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Original Scientific Paper

Petrović, S., Matić, A., Devedžić, G., Ristić, B., Ćuković, S.

DIFFERENCES IN TIBIAL ROTATION AND TRANSLATION IN ACL DEFICIENT AND HEALTHY KNEES

Received: 7 July 2012 / Accepted: 23 August 2012

Abstract: *Anterior cruciate ligament (ACL) reconstructive surgery is used for achieving stability of the knee and normal gait pattern. Anterior – posterior translation and internal – external rotation are defined as the leading pathological parameters of the ACL deficiency. Nineteen adult men were examined in this study. Patients were walking along defined pathway at their own speed. Pathological parameters were defined based on kinematic data obtained by recording with six infrared cameras. Maximal values of the AP translation and IE rotation in early stance phase were recorded during preoperational measurement. Significiant value decrease of the AP translation and IE rotation were recorded after reconstructive ACL surgery.*

Key words: *anterior cruciate ligament, gait cycle, knee kinematic, reconstruction*

Razlike u rotaciji i translaciji ACL oštećenog i zdravog kolena. *Rekonstruktivna hirurgija prednjeg ukrštenog ligamenta (ACL) se koristi za postizanje stabilnosti kolena i normalnog hoda. Prednja – zadnja translacija i unutrašnja - spoljašnja rotacija su definisani kao vodeći nedostatak patoloških parametara ACL. Devetnaest odraslih muškarca su ispitivani u ovom radu. Pacijenti su hodali duž definisane putanje proizvoljnom brzinom. Patološki parametri su definisani na osnovu kinematskih podataka dobijenih snimanjem sa šest infracrvenih kamera. Maksimalne vrednosti AP translacije i IE rotacije u ranoj fazi zabeleženo tokom pred operativnih merenja. Značajne vrednosti smanjenja AP translacije i IE rotacije zabeleženo posle rekonstruktivne ACL operacije.*

Ključne reči: *prednji ukršteni ligamenti, kružno hodanje, kinematika kolena, rekonstrukcija*

1. INTRODUCTION

Anterior cruciate ligament (ACL) injuries are very common. Therefore, each year many people undergo ACL reconstructive surgery. Ligaments reconstruction is commonly based on using patellar tendon graft or a hamstring graft in order to resume knee stability and pain relief, and possibility of the recovery to athletic activities [1, 2].

Normal function of the knee lies in complex relationship of the movement and stability. Anterior cruciate ligaments of the knee are of the essential importance for providing passive restraint anterior – posterior knee movement. Primary function of the ACL is to prevent occurrence of the tibial translation along anterior – posterior (AP) direction, and to keep internal – external (IE) rotation in the appropriate limits [2, 3].

Purpose of this study is to present more precise and objective method for determining ACL deficient knees, and for judging the successfulness of the reconstructive surgery.

2. METHODS AND MATERIALS

2.1 Patients

Nineteen adult men with ACL deficient knees have voluntary agreed to participate in experiment of the gait analysis. Mean height of the patients is 183.33±2.24 cm, mean weight is 86±3.48kg, and mean value of the patients' age is 29.89±1.73.

Test analysis and surgery were performed at Clinical Centre Kragujevac, (Clinic for Orthopedics and Traumatology).

2.2 Instrumentation and protocol

3D kinematic data were recorded using OptiTrack (Natural Point, Inc., Oregon, www.naturalpoint.com) system with six infrared cameras (V100:R2) resolution 640x480 and software ARENA (Natural Point, Inc., Oregon, www.naturalpoint.com). On the patient's lower extremity four fluorescent markers, each 10mm in diameter, were set (Fig. 1):

- at region of the great trochanter (RGT),
- at lateral epicondyle of the femur (LEF),
- at tuberosity of the tibia (TT), and
- at the centre of the ankle joint (CAJ) .

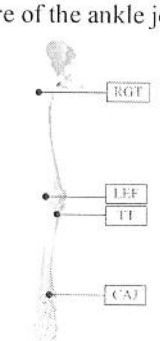


Fig. 1. Clinical positions of the leg landmarks

Patients walked 5.00m long pathway along which cameras were placed.

By protocol, patients had task to walk at their own speed. This task was performed four times. Preoperational measuring was performed the day before surgery and post operational measuring 15 days after the surgery.

