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DEVELOPMENT AND EXAMINATION OF A KNEE PROSTHESIS GEOMETRY

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Abstract

The necessity for the knee prosthesis is confirmed by the large increase in the number of patients suffering from arthrosis, which is a present-day disease. Despite this need, there doesn't exist an optimal knee prosthesis. Nowadays the development of the knee prostheses is progressing. It is very difficult to define the required geometry with traditional methods, because the movement conditions to be created by the prostheses should be similar to the movements of the human knee. During previous research the biomechanical research team of the Szent István University occupied with experimental measurements of the healthy human knee joint movement. In this paper I would like to introduce a method of prosthesis geometry development. As a result, a knee prosthesis geometry has been created which is approaching the movement form of the real human knee joint.

Keywords: *knee, kinematics, prosthesis, experimental apparatus.*

1. Introduction

Nowadays the proper handling of degenerative abrasion (so called arthrosis) in the knee joint is currently one of the most important orthopaedic problems. The appropriate treatment of this disease is total knee replacement. Unfortunately, in reality, there is no knee prosthesis available which can improve the patient's quality of life in the long term, because the knee prosthesis geometry changes the original knee kinematics [1]. The knee prostheses should meet a wide range of requirements; unfortunately, special movement conditions have not been fulfilled until now.

The main goal of this study is to present a method for developing a special unique knee prosthesis geometry.

The movement created by the knee prosthesis is ensured by the relative displacement of the condylar surfaces. For the geometric development and examination of the knee prosthesis we have modified the geometry of an existing prosthesis. Parametric 3D modelling and surface modelling is used in the design.

In this way, the created prosthesis model is produced by CNC milling technology, and the new geometry was tested with the knee prosthesis test equipment of the Biomechanical Research Group of Szent István University. The basis of the qualification is the difference between the knee prosthesis movement and the healthy human knee joint movement on the same device.

The goal of the procedure is to create a knee prosthesis that reflects the movement expected by the human knee joint.

1.1. The knee movements and the objective function

The knee joint is the most complex joint in the human body. It is a rotating-hinge joint with 6 degrees of freedom [2], The movement possibilities are shown in Figure 1.

During this research the rotation and the flexion are important forms of knee movement. The rotational movement can be viewed into two parts: the intended and involuntary rotation. The involuntary rotation is not the result of muscle function [3]. The flexion of the tibia starts with a slight internal rotation and the extension of the tibia clearly starts with an outer rotation. The intended rotation is a feature of the bended knee joint

In the healthy human knee joint the femur condyles are asymmetric, that means that during flexion and extension the lateral side makes a longer movement than the medial side. . Our research team and the team of surgeons with which we cooperated has a common hypothesis. According to that we assume that this geometric peculiarity between the condyles is what causes the tibial internal and outer rotation.

The biomechanical research team of the Szent István University during their work determined the motion function of the healthy human knee joint which describes the knee kinematics. They carried out measurements on cadaver knees using an experimental apparatus **[5].**

The objective function (**Figure 2.**) serves as an input parameter for the knee prosthesis geometry development. The rotational motion can be divided into two main parts, furthermore between the two separated movement forms there is a transition segment. That means it is possible to approach the movement with a trilinear function.

2. Materials and methods

In the following chapter we present the knee prosthesis testing equipment which was created by our Research team. The equipment which was developed for the cadaver knee testing was not suitable for the knee prosthesis testing; therefore it was necessary to develop a prosthesis measuring system.

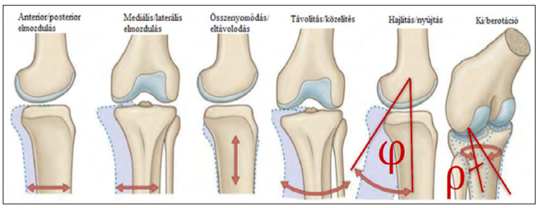

Figure 1. *The movement possibilities of the knee joint* ***[4]***

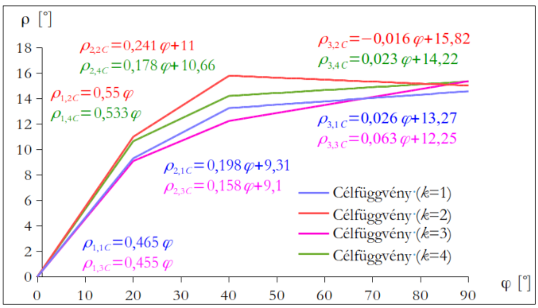

Figure 2. *The objective function which describes the motion of the healthy human knee joint* ***[6, 7]***

