LOWER LIMB BIOMECHANICAL ADAPTATIONS TO TOTAL HIP ARTHROPLASTY EXIST DURING SITTING AND STANDING TASKS

Mélanie L. Beaulieu[1], Mario Lamontagne[1,2], Daniel Varin[1] and Paul E. Beaulé[3]

School of Human Kinetics, University of Ottawa, Ottawa, Canada[1]
Department of Mechanical Engineering, University of Ottawa, Ottawa, Canada[2]
Division of Orthopaedic Surgery, University of Ottawa, Ottawa, Canada[3]

The purpose of this study was to determine the effect of total hip arthroplasty (THA) on lower limb mechanics during the tasks of sit-to-stand and stand-to-sit. Twenty THA patients and 20 control participants performed three trials of sit-to-stand and stand-to-sit. Three-dimensional (3D) hip, knee and ankle angles were calculated. Forces, moments and powers were obtained with an inverse dynamics approach. THA patients exhibited lower joint forces and moments, as well as lower hip flexion and higher abduction angles, near seat-on and seat-off. These results indicate that THA patients were able to adopt a strategy that allowed them to reduce loading at the operated lower limb joints. Although such a strategy may be desirable given that higher loads can increase friction and accelerate wear of the prosthesis, reduced loading may be an indication of inadequate muscle strength that needs to be addressed.

KEY WORDS: total hip arthroplasty, sit-to-stand, stand-to-sit, kinematics, kinetics.

INTRODUCTION: Total hip arthroplasty (THA) is known to be a successful joint replacement procedure given that most patients experience significant pain alleviation, as well as an improvement in their capability to perform essential daily activities (Mancuso et al., 1997). In spite of these positive outcomes, the literature reveals that numerous biomechanical adaptations persist post-operatively during the execution of a number of daily activities (Foucher et al., 2008; Talis et al., 2008). For example, Talis et al. (2008) found that THA patients, when asked to stand up from a chair, displayed asymmetrical lower limb loading patterns that favoured the non-operated limb (i.e., unloading operated limb) – a strategy that may eventually elicit a joint disorder in the non-operated lower limb. However, kinematic and kinetic data of the lower limb joints were not obtained, thus preventing the researchers from elucidating the source of this asymmetry. To our knowledge, no other published studies have investigated the effect of THA on sit-to-stand biomechanics, despite the fact that it is a demanding, yet essential task that one must perform daily to maintain his/her independency. Furthermore, the sit-to-stand, as well as the stand-to-sit, tasks are also important elements of certain athletic activities, such as sitting in and standing out of a golf cart, canoe or kayak in order to enjoy a round of golf or paddling sports. In fact, THA patients have expressed dissatisfaction with their ability to perform athletic activities and sports (Mancuso et al., 1997). As proposed by Talis et al. (2008), their inability to perform standing and sitting manoeuvres may stem from prolonged muscle weakness, movement patterns adopted pre-operatively or adaptive behaviour as a result of surgery. Interestingly, it was found that sit-to-stand biomechanics of healthy adults were most affected by a reduction in hip muscle strength in comparison with strength of the muscles acting on the knee joint (Gross et al., 1998).

As for the biomechanics of the stand-to-sit task, a paucity of research has been published, even with regard to healthy individuals (Dubost et al., 2005). Consequently, a thorough biomechanical analysis of THA patients performing the sit-to-stand and stand-to-sit tasks is needed to elucidate the causes of these patients' deficiencies and dissatisfactions. Moreover, the results of this study could potentially be utilized to modify existing rehabilitation programs accordingly. The purpose of the present study was to determine the effect of THA on lower limb mechanics during the tasks of sit-to-stand and stand-to-sit by comparing three-dimensional (3D) hip, knee and ankle joint angles, joint reactions forces, moments and powers of THA patients with those of healthy, matched control participants.

METHODS: Participants: To achieve the purpose of this study, a total of 40 participants were recruited – 20 patients having undergone THA by means of a lateral surgical approach in the past 6-15 months (10 women, 10 men; age: 66.2 ± 6.7 yr; BMI: 27.2 ± 5 kg/m^2) and 20 healthy control participants, matched for gender, age and BMI (10 women, 10 men; age: 63.5 ± 4.4 yr; BMI: 24.9 ± 3.5 kg/m^2). THA patients were excluded if they had undergone hip replacement surgery for the contralateral hip joint, hip replacement due to an infection, a fracture or a failure of a previous prosthesis or hip replacement during which a concomitant surgical procedure was performed. Potential participants were also excluded if they suffered from any former or current condition that could alter their gait (e.g., stroke) or serious lower limb injury or disease (with the exception of the hip implant for the experimental group). Prior to participating in the study, which was approved by the institutions' research ethics boards, all participants signed an informed written consent.

