



UNIVERSITY OF NOVI SAD
Faculty of Technical Sciences
Department of Production Engineering
NOVI SAD, SERBIA



UDK 621

ISSN 1821-4932

JOURNAL OF
PRODUCTION ENGINEERING

Volume 16

No.1

Novi Sad, 2013



University of Novi Sad
FACULTY OF TECHNICAL SCIENCES
DEPARTMENT OF PRODUCTION ENGINEERING
21000 NOVI SAD, Trg Dositeja Obradovica 6, SERBIA



UDK 621

ISSN 1821-4932

JOURNAL OF
PRODUCTION ENGINEERING

Volume 16

Number 1

Novi Sad, March 2013

Publisher: FACULTY OF TECHNICAL SCIENCES
DEPARTMENT OF PRODUCTION ENGINEERING
21000 NOVI SAD, Trg Dositeja Obradovica 6
SERBIA

Editor-in-chief: Dr. Pavel Kovač, *Professor, Serbia*

Reviewers: Dr. Miroslav BADIDA, *Prof. Ing. Slovak Republic*
Dr. Janko HODOLIČ, *Professor, Serbia*
Dr. Marin GOSTIMIROVIĆ, *Professor, Serbia*
Dr. Frantisek HOLESOVSKY, *Professor, Czech Republic*
Dr. Janez KOPAČ, *Professor, Slovenia*
Dr. Pavel KOVAČ, *Professor, Serbia*
Dr. Mikolaj KUZINOVSKI, *Professor, Macedonia*
Dr. Ildiko MANKOVA, *Professor, Slovak Republic*
Dr. Snežana RADONJIĆ, *Professor, Serbia*
Dr. Krzysztof ROKOSZ, *Professor, Poland*
Dr. Branko ŠKORIĆ, *Professor, Serbia*
Dr. Ljubomir ŠOOŠ, *Professor., Slovak Republic*
Dr. Miodrag HADŽISTEVIC, *Assoc. Professor, Serbia*
Dr. Mijodrag MILOŠEVIĆ, *Assist. Professor, Serbia*
Dr. Đorđe VUKELIĆ, *Assist. Professor, Serbia*

Technical treatment and design: M.Sc. Borislav Savković, *Assistant*
Dr. Mijodrag Milošević, *Assist. Professor*

Manuscript submitted for publication: March 10, 2013.
Printing: 1st
Circulation: 300 copies

CIP classification:

Printing by: FTN, *Graphic Center*
GRID, Novi Sad

ISSN: 1821-4932

CIP – Каталогизacija y publikaciji
Библиотека Матице српске, Нови Сад

621

JOURNAL of Production Engineering / editor in chief
Pavel Kovač. – Vol. 12, No. 1 (2009)- . – Novi Sad :
Faculty of Technical Sciences, Department for Production
Engineering, 2009-. – 30 cm

Dva puta godišnje (2012-). Je nastavak: Časopis proizvodno
mašinstvo = ISSN
0354-6446
ISSN 1821-4932



Contents

ORIGINAL SCIENTIFIC PAPER

Gostimirovic, M., Rodic, D., Kovac, P., Pucovsky, V., Sekulic, M. MODELING OF MATERIAL REMOVAL RATE IN EDM USING NEURAL FUZZY SYSTEMS	1
Homar, D., Kopač, J., Dolinšek, S. ADDITIVE MANUFACTURING AND HIGH SPEED CUTTING INCLUDED IN HYBRID MANUFACTURING	5
Peterka, J., Kováč, M., Beňo, M., Zvončan, M. EFFECT OF CUTTING PARAMETERS ON DELAMINATION FACTOR IN ROTARY ULTRASONIC MACHINING OF FIBERGLASS	9
Dučić, N., Čojbašić, Ž., Slavković, R., Radonjić, S. APPLICATION OF NEURAL NETWORKS FOR PREDICTING CHARACTERISTICS OF ELASTIC SUPPORTS TO PRODUCTION MACHINES	13
Gyenge, C., Rafa, A., Pacurar, A., Bob, M. SOME CHARACTERISTICAL ASPECTS REGARDING CNC GRINDING OF SPUR GEARS	17
Borojević, S., Jovišević, V. SELECTION AND CONFIGURATION OF MODULAR COMPONENTS FOR MODULAR FIXTURE DESIGN	21
Savic, B., Slavkovic, R., Veg, E., Urosevic, V., Vlajković, H. USE OF VIRTUAL AND ACTUAL VIBRO-DIAGNOSTICS FOR BETTER CONDITION MONITORING	27
Zuperl, U., Cus, F. FIXTURE ANALYSIS MODULE, AN ESSENTIAL ELEMENT OF THE INTELLIGENT FIXTURING SYSTEM	31
Mansour, G., Sagris, D., Tsiafis, Ch., Mitsi, S., Bouzakis, K.-D. EVOLUTION OF A HYBRID METHOD FOR INDUSTRIAL MANIPULATOR DESIGN OPTIMIZATION	35
Novak-Marcincin, J., Barna, J., Torok, J. ADVANCED AUGMENTED REALITY APPLICATIONS IN THE PRODUCTION PROCESSES	39
Petrović, P.B., Lukić, N., Danilov, I., Miković, V. CANONISATION OF ACTUATION STIFFNESS MATRIX IN KINEMATICALLY REDUNDANT INDUSTRIAL HUMANOID ROBOTS	43