2.1. The knee prosthesis test apparatus

The main components of the device are the prosthesis test part and the mechanism which moves and rolls the knee condyles and tibial surfaces on each other. The motion-guiding stepper motor transmits its torque; meanwhile incremental rotary encoders in the device record the flexion angle values and the associated values of the tibial rotation. The test apparatus provides six degrees of freedom of movement with its two-way guide line.

The moving axis only carries out the required flexion with the help of the stepper motor and it allows the tibial component to move freely. To maintain the required surface contact, the four-head thigh muscle was built in as a rubber muscle model. With the help of the force cell the quadriceps tendon force during the flexion can be measured.

During the measurements, the prosthesis components were positioned with a preload of 120N. The force measured by the force cell was monitored in the flexion range with the Spider 8 measure-data acquisition system. **Figure 3.** shows the experimental knee test apparatus, marked with a red color on the femur prosthesis component, and blue on the tibial component.

The main parameters that describe the measurement process are:

– preload: 120N;
– range of motion: 0° – 120°;
– resolution of the incremental transducers: 0.18°.

2.2. The design method of the knee prosthesis geometry

In the development of this knee prosthesis geometry, a commercially available knee prosthesis was chosen as an initial parameter.

During development, the femur component is assumed to be constant and a tibial prosthesis component is created. This method is used because experience shows in general that the femoral component geometry is acceptable The problem occurs typically in the tibial component so that is what we are working on. **Figure 4.** shows the two components of the prosthesis . During the geometric development a hypothesis was applied. According to this, with the help of a suitable femoral component an associated tibial component can be designed to produce a joint directed motion. This hypothesis is based on the theory that the knee joint movement is not determined by the joint ligaments, but by the joint geometry surface properties.

The femoral and tibial components are mated relative to each other in the modelling area by the working conditions of the test apparatus After that we guided the tibial component all the way through on the femoral component according to the objective function. The input parameter of the geometry design was the objective function k = 1.

Finally the surfaces were extracted from each other which are rotated at every 10° as on the **Figure 5.** shown.

2.3. The manufactured knee prosthesis

With the usage from the above described method I developed the 3D CAD model of the tibial prosthesis component and it was milled on a CNC milling machine (**Figure 6**).

The milled knee prosthesis component was made using the same method and technology as used for knee implants nowadays. UMHW-PE polymer was chosen for the tibial prosthesis component. This is also the same material as used in real knee prostheses. This provides adequate mechanical resistance as well.

3. Results and discussion

The knee prosthesis specimen was subjected to a series of experimental measurements. As shown in **Figure 3.** the knee prosthesis testing apparatus was used for the experiments. Before the start of the measurements, a test calibration of the test equipment was performed. After that the used knee prosthesis was measured, shown in **Figure 4.** It is clearly visible that on the commercially available prosthesis a rotation is not achieved. The examined tibial component was symmetrical in its functional surface.

These experimental measurements were repeated five times. The developed geometry is rated by the cadaver knee joint objective function. During the measurements it wasn't necessary to adjust the prosthesis components to the root position, because the geometry has returned to its starting position.

In this case, the measurements were not only examined for the flexion range, but also for the extension range as well.

This phenomenon has not been observed in our previous work **[8]**.

