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Determination of Force Components Acting on Insertion Points of an Artificial Ligament during the Gait Cycle

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Abstract

This paper presents force components determination using reverse dynamics method and AnyBody software, during gait cycle on the insertion points on an artificial anterior cruciate ligament. Results showed a different behavior between the two insertion points studied, namely that for the lower insertion point the normal component values are most significant. These results can be further used for finite element analysis in the design of new artificial ligaments.

Key words: *ligament, reverse dynamics, AnyBody, gait cycle*

Introduction

Reverse dynamics is used in biomechanics to determine joint forces and moments, assuming that the movement and exterior forces value are known [1]. This method is based on Newton-Euler equations and it was used by other authors [2-4] to study the joint forces and moments due to the action of muscles, on real subjects. The method presumes that the biomechanical system's cinematic values are well defined and it's purpose is to determine the values that produce the movement. Joint moments can be used to evaluate the contribution of the muscle groups that are dominant for gait cycle [5]. For example (Fig. 1.) for the right knee joint at the beginning of the gait cycle a positive joint moment is observed followed by a significant decrease in value that indicates a flexion-extension movement.

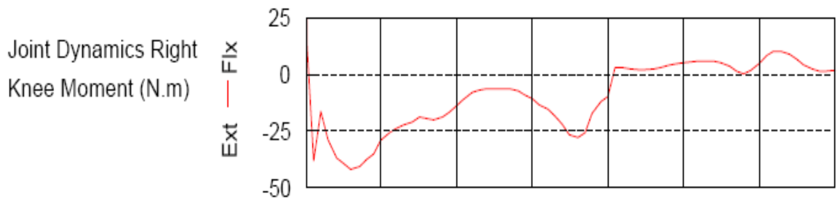

Fig. 1. Joint dynamics right knee moment [6]

This method used in biomechanics has some limitations one of which is due to the fact that values of joint reaction are underestimated because of: individual muscle activity that is not taken into consideration and because the individual muscles and tendons contribution to the gait cycle cannot be determined.

„AnyBody” software calculates, in a point or driveline defined by user, the forces and moments acting on a joint [7]. Algortihms used to solve this reverse dynamics problem are based on classic methods found in literature. They recive as input data the trajectories of the drivelines and the exterior forces acting on the sistem and they calculate the value of muscle forces capable to do movement under the specified conditions.

Method

The algorithm use for the selection of activ muscles available in AnyScript are the following: quadratic, linear, polynomial, min / max, AnyBody software allows the use of any of these algorithms. In literature the quadratic and polynomial algorithm are used, because the muscular activity resulted has a similar trend to the corresponding data obtained by electromyography.

For the insertion points of the artificial anterior cruciate ligament, the forces are reduced to two points of interest, one for the upper side correspondent to the femur and the other one on the lower side correspondent to the tibia (fig. 2.).

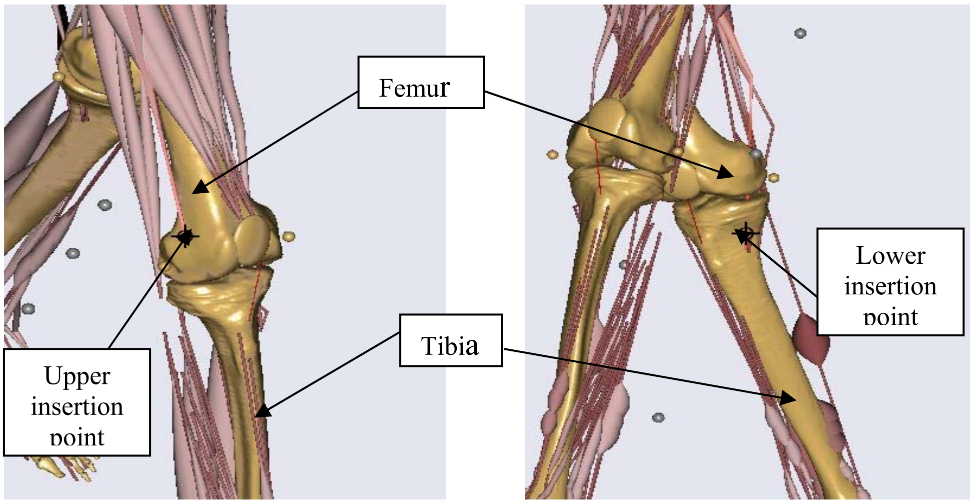

Fig.2. Insertion points of artificial anterior cruciate ligament

The algorithm used for the selection of the active muscles was polynomial of order two and for the result determination the foces developed by the muscles where taken into account, thus the joint stresses are close to reality.

Starting from the standard model for the human gait cycle (GaitUniMiamiTD) of AnyBody software, some changes where done in order allow the determination of the acting forces on the two points of interest (fig. 2).

Results and Discussions

The results obtained for the upper point corresponding to the femur are showed in Fig. 3. The lateral component and the normal component of the forces acting on the upper insertion point of the artificial ligament have similar maximum values approximate 1000 N for the first one and

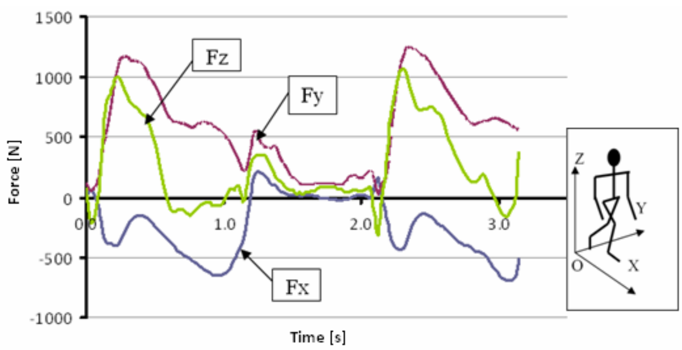

Fig. 3. Forces acting on the upper insertion point of the artificial ligament

1250 N for the lateral component, this occurs at the beginning of the step.

The minimum value of these two force components is 13 N for lateral and 310 N for the normal, this occurs and the end of the gait cycle. The axial component has similar value with a maximum 91 N of and a minimum of -645 N. These values show that in the upper point of insertion the higher stresses are on the lateral and normal component, namely at the beginning of the step.