Todić, V., Lukić, D., Milošević, M., Jovičić, G., Vukman, J. MANUFACTURABILITY OF PRODUCT DESIGN REGARDING SUITABILITY FOR MANUFACTURING AND ASSEMBLY (DfMA)	47
Topčić, A., Cerjaković E., Herić, M. SIMULATION OF RELOADING SEGMENTS OF INTERNAL TRANSPORTATION SYSTEMS BY ARTIFICIAL NEURAL NETWORKS.....	51
Arsovski, S., Lazić, M., Krivokapić, Z., Tadić, D., Grubor, S. AN APPROACH TO DEFINE OPTIMAL TECHNOLOGY PORTFOLIO OF ELV RECYCLING	55
Tichá, M., Budak, I. LCA APPLICATION IN EPD AND ECO-EFFICIENCY	59
Neugebauer, R., Voelkner, W., Mauermann, R., Israel, M. CLINCHING IN STEEL AND RAILWAY CONSTRUCTION, SHIPBUILDING AND COMMERCIAL VEHICLES	63
Rajnovic, D., Sidjanin, L. THE DUCTILE TO BRITTLE TRANSITION TEMPERATURE OF UNALLOYED ADI MATERIAL	69
Petrović, S., Matic, A., Devedžić, G., Ristić, B., Čuković, S. DIFFERENCES IN TIBIAL ROTATION AND TRANSLATION IN ACL DEFICIENT AND HEALTHY KNEES.....	73
Puskar, T., Jevremovic, D., Eggbeer, D., Lapcevic, A., Trifkovic, B., Vukelic, D., Williams, R.J. DETERMINATION OF CORROSION CHARACTERISTICS OF DENTAL ALLOY BY INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY	77
Tabaković, S., Zeljković, M., Živković, A., Grujić, J. DEVELOPMENT OF THE ENDOPROSTHESIS OF THE FEMUR ACCORDING TO THE CHARACTERISTICS OF A SPECIFIC PATIENT.....	81
 PRELIMINARY NOTE	
Senderská, K., Lešková, A., Mareš, A. DESIGN CHARACTERISTICS OF MANUAL ASSEMBLY WORKSTATION SYSTEM IN THE LEAN PRODUCTION STRUCTURES	87
Alexandrov, S., Lyamina, E., Manabe, K. A THEORETICAL STUDY ON SURFACE ROUGHING IN PURE BENDING OF VISCOPLASTIC SHEETS.....	93
Maňko, M., Košíková, ISO 50001 AS THE BASIS FOR IMPLEMENTING AN ENVIRONMENTAL MANAGEMENT SYSTEM	97
IN MEMORIAM: Professor Jožef Rekecki	101
 INSTRUCTION FOR CONTRIBUTORS	103

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. Significant 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 voluntarily agreed to participate in experiment of the gait analysis. Mean height of the patients is 183.33 ± 2.24 cm, mean weight is 86 ± 3.48 kg, 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).

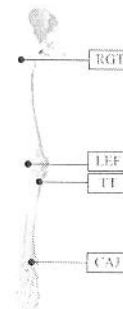


Fig. 1. Clinical positions of the leg landmarks

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].

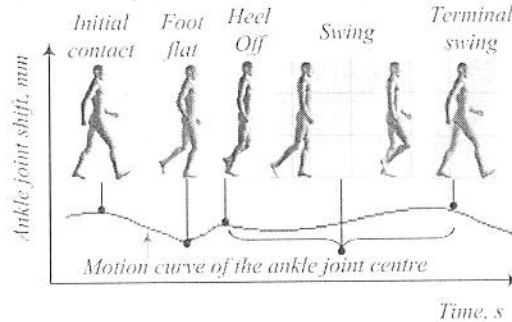


Fig. 2. Phases of the gait cycle

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]:

$$x_{ii} \perp y_{ii} \text{ i } t_i \perp n_i \Rightarrow x_{ii} \parallel t_i \text{ i } y_{ii} \parallel n_i \quad (1)$$

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]:

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

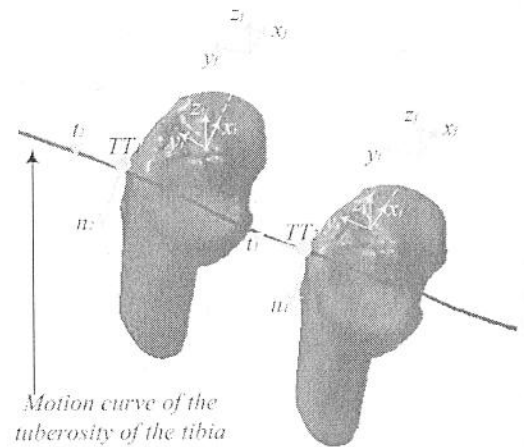


Fig. 3. Tibial translation along AP direction and IE rotation

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 - anterior-posterior axis of the femur, z_f - superior - inferior axis of the femur, x_t - mediolateral axis of the tibia, y_t - anterior-posterior axis of the tibia, z_t - superior - inferior axis of the tibia, t_1, t_2 - tangent line of the curve at the point TT_1 , 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]:

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

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 curves of the AP translation and IE rotation eight order Fourier approximation is applied.

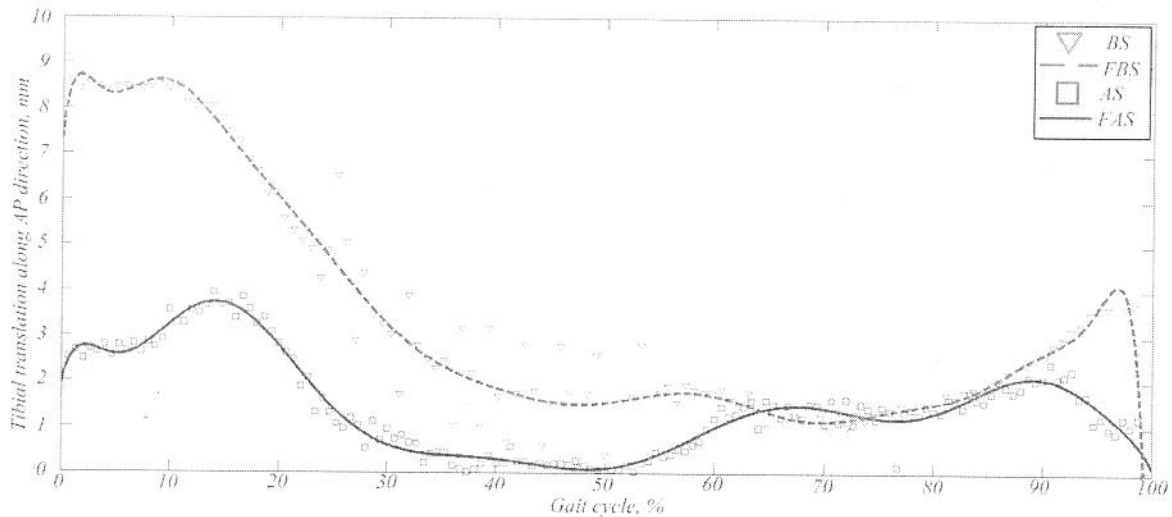
The horizontal axis shows percentage distribution of the gait cycle and the vertical axis shows difference of the tibial translation changing in millimeters, e.g. difference of the IE angle rotation changing.

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

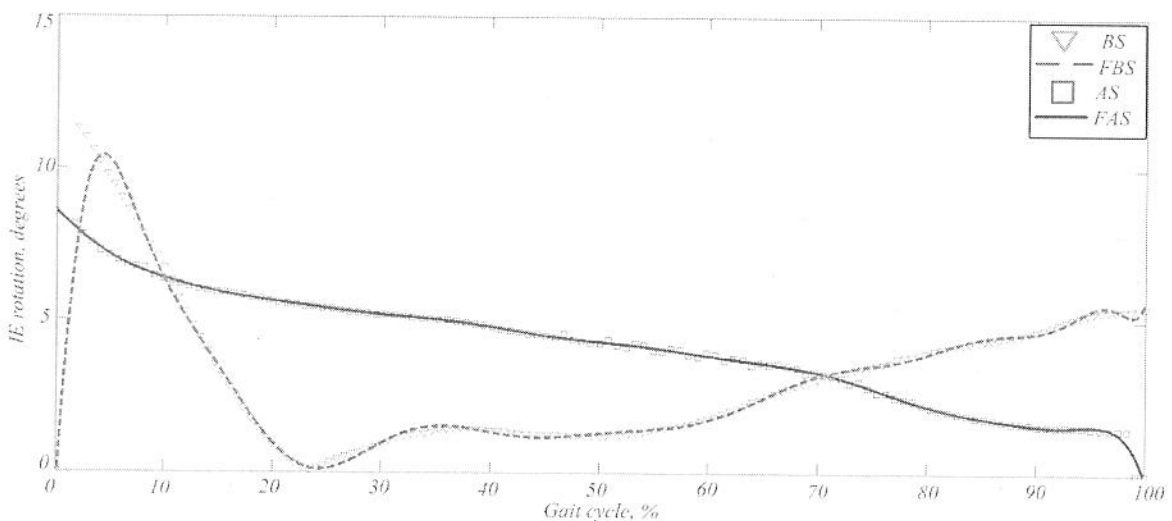
$6.619 \pm 1.447 \text{mm}$, and for IE rotation is $6.169 \pm 0.711^\circ$ [7].