Data Collection: Three-dimensional kinematics of the sit-to-stand and stand-to-sit tasks were collected at 200 Hz by means of a nine-camera digital optical motion capture system (Vicon MX, Oxford, UK), as well as 45 retro-reflective markers (14 mm diameter) placed on various landmarks of the participants according to a modified Helen Hayes marker set. Furthermore, 3D ground reaction forces were recorded at 1000 Hz with two force platforms (AMTI, Model ORC-6-2000, Watertown, MA, USA) positioned side-by-side and 10 cm in front of a height-adjustable bench. The height of the bench was adjusted to correspond to the height of the participant's tibial plateau. The participants performed three trials of each task – sit-to-stand and stand-to-sit – without the assistance of their arms and with each foot positioned on a force platform approximately shoulder-width apart, facing anteriorly.

Data Analysis: To remove noise from the data, a Woltring filter (predicted Mean-Square Error value of 15 mm^2) and a low pass Butterworth filter were applied to the 3D marker trajectories and ground reaction forces, respectively. The peak and range of the joint angles during the entire task, as well as the peak joint kinetics after seat-off for the sit-to-stand trials and before seat-on for the stand-to-sit trials were extracted from the calculated 3D hip, knee and ankle angles, joint reaction forces, moments and powers. These data were obtained from the operated limb in the THA group and from the dominance-matched limb in the control group.

Statistics: A series of one-way ANOVAs were performed, by means of SPSS statistical analysis software (SSPS for Windows, version 15.0, SPSS Inc., Chicago, USA), to determine the presence of significant differences between the THA and control groups with regard to all dependant variables. Alpha levels of 0.0167 and 0.025 (corrected for multiple comparisons) were used to determine statistical significance of the kinematic and kinetic variables, respectively.

RESULTS: Results from statistical analyses indicate that the THA and control groups were indeed matched for age (p=0.142) and BMI (p=0.092). It was also found that the majority of the statistically significant differences between the groups occurred near the time of seat-off and seat-on for the sit-to-stand (Table 1) and stand-to-sit (Table 2) tasks, respectively. For this reason, in addition to the constraint of limited space, only those variables will be presented and discussed.

DISCUSSION: Results clearly indicate that the mechanics of the sit-to-stand and stand-to-sit tasks have not returned to normal after total hip arthroplasty. Interestingly, most of the variables that significantly differed between groups for the sit-to-stand task were also found to differ for the stand-to-sit task. These abnormalities were most noticeable at seat-off and seat-on. With regard to kinematics, THA patients placed their operated hip in a more abducted position

Table 1. Means (standard deviation) of the significantly different kinematic and kinetic variables between THA patients (operated leg) and control participants (matched leg) near seat-off (SOF) of the sit-to-stand task.

Type of variable	Joint	Variable	Value THA	Value Control	p-value
Angle (°)	Hip	Peak flexion	81.6 (9.2)	90.3 (5.3)	0.001
	Hip	Peak abduction	-10.3 (6.8)	-4.7 (5.8)	0.008
	Knee	Flexion near SOF	73.9 (9.9)	83.6 (8.2)	0.002
	Ankle	External rotation near SOF	-16.8 (6.6)	-22.2 (6.3)	0.012
Joint Reaction Force (N/kg)	Hip	Peak anterior	-2.48 (0.49)	-3.33 (0.50)	0.000
	Knee	Peak proximal	4.20 (0.51)	4.98 (0.52)	0.000
	Ankle	Peak proximal	4.86 (0.52)	5.69 (0.49)	0.000
Moment (Nm/kg)	Hip	Peak extension	-0.48 (0.18)	-0.65 (0.19)	0.005
	Sum*	Peak extension	-0.96 (0.25)	-1.20 (0.18)	0.001

*This variable is defined as the sum of the sagittal plane hip, knee and ankle moments.

Table 2. Means (standard deviation) of the significantly different kinematic and kinetic variables between THA patients (operated leg) and control participants (matched leg) near seat-on (SON) of the stand-to-sit task.

Type of variable	Joint	Variable	Value THA	Value Control	p-value
Angle (°)	Hip	Peak flexion	81.5 (8.1)	91.5 (5.9)	0.000
	Hip	Abduction near SON	-9.1 (6.4)	-2.7 (7.3)	0.005
	Ankle	External rotation near SON	-16.2 (6.2)	-21.5 (6.6)	0.012
Joint Reaction Force (N/kg)	Hip	Peak anterior	-2.18 (0.72)	-3.09 (0.38)	0.000
	Knee	Peak proximal	3.56 (0.78)	4.33 (0.41)	0.000
	Ankle	Peak proximal	4.51 (0.83)	5.39 (0.43)	0.000
Moment (Nm/kg)	Hip	Peak extension	-0.47 (0.25)	-0.69 (0.16)	0.002
	Sum*	Peak extension	-0.80 (0.30)	-1.04 (0.15)	0.002

*This variable is defined as the sum of the sagittal plane hip, knee and ankle moments.

than the control participants. This phenomenon was accompanied by a more externally rotated ankle joint complex – most likely a result of this increased hip abduction. Such kinematics resulted in reduced joint reaction forces at the hip, knee and ankle in comparison with the control participants. Unfortunately, to our knowledge, no other study has analyzed the three-dimensional kinematics and kinetics of either sit-to-stand or stand-to-sit tasks in hip replacement patients, hence preventing us from comparing these results. THA patients also performed these tasks with lower moments of force about the hip joint. Similar results have been reported with total knee arthroplasty patients (Mizner & Snyder-Mackler, 2005), where low quadriceps strength and activity level were related to low hip and knee moments of force in the sagittal plane.