2.3 Kinematic data

Movement curves were recorded in regions of the fluorescent markers' positions for the ACL deficient and healthy knees.

Patients gait were presented with a three–dimensional curves, which were exported from ARENA software in standard VICON .c3d format, and were further processed in Catia V5 (Dassault Systemes, France, www.3ds.com) and MatLab (The MathWorks, Inc., USA, www.mathworks.com).

In order to define pathological gait parameters, phases of the gait cycle were assigned on the basis of centre ankle joint curve in sagittal plane (Fig. 2) [4].

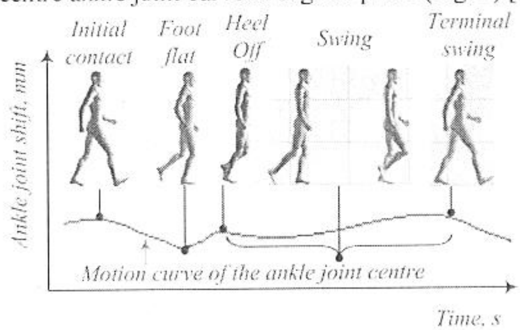


Fig. 2. Phases of the gait cycle

Gait cycle begins when one foot contacts the ground, and ends when that foot contacts the ground again. Initial contact between foot and the ground labels beginning of the ankle joint center curve descend to local minimum. Local minimum labels foot flat phase of the gait cycle. Continuous curve increase, marking heel–off and transition in swing phase. In this phase, movement curve is conditionally horizontal. Curve decrease to next local minimum labels end of the swing phase and transition in terminal swing phase which define end of the gait cycle [4].

Classification of the movement curves were performed in two groups, one group with deficient ACL knees, and another group with healthy ACL knees.

Values which define tibial shift relative to the femur are given in function of time, e.g. defined in the percentage of the gait cycle relative to time.

2.4 Data analysis

Femoral coordinate system can be considered for referent coordinate system that does not change its orientation because tibial translation and rotation (AP translation and IE rotation) relative to the femur occurs in the deficient ACL knees [4, 5, 6, 7].

If we consider tibia as rigid body, its movement can be identified with movement of the marker placed at the tuberosity of the tibia. In one moment (point TT_1), coordinate system of the tibia occupies certain position relative to the femur. In that case, it is possible to define tangent line on the movement curve t_1 and corresponding normal line n_1 at the point TT_1. In next moment (point TT_2), coordinate system of the tibia capture another position relative to the femoral coordinate system where it is possible to determine tangent line on the movement curve t_2 and corresponding normal line n_2 at the point TT_2.

Tangent and normal lines on the movement curve of the tibia will match respectively with x – axis and y – axis at any time [4]:

$$x_{ti} \perp y_{ti} \;\; i \;\; t_i \perp n_i \Rightarrow x_{ti} \parallel t_i \;\; i \;\; y_{ti} \parallel n_i \qquad (1).$$

Determination of the IE rotation angle is based on definition of the movement curve tangent line coefficient and on definition of the angle between tangent line and AP axis of the femoral coordinate system (Fig. 3) [4, 7]:

$$t = f'(x_i) = \frac{dy_i}{dx_i} \qquad (2).$$

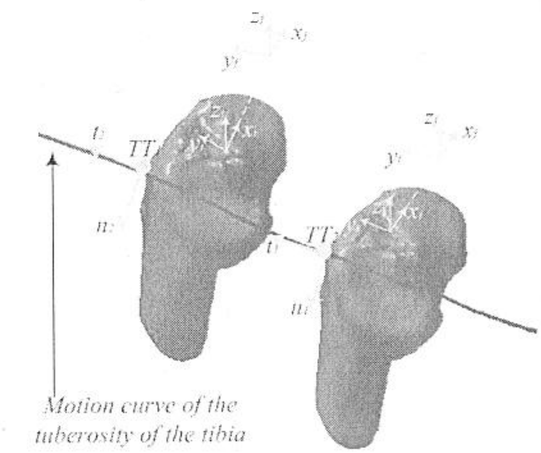


Fig. 3. Tibial translation along AP direction and IE rotation

LEGEND:

TT_1 - tuberosity of the tibia in one moment, TT_2 - tuberosity of the tibia in one moment, x_f - mediolateral axis of the femur, y_f - anteriorposterior axis of the femur, z_f - superior - inferior axis of the femur, x_t - mediolateral axis of the tibia, y_t - anteriorposterior axis of the tibia, z_t - superior - inferior axis of the tibia, t_1, t_2 - tangent line of the curve at the point TT1, e.g. TT_2, and n_1, n_2 - normal line of the curve at the point TT_1, e.g. TT_2

Value of the distance between points TT_1 and TT_2 along all directions and planes indicates possibility of the ACL deficient knees. Since displacement along inferior – superior and medial – lateral directions is negligible, determination of the tibial translation along AP direction (Fig. 3) is conducted by successive calculating the affine coordinates along AP direction [4]:

$$d_{TTAP} = (TT)_{i+1} - (TT)_i \qquad (3),$$

where is

$(TT)_i$ - tuberosity of the tibia in i - th moment, and

$(TT)_{i+1}$ - tuberosity of the tibia in i+1 - th moment.

3. RESULTS

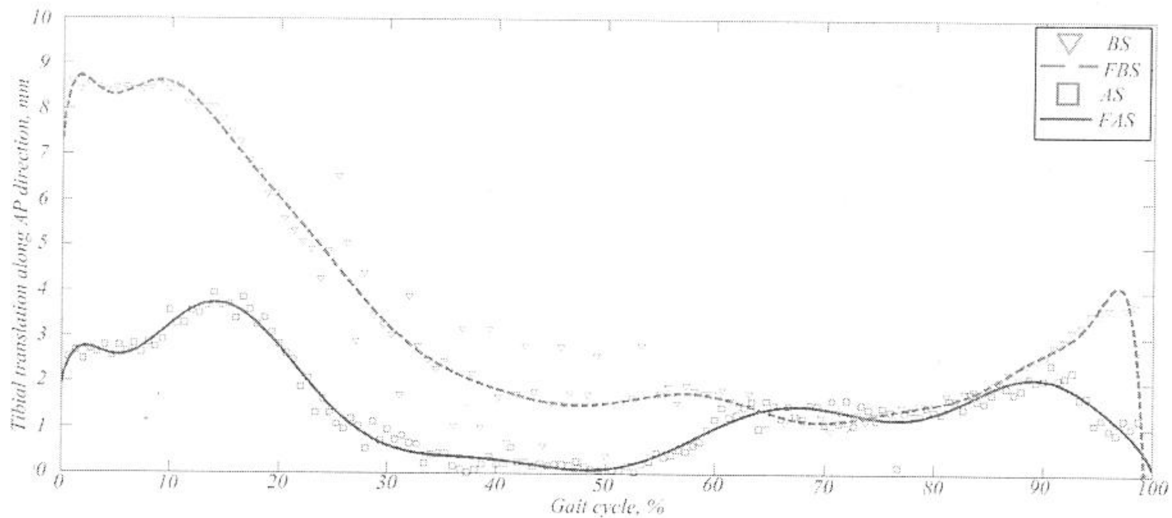
In order to obtain cuves of the AP translation and IE rotation eight order Furier approximation is applied.

The horizontal axis shows percentage distribution of the gait cycle and the vertical axis shows difference of the tibial translation changing in milimeters, e.g. difference of the IE angle rotation changing.

