TRANSLATIONAL MOTIONS IN HUMAN KNEE JOINT MODEL

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ABSTRACT

Different authors are dealing with description of motion components of human knee joint. The relative motion between femur and tibia realized by knee joint is ensured by complicated condyle surfaces and ligaments. Main part of authors focus merely on rotational displacement of human knee joint such as flexion-extension, abduction-adduction, tibial rotation. In order to achieve implanted prostheses we have to recognize not only the rotational but also translational kinematical parameters of human knee joint.

Authors of this paper for description of motion of knee joint joined coordinate-systems on the basis of anatomical landmarks to the femur and tibia moreover joined a three-cylindrical mechanism as mechanical model to the axes of coordinate-systems. In 2nd phase authors determined the six independent kinematical parameters of tibia compared to the fixed femur during flexion and extension. The experimental examinations were carried out on cadaver knees. The positioning was tracked by optical positioning appliance.

1. INTRODUCTION

Different constraints enable relative motion of joined rigid bodies referring to each other. The constraints depending on their shapes have one or more degree of freedom. In case of joints the degree of freedom cannot be always determined. It is expedient to treat the human knee joint as six degree of freedom because of its complicated shape. In this case to the precise description of motion achieved by knee joint we need six independent position parameters [1, 7].

In recent years the number of kinematical models of anatomical joints has increased. In case of certain models so many researchers have measured and described joint motion with less than six degrees of freedom. Obviously the treatment of six degree of freedom models is the most difficult. The motion of human knee joint can be described by following components: The flexion-extension is defined around the medio-lateral axis, internal-external rotation around the tibial axis and the abduction-adduction around the anterior-posterior (floating) axis. The medio-lateral translation is measured along the medio-lateral axis, proximal-distal translation along the tibial axis and antero-posterior translation along the mutually perpendicular floating axis.

Description of motion components in such a way a little bit subjective. In order to descript the motion components precisely it is needed to join coordinate-systems to the femur and tibia consequently.

In recent decades to measure kinematical parameters of human knee joint different methods have been developed. In these methods it is measured and processed the motion of markers fastened to femur and tibia referring to each other. In vitro mechanical investigations are mainly phantom or simulated computer models or cadaver motion experiments [7].

The visual examinations were based on marker technique to sign single points or axis of the extremities delineating their motion. In spite of that the newly introduced techniques developed in an enormous numbers in the last decades e.g. the radiology, fluoroscopy, three-dimensional CT, MRI, stereophotogrammetry, ultrasound, etc. most of the results were unreliable, inconsistent with other published data [3, 4, 5, 6]. The range of the tibia out and in-rotation along the flexion-extension motion of the knee had been established by different authors as between 5 up to 17 degrees, moreover the character of this diagram is variable [8, 9]. On the basis of difference of published results it is quite difficult to establish exact character concerning the motion of knee joint.

2. METHOD

Authors developed a special appliance [10, 11, 12] in order to make a serial experiments. The aim of them was the determination of change of six independent kinematical parameters of tibia (shin bone) compared to femur (thigh bone) during of motion of human knee joint. From recorded data needed parameters can be determined by the aid of kinematical model.

To the presented sensitivity investigation it is necessary to determine anatomical landmarks on femur and tibia moreover coordinate-systems joining to the determined anatomical landmarks. Details of this process can be found in paper of Katona et al [13, 14, 15]. Considering the biological characters of femur and tibia the optical positioning of anatomical landmarks can be achieved with more or less position mistakes. The aim of this paper is the determination of the effects on kinematical parameters of position mistakes during flexion-extension of human knee joint.

Authors on the basis of current international standards and conventions (e.g. from the International Society of Biomechanics) [16] using the above mentioned anatomical landmarks joined coordinate-systems to femur and tibia.

