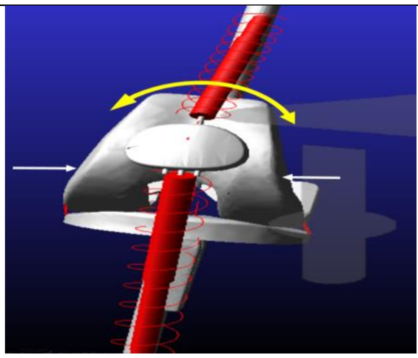
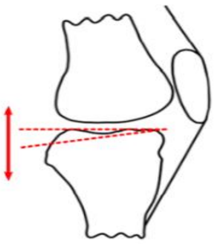
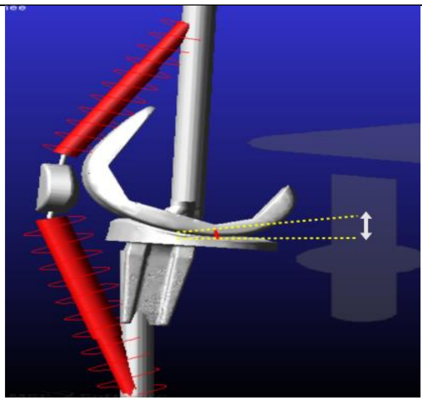
Table2: Comparing between the cylindrical joint and spherical joint

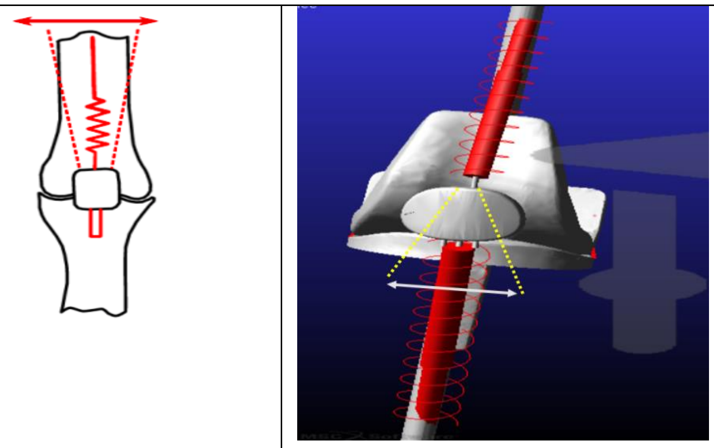
	Error rate comparing with measurement of the knee prosthesis for test machine (Balassa)
Using cylindrical joint	7,2%
Using spherical joint	5,57%

As we can see the different between the joints (geometry of the model) results and the measurements of the knee prosthesis for the test machine, that show us the best joint can give us the less error rate to be more close to the test machine in this study.so we will say that the best joint to make the best version of the multibody model it is spherical joint.

3.3 Developing the kinematic motion of Multibody model M2 for the knee prosthesis geometry

ADAMS Software is the most widely used multibody dynamics and motion analysis software in the world. Adams helps engineers study the dynamics of moving parts, how loads and forces are distributed throughout mechanical systems, and improve and optimize their products' performance (Fig 3.9).

		**Femur** [0° ↔ 5°] **Tibia** [0°] **Quadriceps** [0° ↔ 10°]
		**Femur** [0°] **Tibia** [0° ↔ 10°] **Quadriceps** [0° ↔ 10°]



Femur [0°]

Tibia [0°]

Quadriceps [0° ↔ 10°]

Fig 3.9 This diagram shows the specific movement measurements of our model, for the rotation degree of the femur and tibia and quadriceps.

Table 3 Errors of the multibody model at different positions.

Position	Position of the model	Error Δ	
1	-Femur curse =5° -Tibia Leans Back = 0° -Quadriceps = 10°	12,48%	Good
2	-Femur curse = 5° -Tibia Leans Back = 10° -Quadriceps = 3°	6,09%	Good
3	-Femur curse = 5° -Tibia Leans Back = 10° -Quadriceps = 7°	8,23%	Good
4	-Femur curse = 0° -Tibia Leans Back = 0° -Quadriceps = 3°	16,66%	Acceptable
5	-Femur curse = 0° -Tibia Leans Back = 0° -Quadriceps = 7°	20,13%	Not acceptable

The error less than 10% we can say that it is very good results can be close to test machine results, and if the error between the 10% and 20% we can say that it is acceptable, but if the error more than 20% that results is not good because of the different results between the test machine and the multibody model so big.

So we conclude form that table our multibody model can work like the test machine with less error at 4 position as showed in the table 7, but there are one case shown us big number of error between the test machine and our multibody model at the position number 5. When we put the femur at 0° and tibia at 0° as well and quadriceps at 7° do not work like the test machine, and given us big error.

