LOWER LIMB KINEMATICS AND KINETICS AFTER TOTAL KNEE ARTHROPLASTY SURGERY DURING RUNNING – A CASE STUDY

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To date orthopedist's recommendations concerning high impact activities after knee arthroplasty surgery such as running are rather based on conjectures than evidence based research. Hence this study aimed to investigate walking and running locomotion of a female total knee arthroplasty patient by means of an inverse dynamic approach. The results showed reduced knee adduction moments in the affected knee and a redistribution of generated energy to the detriment of the hip joint during running. The described results should be confirmed by further studies with larger cohorts. The primary purpose should be to provide profound information to patients after knee arthroplasty surgery regarding possibilities and limitations of high impact sports activities participation.

KEY WORDS: knee arthroplasty, running, AnyBody.

INTRODUCTION: Orthopedists recommend patients after knee arthroplasty surgeries to pursue an active lifestyle and thereby to improve e.g. muscle strength, aerobic capacity as well as weight reduction. Sports participation is stated to be a valid tool to achieve one's individual goals. However there is a debate how much and what kind of sports activities patients with replaced knee joints can participate in. To the present day clinical recommendations are rather based on expert opinion or surgeons preferences respectively than on research evidence (Witjes, Gouttebarge, Kuijer, van Geenen, Poolman & Kerkhoffs, 2016). In this regard several surveys (e.g. "1999 Knee Society Survey" by Healy, Iorio & Lemos, 2001) categorize various sports activities, some of whom are more or less recommended for patients with total knee arthroplasty (TKA). According to Healy et al. (2001), interviewed surgeons discouraged participation in so called "high impact sports" (HIS) like running or tennis due to higher risks of implant loosening, polyethylene wear and trauma leading to premature revision surgery. Nevertheless, a recent systematic review by Witjes et al. (2016) clarifies that 43% of TKA-patients are able to return to HIS, whereby only 7% participated in HIS preoperatively. Particularly, younger active patients, who want to perform HIS could benefit of evidence based recommendations. Surprisingly, biomechanical studies analyzing HIS, like for instance running, in patients with knee prosthesis are very rare. In the unique studies of Bergmann, Bender, Graichen, Dymke, Rohlmann, Trepczynski, Heller & Kutzner (2014) and D'Lima, Steklov, Patil & Colwell (2008) different daily activities (including running) in patients after TKA were investigated by means of custom made tibial components with integrated strain gauges to measure forces and moments. The authors measured peak forces up to 5 times body weight during running compared to 1.8 to 2.5 times body weight during level walking (D'Lima et al., 2008). However, the non-operated limb and further joints of the lower extremity were not considered remaining potentially undetected compensatory mechanisms. The purpose of this current case study is to describe the kinematics and kinetics of a TKA-patient during level walking and running. Besides, this investigation aims to motivate other authors to accomplish further studies in this field of research, providing patients with knee endoprosthesis evidence based recommendations in daily clinical practice concerning sports activities.

METHODS: One female subject, 52 years of age, participated one year after TKA-surgery in this study (Table 1). The initial diagnosis was osteoarthritis with symptom-free contralateral limb and no musculoskeletal disabilities. After the knee replacement surgery the subject ran on average eight kilometers a week. Motion analysis was performed using an optoelectronic eleven-camera motion capture system (100 Hz, Vicon, Oxford, UK). Two force plates (1000 Hz, Kistler, Winterthur, Switzerland) were embedded in the floor. According to the author's own created marker-set, fifty retro-reflective markers were attached to subject's feet, shank, thighs, pelvis, thorax, upper arm, lower arm and head to create a 17-segment rigid model. Subject's segment lengths were measured to define the moments of inertia more accurately. Kinematics and kinetics calculations were performed with AnyBody Modeling System (AnyBody Technology, Aalborg, DK). A Butterworth low pass filter (recursive, 6 Hz cut off for level walking, 40 Hz for running) was applied for kinematic and kinetic data. Data post-processing was conducted with Matlab 2013b (The MathWorks, Inc., Natick, US). Moments are presented as external moments normalized by body weight and height. The subject completed two tasks on the ground: level walking (1.4 m/s) and running (2.8 m/s). For each motor task five trials were averaged for data analysis. No statistical analysis was performed. Discrete values are presented as means of five trials. Only the first 50% of stance phase were included, except the transversal plane values (0-100% of stance phase).