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 $3.0901 \pm 0.551 \text{mm}$, and IE rotation is $2.382 \pm 0.477^\circ$ [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.

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 decrease 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 significant 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.

ACKNOWLEDGNMENTS

This work has been partly supported by Ministry of Education and Science of Serbia, Grants No. III-41007 and project supported by Faculty of Medicine Kragujevac, Grant JP 20/10.

5. REFERENCES

- [1] Dauty M., Menu P., Dubois C.: *Effect of running retraining after knee anterior cruciate ligament reconstruction*, Annals of Physical and rehabilitation Medecine, 53, p.p 150 – 161, 2010.
- [2] Beasley L.S., Weiland D.E., Vidal A. F., Chhabra A., Herzka A.S., Feng M.T., West R.V.: *Anterior Cruciate Ligament Reconstruction: A Literature Review of the Anatomy, Biomechanics, Surgical Considerations, and Clinical Outcomes*, Operative Techniques in Orthopaedics, 15, p.p. 5 – 19, 2005.
- [3] Scanlan S.F., Chaudhari A.M.W., Dyrby C.O.,

Andriacchi T.P.: *Differences in tibial rotation during walking in ACL reconstructed and healthy contralateral knees*, Journal of Biomechanics, 42, p.p. 1817 – 1822, 2010.

- [4] Matić A., Ristić B., Devedžić G., Filipović N., Petrović S., Mijailović N., Čuković S.: *Gait analysis in the patients with chronic anterior cruciate ligament injury*, Serbian Journal of Experimental and Clinical Research, 13, p.p. 49 - 54, 2012.
- [5] Yeow C.H., Gan W.L., Lee P.V.S., Goh J.C.H.: *Effect of an anterior - sloped brace joint on anterior tibial translation and axial tibial rotation: A motion analysis study*, Clinical Biomechanics, 25, p.p. 1025 - 1030, 2010.
- [6] Kozanek M., Hosseini A., Liu F., Van de Velde S.K., Gill T.J., Rubash H.E.: *Tibiofemoral kinematics and condylar motion during the stance phase of gait*, Journal of Biomechanics, 42, p.p. 1877 - 1884, 2009.
- [7] Shelburne K., Pandy M.G., Torry M.R.: *Comparasion of shear forces and ligament loading in the healthy and ACL - deficient knee during gait*, Journal of Biomechanics, 37, p. p. 313 -319, 2004.
- [8] Koh A.S.B., Nagai T., Motojima S., Sell T.C., Lephart S.M.: *Concepts and Measurement of In Vivo Tibiofemoral Kinematics*, Operative Techniques in Orthopedics, 15, p.p. 43-48, 2005.
- [9] Bergamini E., Pillet H., Hausselle J., Thoreux P., Guerard S., Camomilla V., Cappozzo A., Skalli W.: *Tibio-femoral joint constraints for bone pose estimation during movement using multi-body optimization*, Gait & Posture, 33, p.p. 706 - 711, 2011.
- [10] Bull A.M.J., Ernsshaw P.H., Smith A., Katchburian, Hassan A.N.A., Amis A.A.: *Intraoperative measurement of knee kinematics in reconstruction of the anterior cruciate ligament*, The journal of bone & joint surgery, 84-B, p.p 1075 - 1081, 2002.
- [11] Wang H., Fleischli J. E., Zheng N.N.: *Effect of lower limb dominance on knee joint kinematics after anterior cruciate ligament reconstruction*, Clinical Biomechanics, 27, p.p. 170 - 175, 2012.

Authors: Prof. Dr. Goran Devedžić, Suzana Petrović, dipl.ing., Saša Čuković, dipl.ing., University of Kragujevac, Faculty of Engineering, Department for Production Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, Phone.: +381 34 -, Fax: E-mail: devedzic@kg.ac.rs
suzana.petrovic@mfg.rs
cukovic@kg.ac.rs

Prof. Dr Branko Ristić, Dr Aleksandar Matić, University of Kragujevac, Faculty of Medicine, Svetozara Markovića 69, 34000 Kragujevac, Serbia, Phone.: +381 34 306 - 800, Fax: E-mail: branko.ristic@gmail.com
aleksandarmatic@gmail.com