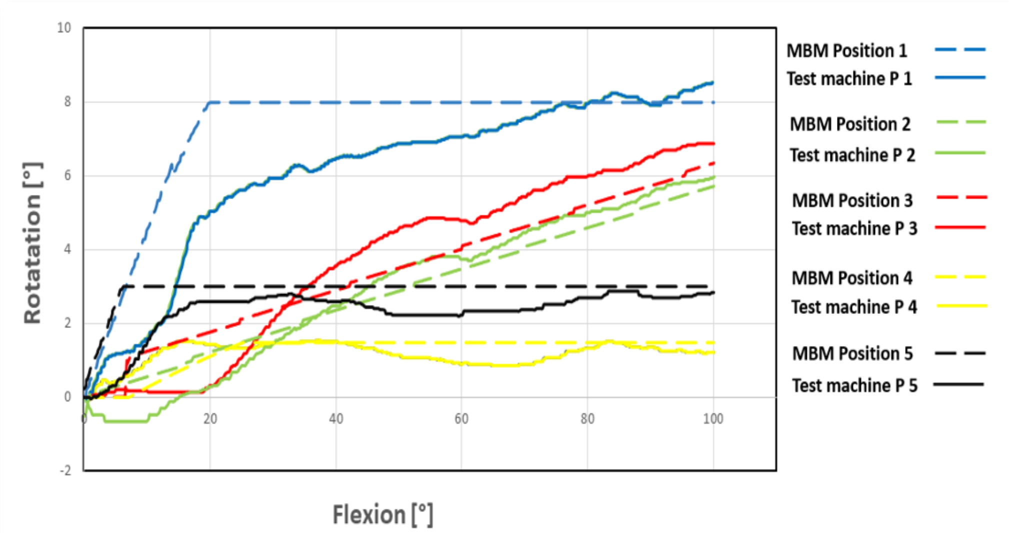


Fig 3.10 Verification results of our virtual model with the prosthesis developed with a test machine by making several prosthesis measurements.

To validate the results from the numerical studies, we compared our virtual numerical model specifically for rotation of the femur and Tibia with the prosthesis joint that has been tested using the test machine at MATE University in different positions. We noticed there is a slight difference in the error rate between the test machine results and our multibody model in first 4 specific position, but there is one case do not work perfectly as the test machine table 3. In this case, we validate the new model that enables us to make multiple measurements of a rotation of the knee. As a result of test machine with slight error rate, and we can change the materials made of artificial joints, more accessible, and obtain faster results without many calculations.

3.4 Developing the new prosthesis geometry

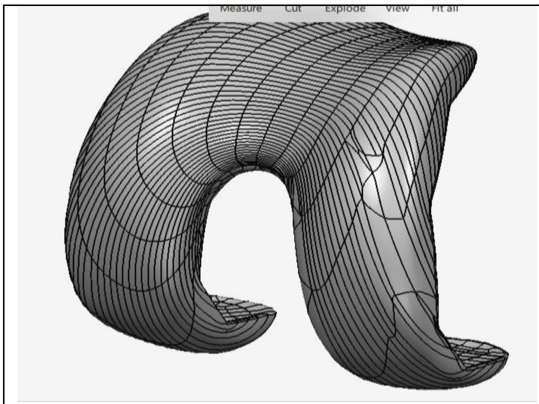
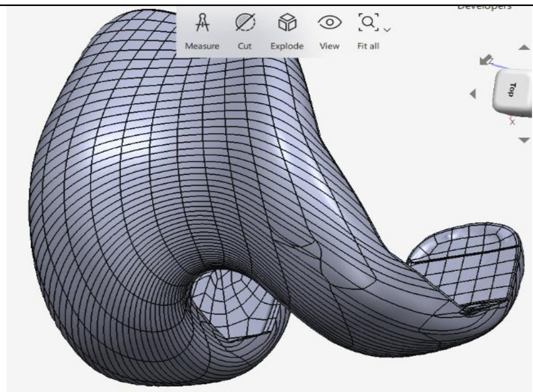
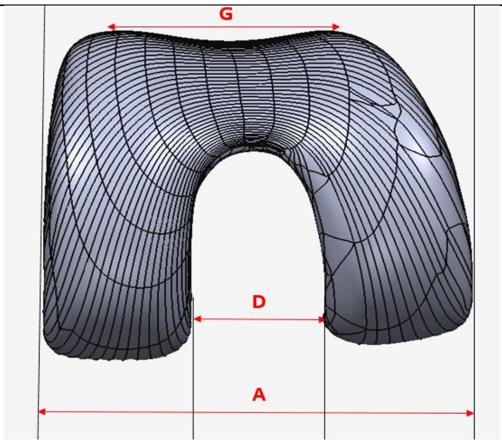
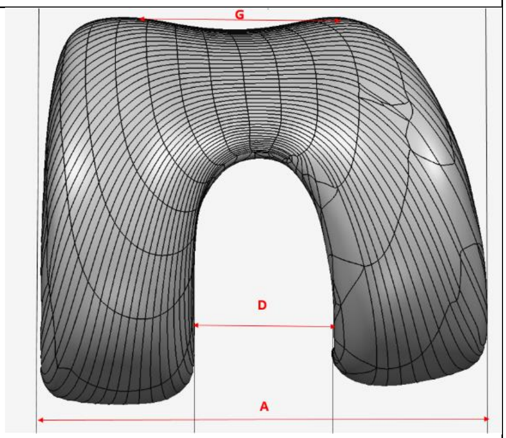
	

Fig.3.11 The previous femur for the original multibody model	Fig.3.12 The new femur for the new multibody model

With using Solidworks we made some changing at the femur structure Figs 3.11 and 3.12, with these modification we let the femur moving more effected, and some changes in length width and thickness.