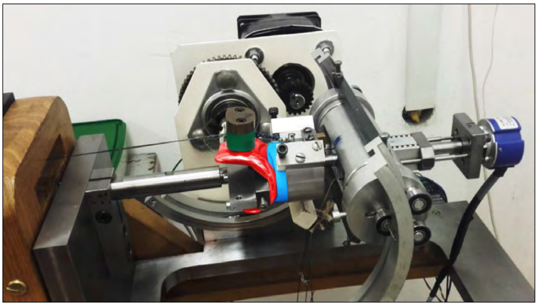

Figure 3. *The experimental test apparatus for kinematic knee prostheses measurements*

Figure 4. *A commercially available knee prosthesis*

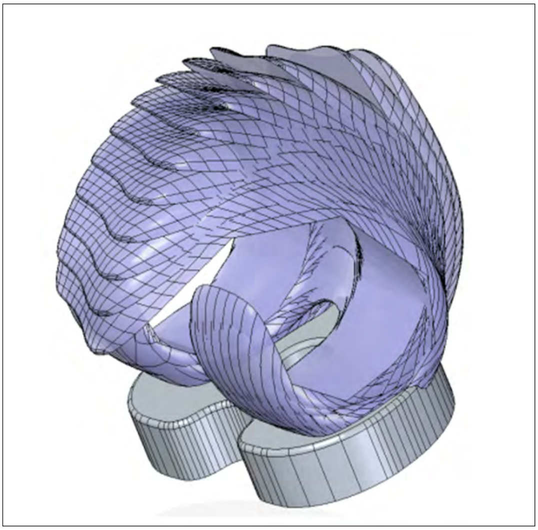

Figure 5. *The prosthesis geometries rotated into each other*

Figure 6. *CNC milled tibial prosthesis geometry*

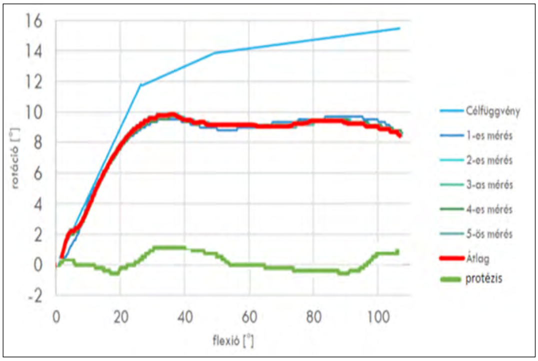

Figure 7. *Experimental measurement results*

4. Conclusions

The present paper demonstrates a hypothesis for the kinematical design method of knee prosthesis geometries. The basic principle of the method is to move the two prosthetic components together according to the objective function. After that the resulting surface sections are extracted from each other. The formed surfaces do not form a shape-closing relationship and are able to slide apart, but there is a surface section that can approach the objective function.

The relevance of the measurement result shown in **Figure 7.** lies in the fact that the prosthesis geometries that are currently used create very little rotation. Our Research Team has developed several prosthesis design methods **[8]**, but the presented results in this study are actually the best in that they approach the real knee movement.

In future work the new geometry should be examined for abrasion-resistance as well. If it meet the requirements, it will be possible to use it in the praxis.

References:

[1] Ostermeier S., Hurschler C., Stukenborg-Colsman C.: *Quadriceps function after TKA – an in vitro study in a knee kinematic simulator*. Clinical Biomechanics 19. (2004) 270–276.

[2] Grood E. S., Suntay W. J.: *A joint coordinate system for the clinical description of three-dimensional motions: application to the knee*. Journal of Biomechanical Engineering. 105/2. (1983) 136–144. https://doi.org/10.1115/1.3138397

[3] Miltényi M.: *A sportmozgások anatómiai alapjai.* Budapest, 1980. 164–185.

[4] Standring S.: *Gray's Anathomy, The anatomical basis of clinical practice*. Spain, Churchill-Livingstone-Elsevier Press, 40th Edition, 2008. 4300–4354.

[5] Szakál Z.: *Mérőberendezés térdízület mozgásvizsgálatához*. GÉP 57/1. (2006) 37-40.

[6] Katona G., Csizmadia M. B., Andrónyi K.: *Determination of reference function to knee prosthesis rating*. Biomechanica Hungarica 6/1. (2013) 293–301.

[7] Katona G., Csizmadia M. B., Balassa G.: *Az egészséges emberi térdízület kinematikáját leíró „célfüggvény" létrehozása.* Biomechanica Hungarica 10/1. (2017) 9–21.

[8] Kopcsányi G., Balassa G.P., Oldal I.: *Térdprotézis kinematikájának javítása evolúciós algoritmus alkalmazásával.* Biomechanica Hungarica 10/1. (2017) 65–73.