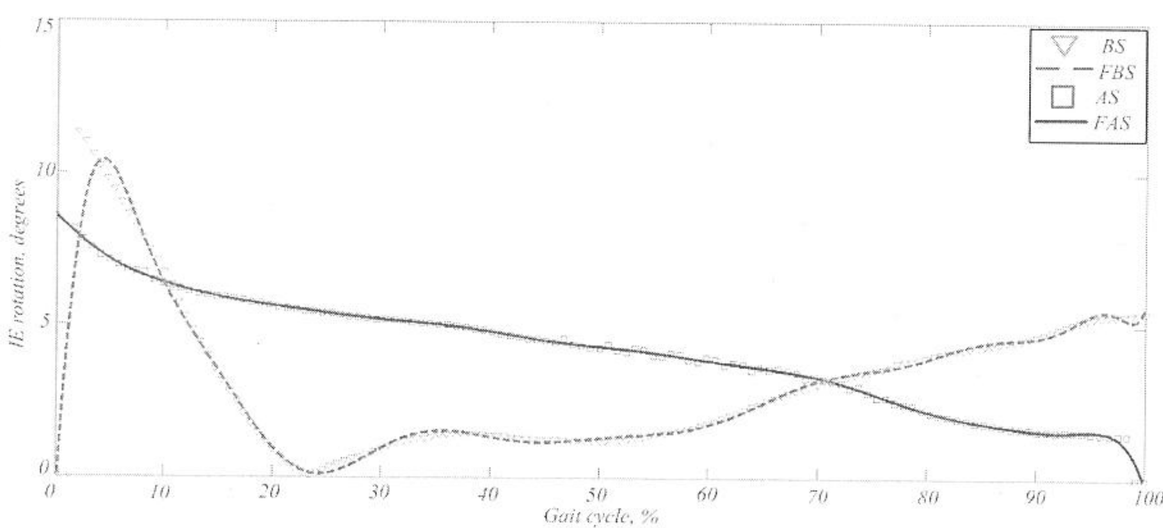
Diagrams at the Figure 4 show that these pathological parameters have the big influence on the knee stability. Measurements before operation, at the initial contact between foot and the ground which correspond to 20% of the horizontal axis, points to the high amplitudes of the AP translation, e.g. IE rotation. Before, surgery, mean value of the AP translation is 6.619±1.447mm, and for IE rotation is 6.169 ±0.711° [7].

Curves on diagrams which show patients' walk pattern after surgery has lower amplitudes, and intensity of the AP translation and IE rotation changes is decreased. Mean value along AP direction is 3.0901±0.551mm, and IE rotation is 2.382±0.477° [4].

Student t – test was used for purpose of the statistical significance of the experimental results. It can be seen that the character of the change in preoperational and post operational period is not random, but is created under the influence of the systematic or experimental factors for possible error P<0.1 and for certainty of the P>99%.



a)



b)

Fig.4. Values of the pathological parameters during gait cycle for: a) AP translation, and b) IE rotation

LEGEND:

BS - Changes of the tibial AP translation (or changes of the IE angle) before surgery, *FBS* – Fitted curve of the tibial AP translation (or changes of the IE angle) before surgery, *AS* - Changes of the tibial AP translation (or changes of the IE angle) after surgery, and *FAS* - Fitted curve of the changes tibial AP translation (or changes of the IE angle) after surgery after surgery.

4. DISCUSSION AND CONCLUSIONS

Knowing knee kinematics is of the great importance for getting relevant knee function information which can be used for improvement treatment of the knee pathology [6]. In this study inovative gait analysis technique is applied.

Stable knee joint implies small values of the AP translation and IE rotation. In order to achieve fuctional role of the ACL, gait cycle specific phases which have influence on pathological kinematic of the ACL deficient knee joint have to be determined.

Numerous reserchers have noticed tibial translation along AP direction and higher values of the IE rotation using in vitro and in vivo experiments [8, 9]. Results of this study shown in Figure 4, concides with results [3, 6]. Maximal values of the AP translation and IE rotation occur in early stance phase when heel strikes [5]. After ligament reconstruction surgery, these values decreased.

Andriacchi et al. and M. Kozanek et al. have shown that there is conection between AP translation and flexion – extension of the knee movement. At initial contact between foot and the ground, anterior position of the tibia relative to the femur is related with extensor mechanisam pulling on the tibia [2,6]. During foot flat phase tibia sliding posteriorly as the knee flexion. This is in agreement with Bergamini et al. which were shown ACL decrese during knee flexion [9]. Our results show (Fig.4) maximal values of the AP translation when knee is in extension, e.g. heel strikes.

Bull et al. in study show that there is significiant reduction of the pathological IE rotation across the whole range of the knee motion measured after ACL reconstruction surgery [10]. This correspond with results shown in Figure 6b, where maximal values of the IE rotation at the begginig of the gait cycle occurs, and after reconstruction surgery decrease [11].

Using the same clinical position of the leg landmarks, limitations of this study are minimized which are related to the measurement errors and data noise coming from skin and soft tissue motion.

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