Femur femoral size for original multibody model	**Femur femoral size for new multibody model**
	

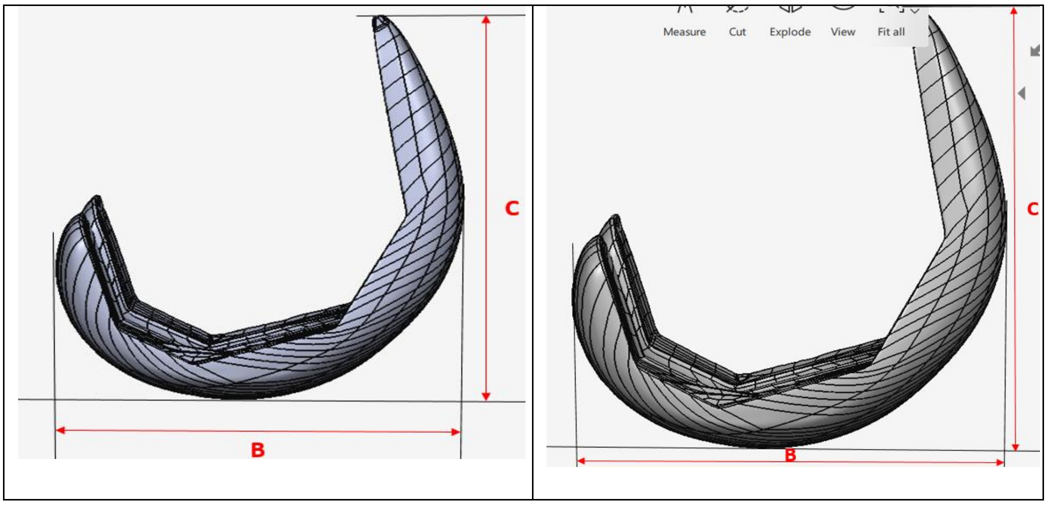


Fig.3.12 Femoral size for the femur

Table 4: Size specifications of the femoral component of total knee replacement.

Femoral size	A	B	C	D	G
Femur of the original multibody model	71,13mm	72,13mm	58,3mm	28,92mm	28,02mm
Femur of the new multibody model	87,07mm	78,8mm	61,2mm	36,2mm	29,51mm

As we can see the table presented the specifications femoral size that have been changed Fig 3.12, so we change the width A to 87,07mm and the length C to 61,2 mm and thickness D to 36,2mm. With these changing at the Table 8 we got the new Multibody model Fig 4.36.

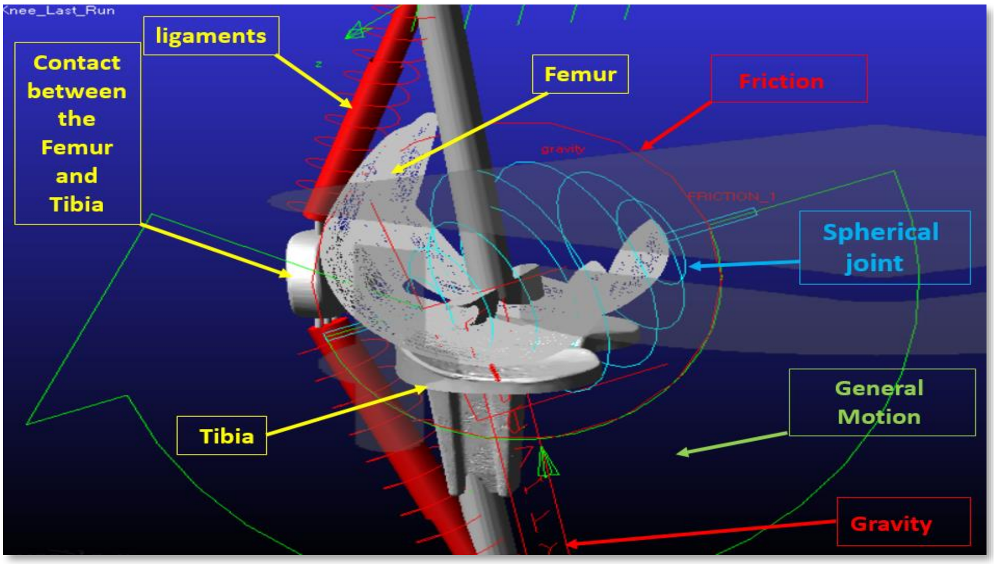


Fig 3.13. Our new multibody model in the MSC.ADAMS.

3.4.1. Boundary conditions for the simulation

After the geometrical model was obtained, the MSC ADAMS program was used to build the multibody model. First, the following boundary conditions were applied to our model (prosthesis geometry):