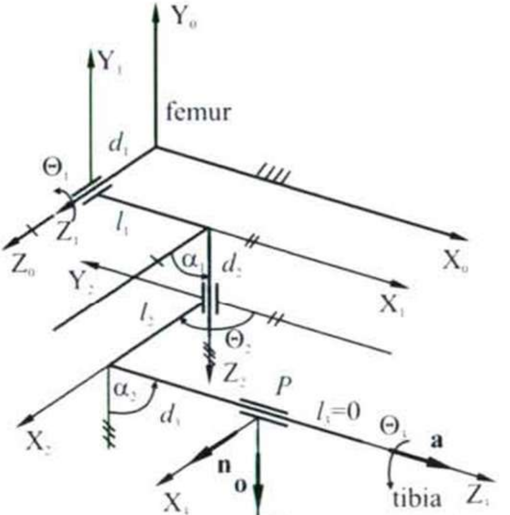


Figure 1. Model in straighten position of the knee joint

3. THE KINEMATICAL MODEL OF THE KNEE JOINT AND OBTAINED RESULTS

The Denavit-Hartenberg coordinates **Hiba! A hivatkozási forrás nem található.** can be used with advantage if the kinematical pairs are cylindrical or planar joints (moving in 3 dimensions). The three-cylinder model of the knee joint: The HD coordinates can be seen at straightens position of the knee joint in Fig. 1. The parameters (α_i, l_i, (i=1,2,3)) can be manipulated optionally because of the specific geometry of the knee joint. On the basis of recommended references the following values are proper approaches: $\alpha_1=\alpha_2=90^\circ$, $\alpha_3=0^\circ$, $l_1=l_2=l_3=0$.

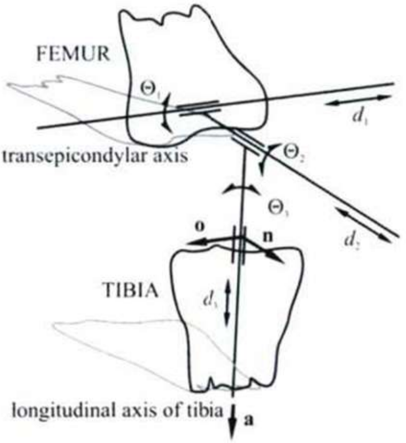


Figure 2. The three-cylinder kinematical model of the knee joint

If these are applied to a three-cylinder model, then the kinematical model of the knee joint is suitable for determining the variables in motion as a three dimensional open-chain mechanism (Fig. 2.).

The definition of these is:

- Θ_1 – flexion,
- Θ_2 – ab/adduction,
- Θ_3 – rotation of the tibia,
- d_1, d_2, d_3 – moving on accordant axes.

It is practical to plot these values in function of flexion [1,2]. The matrix-equation will be the next if the perpendicularity of the axes is taken for granted as the previous.

$$\begin{bmatrix} \cos\Theta_1 & 0 & \sin\Theta_1 & 0 \\ \sin\Theta_1 & 0 & -\cos\Theta_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} \cos\Theta_2 & 0 & \sin\Theta_2 & 0 \\ \sin\Theta_2 & 0 & -\cos\Theta_2 & 0 \\ 0 & 1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} \cos\Theta_3 & -\sin\Theta_3 & 0 & 0 \\ \sin\Theta_3 & \cos\Theta_3 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The next system of equations can be derived from the matrix-equation.

$n_x = \cos\Theta_1 * \cos\Theta_2 * \cos\Theta_3 + \sin\Theta_1 * \sin\Theta_3$

$n_y = \sin\Theta_1 * \cos\Theta_2 * \cos\Theta_3 - \cos\Theta_1 * \sin\Theta_3$

$n_z = \sin\Theta_2 * \cos\Theta_3$

$o_x = -\cos\Theta_1 * \cos\Theta_2 * \sin\Theta_3 + \sin\Theta_1 * \cos\Theta_3$

$o_y = -\sin\Theta_1 * \cos\Theta_2 * \sin\Theta_3 - \cos\Theta_1 * \cos\Theta_3$