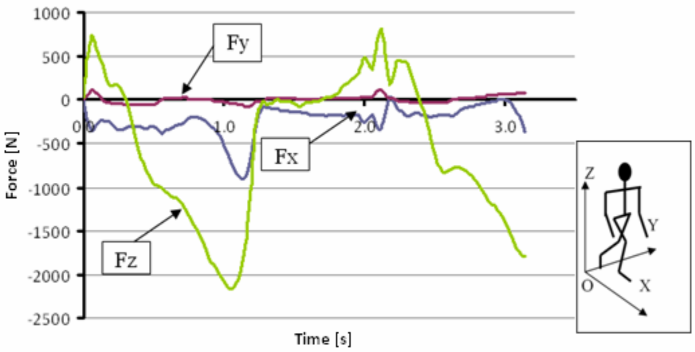

Fig. 4. Forces acting on the lower insertion point of the artificial ligament

The results obtained for the lower point corresponding to the tibia are showed in Fig.4. In this point a different behavior is observed, namely that the normal component values are most significant and reach a maximum of -2130 N during toe off.

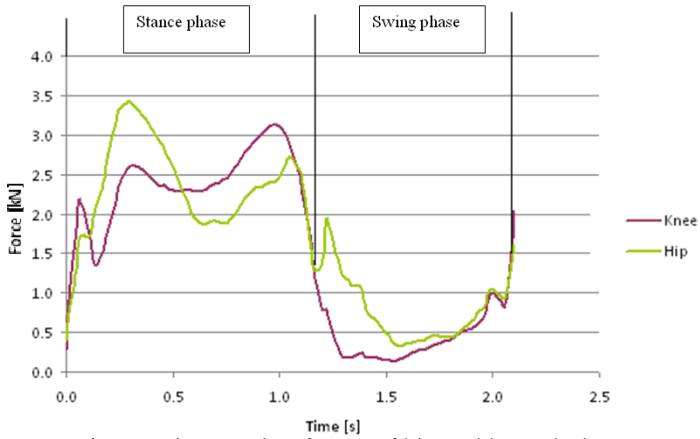

Fig. 5. Joint reaction forces of hip and knee during gait cycle

The peak value for the lateral component in this case is 121 N with a minimum value of -71 N, in correspondence with the other values obtained; we could conclude that the stress level in the lateral component is minimal. The maximum value of the axial component is 32 N with a peak minimum of -897 N at during toe off or at the beginning of the swing phase. For the validation of these results the joint reaction forces of hip and knee were determined using same method (Fig. 5.), the values obtained compared to those described in literature (Fig. 6.)[8-9].

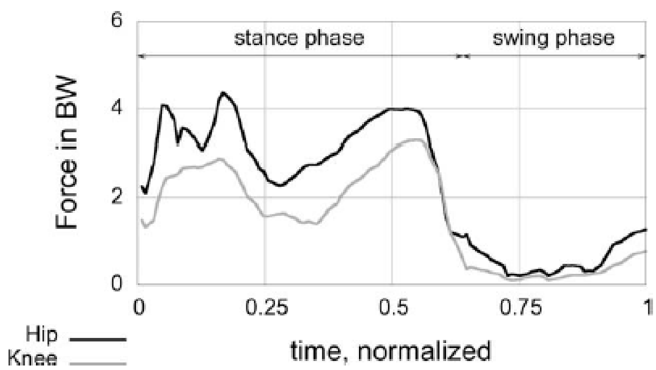

Fig. 6. Calculated resultant hip contact force and knee contact force in bodyweight (BW) over the gait cycle

The calculated resultant hip contact force, as well as the axial force on the tibia plateau showed loading peaks at the beginning, the peak values were 4.4 times bodyweight (1 BW = 85,6kg ~ 840N) for the hip contact force and 3.3 BW for the knee contact force [9]. The determined results have similar values and behavior like those presented in literature.

Conclusions

The artificial cruciate ligament should be designed according to this observations and should be able to sustain a multiaxial load, not just a load on the z axis. Furthermore the insertion points of the artificial ligament should be strong enought to sustain forces up to three times bodyweight on all three axes.

From the values of the force components it can be concluded that the maximum stress level occurs at the beginning of the stance and swing phase of the gait cycle because of the bodyweight load.

This method can be used to determine the value of force components, reaction forces, joint moments during gait cycle, data that can be use in finite element analysis as a alternative approach to pre-clinical tests and to offer a first aspect of the expected mechanical behavior of implants.

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Determinarea forțelor care acționează în punctele de inseție ale unui ligament artificial pe durata ciclului de mers

Rezumat

În această lucrare este prezentată determinarea forțelor care acționează în punctele de inserție ale unui ligament artificial pe durata ciclului de mers utilizând metoda dinamicii inverse si a pachetului sofware dedicat "AnyBody". Rezultatele obținute diferă pentru cele două puncte de inserție prin valorile componentei normale, acestea fiind semnificative. Aceste date pot fi utilizate pentru analiza cu element finit în vederea realizării unor modele noi de ligamente artificiale.