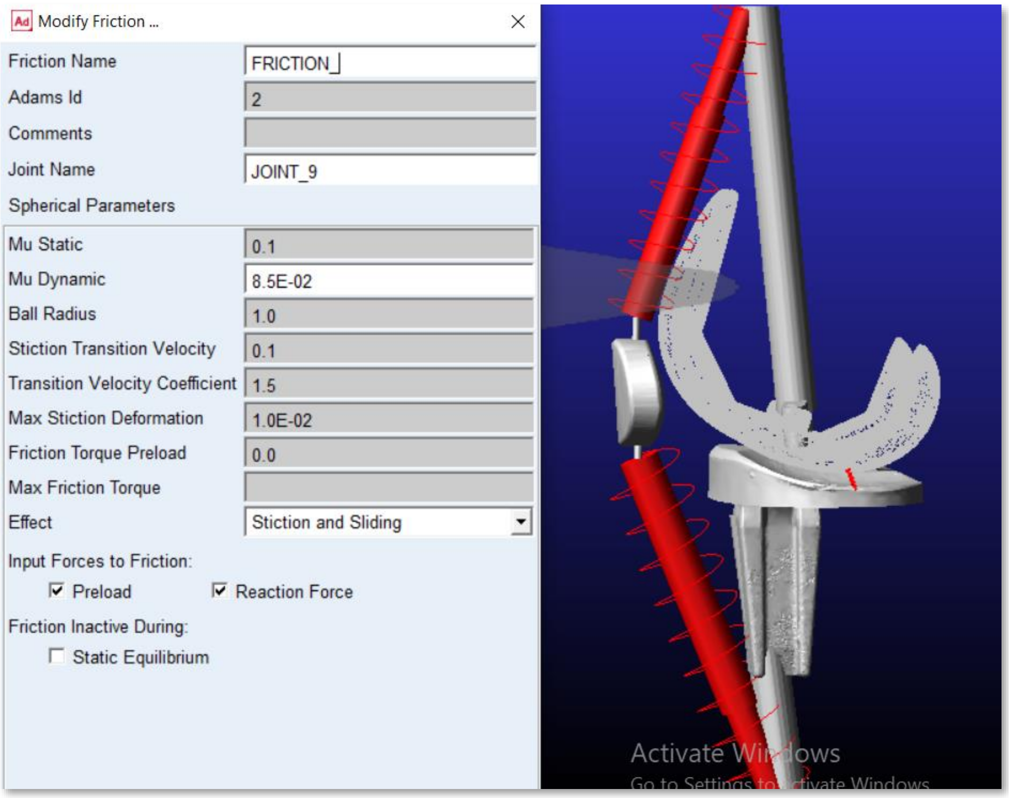


Fig 3.13. Parameters for friction multibody model.

3.4.2. Simulation of the multibody model in different positions

The pictorial representations of the model at the angles of 0° and 100° of flexion are shown in Figs 3.14 and 3.15. The relationship between the angles of rotation and flexion is illustrated in Fig 3.16. It is observed that the sudden increase in the rotational angle was offset by an increase in the angle of curvature. A sharp rise in the flexion angle till 35º was seen beyond the rotational angle of 20º, which indicates the onset of sliding between the tibia and the femur in the knee. Similarly, the flexion angle in the range of 20°-30˚ originates the joint prone to rolling. In contrast, the rotational angle's stability for the flexion angle lies in the range of 30° to 110°. The increasing flexion angle indicates that the tendency of sliding is predominant.

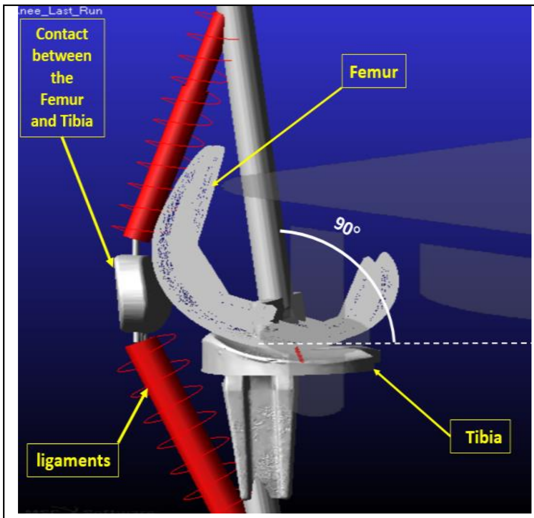


Fig 3.14: Multibody model at the Position 0 º.

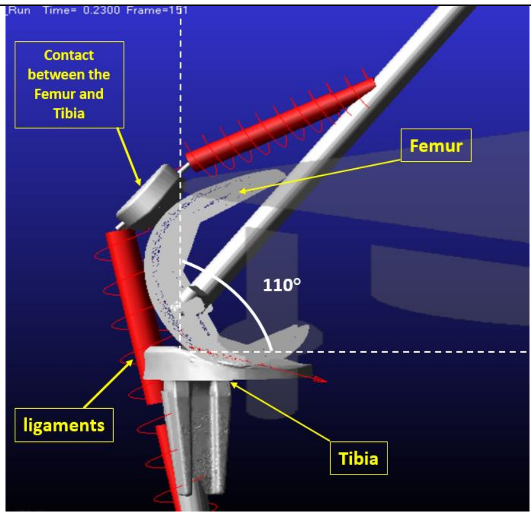


Fig 3.15: Multibody model at the Position 110 º.

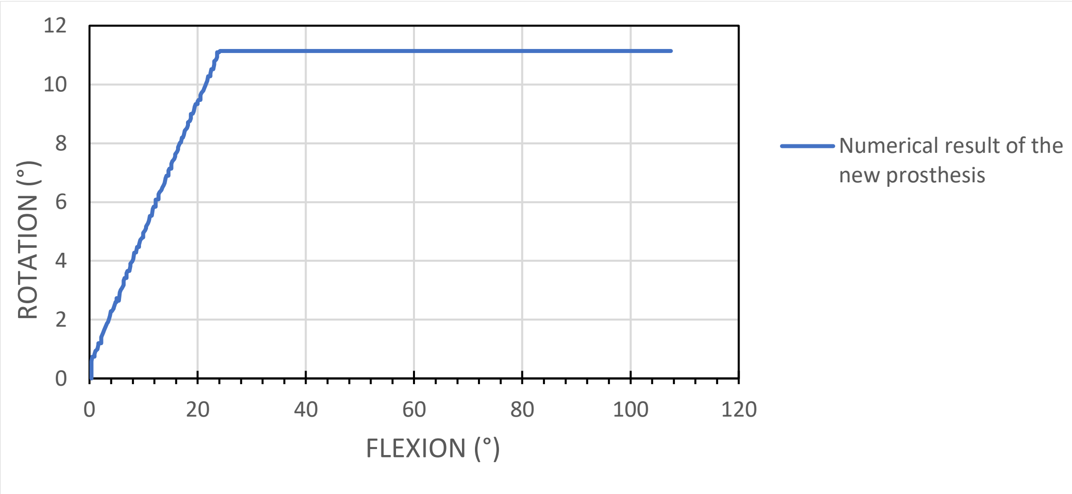


Fig 3.16. A graph of rotation against flexion of our virtual model.