RESULTS: The affected knee showed less internal rotation compared to the not affected knee in level walking as well as in running. Similar range of motion (RoM) was observed during level walking, but considerably less RoM during running in the affected knee. According to this aspect, running was performed with greater transversal knee joint stiffness values in the affected limb (Table 1, 2). In both conditions the subject presented lower adduction and internal rotation moments in the affect knee accompanied by lower adduction angular momentum values. During running similar knee flexion moments were measured in both knees, whereas during level walking the flexion moment was distinctly greater in the affected leg.

Table 1
Subject's characteristics

Age	BMI (kg/cm²)	Height (m)	Sex	Affected limb	Prosthesis
52	27.4	1.72	female	Right	Sigma® (posterior stabilized)
					DePuy Synthes, West Chester, US

Table 2
Knee kinematics and kinetics during level walking

	Angle (°)				**Moment (Nm/kg/m)**		**Angular Momentum (Nm/kg/m/s)**		**Knee Joint Stiffness (Nm/kg/m/°)**	
	Max		**RoM**		**Max**					
Plane	*n.a*	*a*	*n.a*	*a*	*n.a*	*a*	*n.a*	*a*	*n.a*	*a*
Sagittal	9.1	10.7	10.4	8.2	0.12	0.22	0.001	0.03	0.02	0.04
Frontal	2.6	1.8	2.6	1.7	0.35	0.26	0.07	0.05	0.14	0.15
Transversal	6.1	0.7	12.8	12.1	0.15	0.08			0.008	0.006

n.a=not affected limb; a= affected limb

Table 3
Knee kinematics and kinetics during running

	Angle (°)				**Moment (Nm/kg/m)**		**Angular Momentum (Nm/kg/m/s)**		**Knee Joint Stiffness (Nm/kg/m/°)**	
	Max		**RoM**		**Max**					
Plane	*n.a*	*a*	*n.a*	*a*	*n.a*	*a*	*n.a*	*a*	*n.a*	*a*
Sagittal	31	28.7	28.2	20.1	0.88	0.83	0.04	0.05	0.04	0.05
Frontal	2.2	2.7	0.8	1	0.72	0.46	0.06	0.04	0.9	0.48
Transversal	5.9	-2.8	12.7	6.2	0.2	0.1			0.008	0.01

In Figure 1, the illustrated energy contribution shows that the affected knee generated much less positive energy (17% of total work) than the not affected knee (33% of total work) during running. In this regard, the ankle and especially the hip joint compensated that deficit, being more than twice the magnitude of the not affected limb, at least for the hip joint (17% versus 7% of total work, Figure 1).