$o_z = -\sin\Theta_2 * \sin\Theta_3$

$a_x = \cos\Theta_1 * \sin\Theta_2$

$a_y = \sin\Theta_1 * \sin\Theta_2$

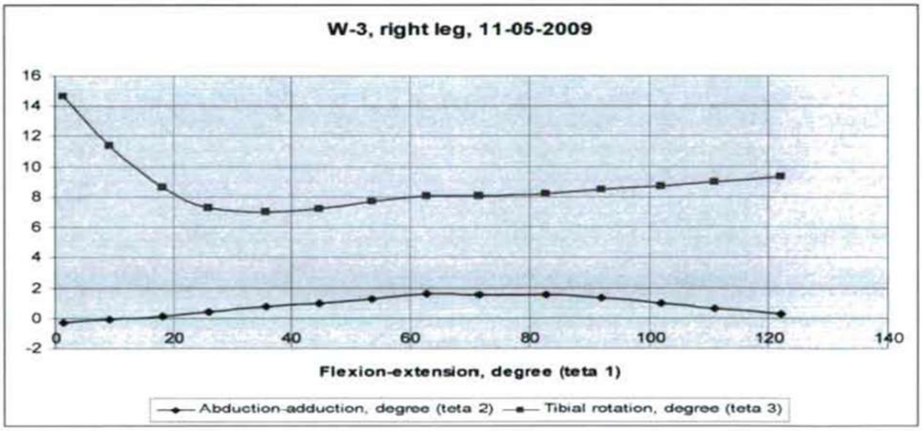
$a_z = -\cos\Theta_2$

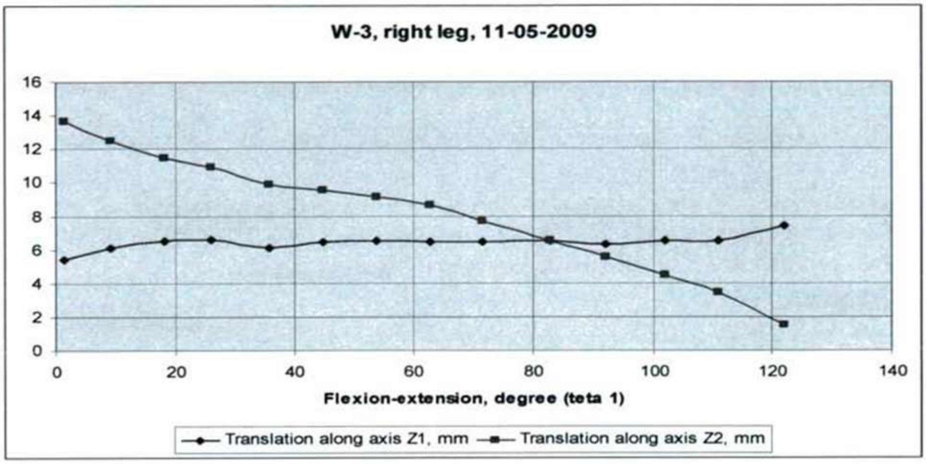
$P_x = d_3 * \cos\Theta_1 * \sin\Theta_2 + d_2 * \sin\Theta_1$

$P_y = d_3 * \sin\Theta_1 * \sin\Theta_2 - d_2 * \cos\Theta_1$

$P_z = -d_3 * \cos\Theta_2 + d_1$

Several conditions should be considered to derive and solve the system of equations. The conditions were the knowledge of the **n**, **o**, **a** unit vectors and the origin (*P*) of the $X_3Y_3Z_3$ coordinate-system attached to the tibia in the $X_0Y_0Z_0$ system (Fig. 1.). The roots of the system of equations: Θ_1, Θ_2, Θ_3, d_1, d_2, d_3. In Fig. 3-4 the obtained diagrams can be seen.