4.4.3. Comparing the current study results of the new prosthesis geometry with a previous results from my previous multibody model M2.

To validate the results from the numerical studies, we compared our virtual numerical model with the prostheses joints that have been tested using the test machine in MATE University. The average values are plotted together against the virtual numerical model, as shown in Fig 3.17. The close similarity between the two curves indicates that this virtual model can replace the measurement with the MATE University test machine.
It was also found that there was a rise in the rotation angle as the flexion angle varied from 0° to 30°. Thus, our model's good value agreement with other prosthetic joints is established in the flexion range of 30° to 110°.

We noticed there are the same results between the proposed model and other prostheses. In this case, we created a new model that enables us to make multiple measurements of a new model. As a result, we can change the materials made of artificial joints, more accessible, and obtain faster results without many calculations.

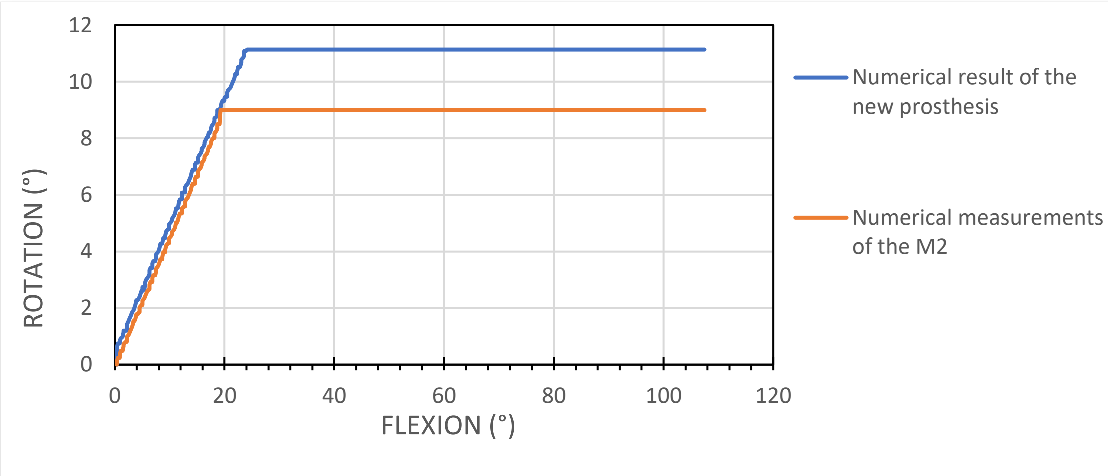


Fig 3.17. Comparing results of our virtual new model with our previous virtual model.

At the end of this part of study, we will say that our new prosthesis geometry is good enough and show us can reach good results better than the original knee prosthesis model.

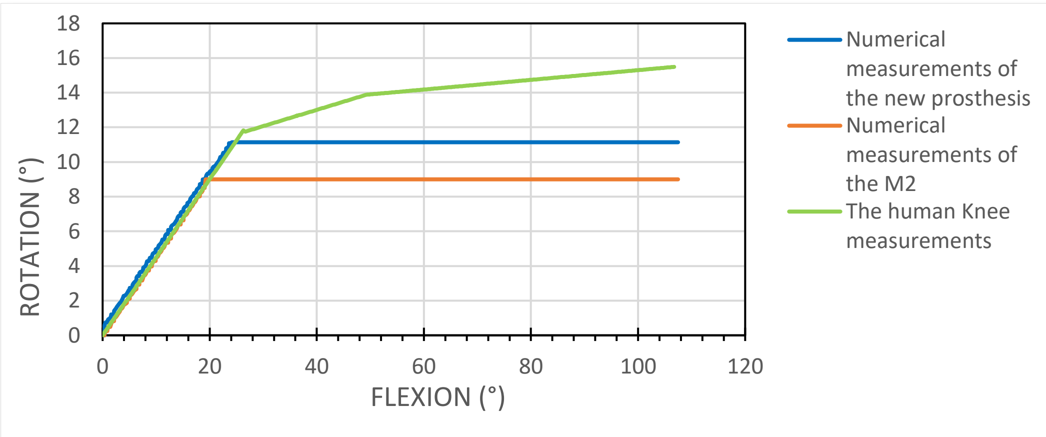


Fig 3.18. Comparing results of our new virtual model with the previous virtual model M2 and with the human knee measurements.

In the end, to validate the results from the numerical studies, we compared our original virtual numerical model with new virtual model with the prostheses joints that have been tested using the test machine in the MATE University. The average values are plotted against the virtual numerical models (new and original geometry), as shown in Fig 3.18. It was also found that there was a rise in the rotation angle as the flexion angle

varied from 0° to 30°. Thus, our models (new and previous) are good value agreement with other prosthetic joints is established in the flexion range of 30° to 110°.
We noticed the same results between the proposed models (new and original) and other prostheses. In this case, we created new models (new and original) that enable us to make multiple measurements of new models. As a result, we can change the materials made of artificial joints, more accessible, and obtain faster results without many calculations. And without cost, we can make several measurements for a person's knee size to be repaired.