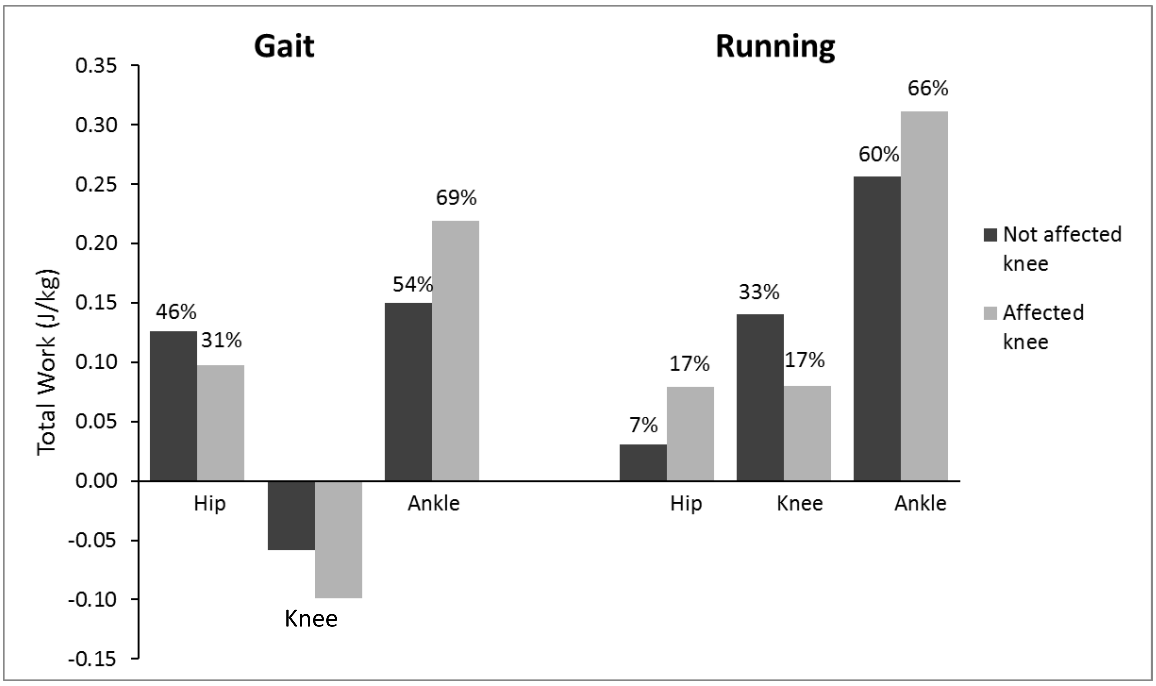

Figure 1: Contribution of the hip, knee and ankle joints to the absorbed and generated energy during stance phase of level walking and running.

DISCUSSION: The current case study provides a rare insight in level walking and running locomotion of a TKA-patient. The results clarify the discrepancy between the affected and not affected knee or limb respectively. Particularly, the running condition showed less knee RoM and interestingly higher transversal plane joint stiffness values in the affected knee compared to the not affected knee. Potential reasons like rotational constraints of the endoprosthesis or muscle co-contraction have to be taken into consideration. Higher knee joint stiffness values during running might contribute to premature component loosening of the tibial tray. In both tasks the maximum knee adduction moment and adduction angular momentum during 50% of stance phase were diminished in the affected knee indicating reduced medial load of endoprosthesis bearing. These results correspond to those of Alnahdi, Zeni & Snyder-Mackler (2010) during level walking. The authors emphasize increased risk of osteoarthritis progression in the medial compartment of the not affect knee. Due to absence of a control group in the current study assumptions regarding the mentioned aspect should be treated with caution. A very interesting finding was a considerable redistribution of generated energy in the affected limb compared to the not affected limb during running. Less energy was generated in the affected knee, whereby in particular the ipsilateral hip joint compensated that deficit, potentially expediting osteoarthritis in the hip joint. Besides the potential risks of running, patients after TKA might improve their bone quality underneath the tibial tray as well the implant fixation (Witjes et al., 2016). Furthermore, highly cross-linked polyethylene is stated to reduce the risk of revision due to decreased wear-particle-induced osteolysis (Chakravarty, Elmallah, Cherian & Kurtz 2015). In this regard studies confirm that polyethylene wear is no longer the common reason for TKA-revision (Sharkey, Lichstein, Shen, Tokarski & Parvizi, 2014), which contradicts the concerns of the interviewed surgeons in the “1999 Knee Society Survey”).

CONCLUSION: The results suggest that the kinematics and kinetics of a TKA-patient are not normal during level walking and especially during running. More biomechanical studies with larger cohorts are necessary to confirm the observed findings. This would provide knee arthroplasty-patients, who wish to return in running sports, a sound guideline to prevent potential risks of complications or even premature revision-surgery.

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