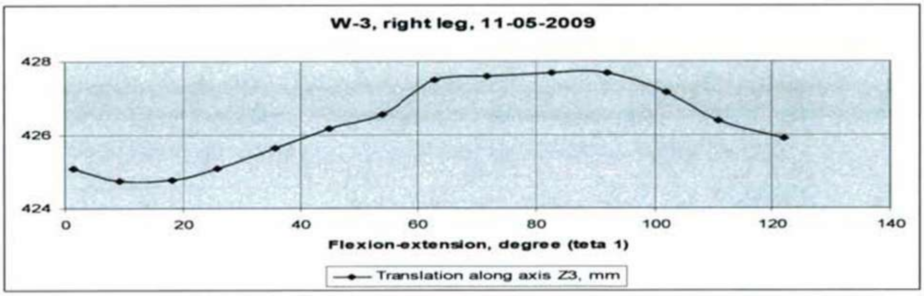


Figure 3. Obtained kinematical parameters of right cadaver knee joint

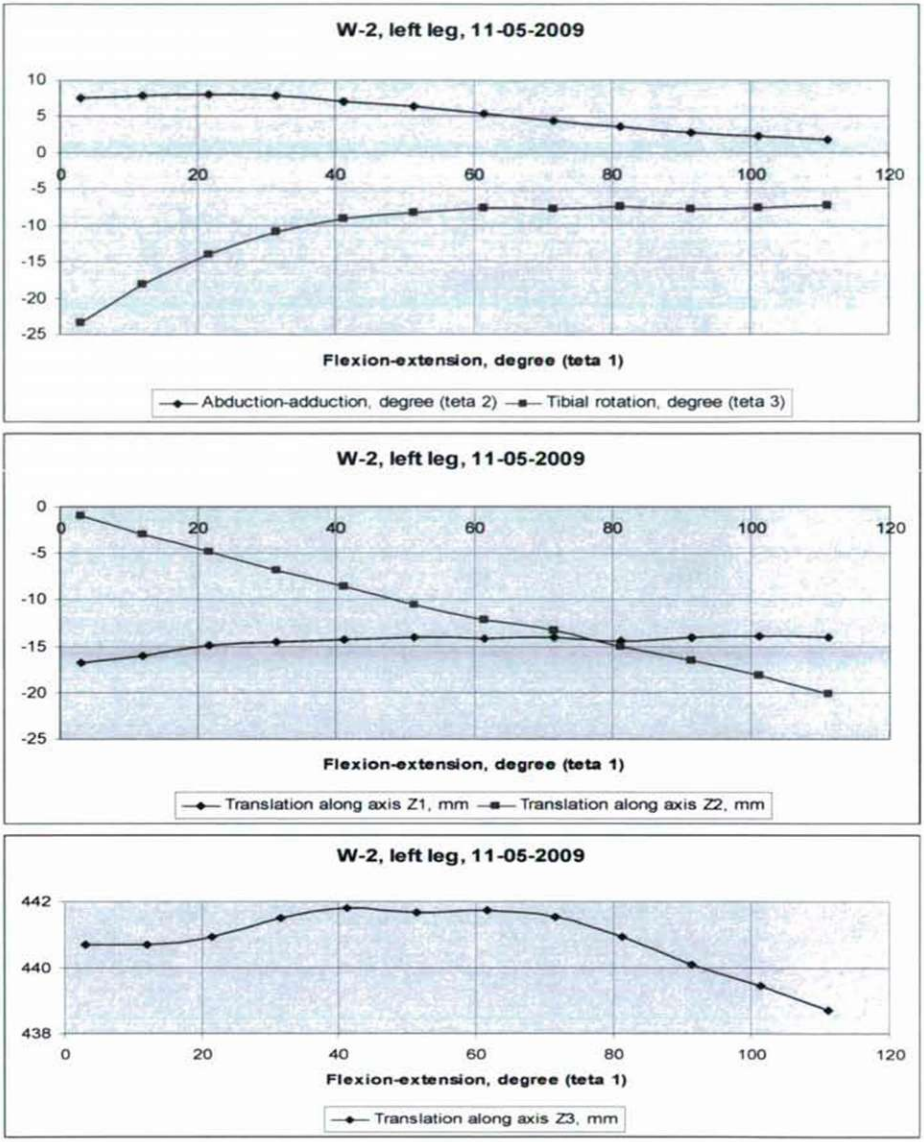


Figure 4. Obtained kinematical parameters of left cadaver knee joint

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