4. NEW SCIENTIFIC RESULTS

1. *New multibody model and numerical method for knee prosthesis*

I have been create the new multibody model of the knee prosthesis geometry by using MSC.ADAMS program, the ADAMS programmer could compute the forces directly. At first, we saved it as PARASOLID, and we imported it into the MSC.ADAMS. The flexion angle was derived by combining the femur and tibia's angular velocities about the x-axis. This was done considering that the model was at 20 degrees for the sliding and rolling at the start of the movement. The angles were divided into three to tackle the three-dimensional movement. To be able to describe all the coordinates, we have restricted the distal femur by the general point motion, as shown in the results. The knee model was restricted by a cylindrical joint, which allows the flexion process between a femur and tibia. Simple linear springs are designed as the boundary between the rectus femur and the patellar tendon. With this model I developed the numerical measurement if the knee prosthesis geometry which fulfils the mechanical requirements of the human knee. The MSC.ADAMS programmer was applied to demonstrate the movement of the human knee joint in terms of rotation and flexion.

2. *Limits of the kinematic motion of multibody model for the knee prosthesis geometry*

I developed the kinematic motion of multibody model for the knee prosthesis geometry and this part of the study was about making rotation for Multibody model like Balassa did that with his test machine at MATE university we did the same study to compare our model with his results and has been determined Multibody model range between 25° to 110° this for the flexion and for the rotation of the femur and tibia it was at 0 degrees and it was this study as well under terms of quadriceps at 3°.Thus, our model's close agreement with other prosthetic joints was established in the flexion range of 25° to 110° with quadriceps fixed at 3 degrees, femur curse at 0 degrees and the Tibia leans back also at 0 degrees.

3. *New knee prosthesis geometry*

I developed the new multibody model of the knee prosthesis geometry and I developed the new numerical measurement and I got the good result better than the previous one so with these results we can replace the previous model with new model, and the results was close to the normal human knee, so the new model can be the best solution to use the numerical measurement of the knee prosthesis geometry, and using the new Multibody model for the new prosthesis with better results and better than the previous model and the test machine method.

5. CONCLUSIONS AND SUGGESTIONS

The MSC.ADAMS programme was applied to determine the human knee joint's movement in terms of rotation and Flexion. The relationship between these two processes was also described. The changes that occur between the condyles of the developed multibody of the prosthesis are also investigated concerning the flexion angle ranging from 20 to 120 degrees. The boundary conditions were determined, and simulations were performed using the ADAM's programme. Three-dimensional geometry was applied in the new virtual model, taking into account the influence of the condyles and collateral. The multibody modelling was used to measure the degree of Flexion and rotation of the knee concerning its position, like extension or Flexion or rotation, as well as inserting a spring between the tibia and femur while observing its effects on the performance of the knee. A slip ration which is higher than 0.45, as was the limit in literature, was achieved. Applying our model, an average value of 0.7 was reached with the maximum getting up to 0.79, and also obtaining an angle between 110° and 120° for the flexion angle. The generated virtual model was used to measure the knee pros-thesis size before its creation. This virtual model could be used to measure the knee prosthesis size before creating it because it saves time, money, and effort instead of using 3D printing technology, and CNC milling consumes our time, money and effort.

At the end we have to compare all the results together between 2 models that have been created by ADAMS program and the test machine measurements and the human knee average Fig 5.1.

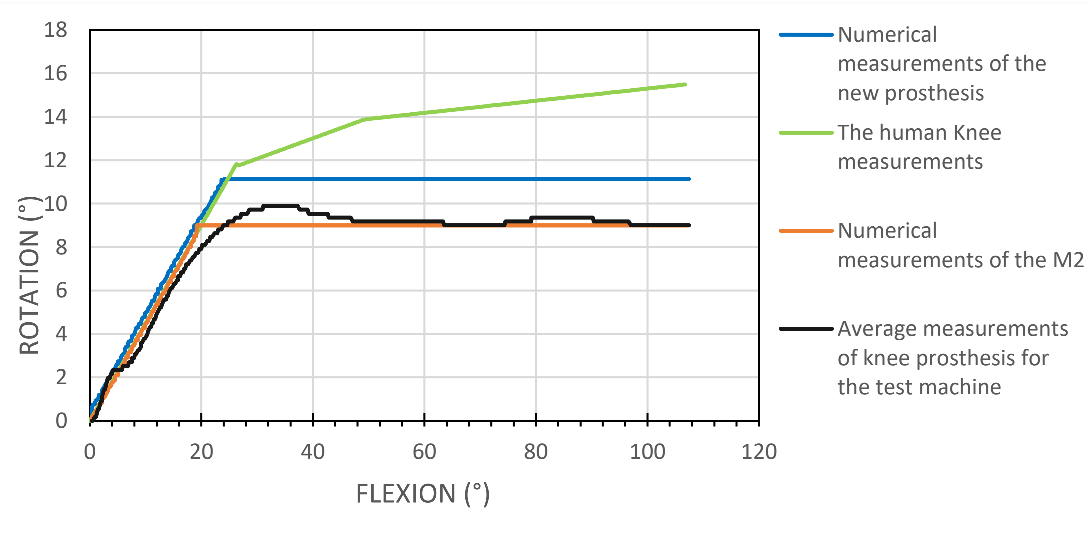


Fig 5.1. Verification results of our new virtual model with the previous virtual model comparing with the human knee measurements and the test machine results.

As we can see there are 2 types of our multibody model for the knee prosthesis geometry comparing with the human knee measurements and the average measurements of knee prosthesis for Balassa,

To know exactly how much different between the lines we will applied the integral equation :

$$\Delta = \frac{\sqrt{\Sigma\left[\left(\frac{f_0 - f_1}{f_0}\right)\Delta\varphi\right]^2}}{\varphi} \tag{5.1}$$

- Comparing between the numerical results of original multibody model and the human knee prosthesis measurements:

$$\Delta = \frac{\sqrt{\Sigma\left[\left(\frac{f_O - f_H}{f_O}\right)\Delta\varphi\right]^2}}{\varphi} = \frac{\sqrt{1085.547}}{106{,}02} = 0{,}3106 = 31{,}06\% \tag{5.2}$$

  That is mean the error rate between the original multibody model and the human knee measurements: 31, 06 %.

- Comparing between the human knee prosthesis results with the new multibody model error rate:

$$\Delta = \frac{\sqrt{\Sigma\left[\left(\frac{f_N - f_H}{f_N}\right)\Delta\varphi\right]^2}}{\varphi} = \frac{\sqrt{499{,}258}}{106{,}02} = 0{,}2107 = 21{,}07\% \tag{5.3}$$

That is mean the error rate between the measurements of the human knee and numerical measurements of the new multibody model: 21, 07 %.

- Comparing between the original multibody model(M1) and measurement of the knee prosthesis for Balassa:

$$\Delta = \frac{\sqrt{\Sigma\left[\left(\frac{f_{M1} - f_B}{f_B}\right)\Delta\varphi\right]^2}}{\varphi} = \frac{\sqrt{58{,}25}}{106{,}02} = 0{,}072 = 7{,}2\% \tag{5.4}$$

That is mean the error rate between the original multibody model and measurement of the knee prosthesis for Balassa: 7, 2%.

- Comparing between the multibody model(M2) and measurement of the knee prosthesis for Balassa:

$$\Delta = \frac{\sqrt{\Sigma\left[\left(\frac{f_{M2} - f_B}{f_B}\right)\Delta\varphi\right]^2}}{\varphi} = \frac{\sqrt{34.978}}{106{,}02} = 0{,}0557 = 5{,}57\% \tag{5.6}$$

That is mean the error rate between the original multibody model (M2) and measurement of the knee prosthesis for test machine: 5, 57 %.

So at the end we will say that with this rate of error between the original model with test machine we can the original model can replace the test machine with just 5,57% of error rate but with faster results and without cost, and we can make several measurements for a person's knee size to be repaired.

It can be said that the application of the multibody model saves time as there is no involvement of the tibia and femur, as needed for the knee prosthesis. More importantly, as the application of the test machine is omitted in our process, our model's approximations to a human knee are carried out directly. Thus, we can make several measurements for a person's knee size to be repaired without cost and we develop another knee prosthesis in ADAMS program by changing the femur as mentioned Figs 3.14, 3.15, and we got new results that can be better than the original model for the rotation part of the movements of the knee prosthesis.

In future work, we will try to create an Ankle virtual model in order to get a new virtual model for the complete human leg with the knee and ankle and all required movements. Furthermore, analysis of the anatomical angles such as the different rotations as human full legs, abduction, and adduction will be conducted.

6. SUMMARY

IMPROVEMENT OF KNEE PROSTHESIS GEOMETRY

In summary, the human knee joint usually suffers progressive deterioration with time. The conventional cure of this issue is to replace it with an alternate knee by applying the prosthesis implant. The reason is that the process causes the abrasion of the different materials rather than just sliding or rolling. This study aims to develop the numerical measurement of the knee prosthesis's geometry, which fulfils the mechanical requirements of the human knee. The MSC.ADAMS programme was applied to demonstrate the movement of the human knee joint in terms of rotation and flexion. The changes between the condyles of the developed multibody of the prosthesis related to the flexion angle ranging from 20–120° were investigated and presented The boundary conditions were determined, and simulations performed using the ADAM's programme. An average value of 0.7 was reached for the slip ration, with the maximum getting up to 0.79. An angle between 110–120° for the flexion angle was obtained. Three-dimensional geometry was applied in the new virtual model, taking into account the influence of the condyles and collateral. The multibody modelling was used to measure the degree of flexion and rotation of the knee concerning its position, like extension, flexion or rotation, and insert a spring between the tibia and femur while observing its effects on the performance of the knee.

It can be said that the application of the multibody model saves time as there is no involvement of the tibia and femur, as needed for the knee prosthesis. More importantly, as the application of the test machine is omitted in our process, our model's approximations to a human knee are carried out directly. Without cost, we can make several measurements for a person's knee size to be repaired.

A slip ration, which is higher than 0.45, was achieved as was the limit in literature. Applying our model, an average value of 0.7 was reached, with the maximum reaching up to 0.79 and obtaining an angle between 110–120° for the flexion angle. The generated virtual model was used to measure the knee prosthesis size before its creation.

Finally, this virtual model could be used to measure the knee prosthesis size before creating it because it saves time, money, and effort instead of using 3D printing technology, and CNC milling consumes our time, money, and effort. So we can say that the multibody model method measurement created can replace the test machine for doing measurement of the prosthesis. Therefore it can serve as a basis for further scientific research. We proved in our method that the factors of the knee prosthesis have a significant influencing effect on the resulting joint kinematics. The ranges recommended by specialists for each prosthesis parameter were confirmed by measurements.

6. ÖSSZEFOGLALÁS (SUMMARY IN HUNGARIAN)

TÉRDPROTÈZIS GEOMETRIA JAVÍTÁSA

Összefoglalva, az emberi térdízület általában idővel fokozatosan romlik. Ennek a problémának a hagyományos gyógymódja az, hogy protézis implantátumot alkalmazunk. Ennek egyik problémája lehet, hogy a nem megfelelő geometria miatt a használat közben a csúszva gördülésre tervezett a protézis anyag további igénybevételt kap, ami kopást, kilazulást okozhat. A tanulmány célja a térdprotézis geometriájának numerikus mérésének kidolgozása, amely megfelel az emberi térd mechanikai mozgásviszonyainak. Az MSC.ADAMS programot alkalmaztam az emberi térdízület mozgásának bemutatására rotáció és hajlítás szempontjából. Megvizsgáltam és bemutattam a protézis kifejlesztett többtestének condylusai között a 20-120°-os hajlítási szöggel kapcsolatos változásokat. A peremfeltételek meghatározása és szimulációi az ADAM program segítségével történtek. A csúszás aránya 0,7-es átlagértéket értek el, a maximum pedig 0,79-re emelkedett. A hajlítási szög 110-120° közötti szöget vett fel. Az új virtuális modellben háromdimenziós geometriát alkalmaztam, figyelembe véve a condylusok és a kollaterális hatását. A többtest modellezést arra használtam, hogy megmérjem a térd hajlításának és elfordulásának mértékét a helyzetére vonatkozóan, mint például a nyújtás, hajlítás vagy elforgatás, és rugót helyeztem be a sípcsont és a combcsont közé, miközben megfigyeltem annak a térd kinematikájára gyakorolt hatását.

Elmondható, hogy a többtest modell alkalmazása időt takarít meg, mivel a térdprotézis vizsgálatához nem szükséges a sípcsont és a combcsont fizikai modellje. Ennél is fontosabb, hogy mivel a tesztgép alkalmazását kihagyjuk a folyamatunkból, a modellünk emberi térdre való közelítését közvetlenül hajtjuk végre. Többletköltség nélkül több mérést is elvégezhetünk a újabb térdprotézis geometriákkal.

0,45-nél nagyobb csúszási arányt értem el, ahogy az irodalomban is megengedett. Modellemet alkalmazva 0,7-es átlagértéket értem el, a maximum elérte a 0,79-et és 110-120° közötti szöget kaptunk a hajlítási szögre. A generált virtuális modellt a térdprotézis kinematikájának mérésére használtam annak legyártása előtt.

Végül ezzel a virtuális modellel megmérhetjük a térdprotézis mozgását a gyártás előtt, amivel időt, pénzt és erőfeszítést takaríthatunk. Nincs szükség sem a 3D nyomtatási technológia sem a CNC marás segítségével létrehozott fizikai modellre, ami időt, pénzt és erőforrásokat emésztene fel. Így elmondhatjuk, hogy a megalkotott többtest modell módszerrel végzett mérés helyettesítheti a protézis mérésére szolgáló tesztgépet. Ezért további tudományos kutatások alapjául szolgálhat. Módszerünkkel igazoltuk, hogy a térdprotézis geometriája jelentős mértékben befolyásolja a kialakuló ízületi kinematikát. A szakemberek által az egyes protézisparaméterekre javasolt tartományokat mérésekkel igazoltuk.

7. MOST IMPORTANT PUBLICATIONS RELATED TO THE THESIS

Refereed papers in foreign languages:

1. **Zehouani Kh**, Boukhari A, (2018), study of Rayleigh Bernard convection by lattice Boltzmann method, Modern environmental science and engineering, New York, USA, 4 (9), 867-871, *Doi: 10.15341/mese(2333-2581)/09.04.2018/001.*

2. **Zehouani Kh,** Oldal I,(2019), Virtual testing method of human knee prosthesis, International Journal of Engineering and Management Sciences (IJEMS), Debrecen, Hungary, Vol.4,386-392. *DOI: 10.21791/IJEMS.2019.1.48.*

3. **Zehouani Kh,** Oldal I,(2021), Developing of Knee Prosthesis in ADAMS Program, Mechanical Engineering Letters, Godollo, Hungary, HU ISSN 2060-3789.

4. **Zehouani Kh**, Oldal I,(2021), Study of Heat Transfer in a Cylinder Subject to Robin's Conditions, Mechanical Engineering Letters, Godollo, Hungary, HU ISSN 2060-3789.

5. **Zehouani Kh,** Oldal I,(2021), Numerical Measurement of a Virtual Model for the Knee Pros-thesis Geometry, Applied scinces, Basel, Switzerland, 11(6), 2541 *https://doi.org/10.3390/app11062541.*

6. **Zehouani Kh,** Oldal I,(2021), Improvement of the test machine for knee prosthesis, Open Journal of Polymer Chemistry, Hong Kong, China, under prosering.

7. **Zehouani Kh,** Oldal I,(2022), Developing the kinematic motion of Multibody model for the knee prosthesis geometry, International Journal for Engineering Modelling, Zagreb, Croatia, under reviewer.

International conference proceedings:

8. **Zehouani Kh,** Oldal I, study of Rayleigh Bernard convection by lattice Boltzmann method,23rd workshop on energy and environment, Gödöllő, Hungary.2017

9. **Zehouani Kh**., Oldal I,Virtual testing method of human knee prosthesis, International Scientific Conference On Advances In Mechanical Engineering, Debrecen, Hungary, October 11-13, 2018.

10. **Zehouani Kh**., Oldal I, flexion-rotation angle of the new model of the knee prosthesis in ADAMS program. BPS Conference in Mechanical Engineering, Gödöllő, Hungary.2019.

11. **Zehouani Kh**., Oldal I, Multi-body model of the knee prosthesis in ADAMS program, International Conference on Engineering & Technology (ICET-19),Ottawa,Canada.2019

International conference abstracts:

12. **Zehouani Kh**., Oldal I, Study of Heat Transfer in a Cylinder, Synergy international conferences-engineering, Agriculture and green industry innovation, Gödöllő, Hungary, October 12-15,2017.
13. **Zehouani Kh**., Oldal I,Test machine of knee prosthesis geomtry, 24rd workshop on energy and environment, Gödöllő, Hungary,2018.