Our results revealed that the THA patients of the present study adopted a movement pattern that reduced forces and moments at all lower limb articulations. This could result from either the surgery, a pre-operative adaptation to alleviate pain or a strategy to prevent dislocation, as sit-to-stand is a task prone to posterior dislocation (Nadzadi et al., 2003). This strategy may gradually lead to muscle atrophy and consequently, a reduction in muscle strength. In such a case, patients would not be able to produce adequate muscle torque after hip replacement, regardless of the absence of pain. Muscle activity during sit-to-stand and stand-to-sit should be investigated in relation to kinematics and kinetics in future studies.

Some authors have expressed concerns about this unloading pattern of the operated hip joint (Talis et al., 2008). They found limb loading to be asymmetrical and thus assumed overloading of the healthy hip. Hence, they cautioned that such a loading pattern could cause premature wear of the non-operated hip. However, although not within the scope of, and therefore not reported in, the present paper, preliminary observations indicated that kinematic and kinetic data of the non-operated leg were similar to those of the control group. This suggests that THA patients adopted a strategy that allowed them to reduce the load on their operated lower limb without overcompensating with the non-operated side. Such a strategy could be desirable in the long term as higher loading could increase friction and accelerate wear of the prosthesis (Williams et al., 2006). On the other hand, this strategy may be an indication of, or may lead to, muscle weakness given that joint reaction forces and moments are highly dependent on those produced by the musculature surrounding the joint. Consequently, regaining muscle strength and being able to adequately load the new joint remains important in order to participate in recreational and athletic activities. Augmenting the strength of the muscles surrounding the new hip joint will ensure adequate muscle synergies, increase prosthesis stability and enable THA patients to better perform daily functional tasks and engage in their favourite recreational activities without limitations.

CONCLUSION: Results obtained from this study indicate that the THA patients displayed sit-to-stand and stand-to-sit kinematics and kinetics that differed from those of the healthy, control participants. These patients used a strategy that allowed them to reduce loading on the prosthesis without compromising the non-operated hip. Although such a strategy may be desirable given that higher loads can increase friction and thus decrease prosthesis longevity, reduced loading may be an indication of inadequate muscle strength. Such muscle weakness needs to be addressed to restore proper muscle synergies and thus, protect the surface on which the implant is affixed. Further investigations are needed to evaluate lower limb joint mechanics of THA patients performing more difficult tasks such as sit-to-stand from a lower position and/or with a lateral lower body displacement in order to better mimic certain tasks found in recreational activities (e.g., getting out of a kayak).

REFERENCES:

Dubost, V., Beauchet, O., Manckoundia, P., Herrmann, F., and Mourey, F. (2005). Decreased trunk angular displacement during sitting down: an early feature of aging. *Physical Therapy*, *85*, 404-412.

Foucher, K. C., Hurwitz, D. E., and Wimmer, M. A. (2008). Do gait adaptations during stair climbing result in changes in implant forces in subjects with total hip replacements compared to normal subjects? *Clinical Biomechanics*, *23*, 754-761.

Gross, M. M., Stevenson, P. J., Charette, S. L., Pyka, G., and Marcus, R. (1998). Effect of muscle strength and movement speed on the biomechanics of rising from a chair in healthy elderly and young women. *Gait and Posture*, *8*, 175-185.

Mancuso, C. A., Salvati, E. A., Johanson, N. A., Peterson, M. G., and Charlson, M. E. (1997). Patients' expectations and satisfaction with total hip arthroplasty. *Journal of Arthroplasty*, *12*, 387-396.

Mizner, R. L., and Snyder-Mackler, L. (2005). Altered loading during walking and sit-to-stand is affected by quadriceps weakness after total knee arthroplasty. *Journal of Orthopaedic Research*, *23*, 1083-1090.

Nadzadi, M. E., Pedersen, D. R., Yack, H. J., Callaghan, J. J., and Brown, T. D. (2003). Kinematics, kinetics, and finite element analysis of commonplace manoeuvres at risk for total hip dislocation. *Journal of Biomechanics*, *36*, 577-591.

Talis, V. L., Grishin, A. A., Solopova, I. A., Oskanyan, T. L., Belenky, V. E., and Ivanenko, Y. P. (2008). Asymmetric leg loading during sit-to-stand, walking and quiet standing in patients after unilateral total hip replacement surgery. *Clinical Biomechanics*, *23*, 424-433.

Williams, S., Jalali-Vahid, D., Brockett, C., Jin, Z., Stone, M. H., Ingham, E., et al. (2006). Effect of swing phase load on metal-on-metal hip lubrication, friction and wear. *Journal of Biomechanics*, *39*, 2274-2281.

Acknowledgement

The authors would like to acknowledge the contribution of Drs. Kim, Feibel, and Giachino of The Ottawa Hospital, Dr Cranney of the OHRI, as well as Drs. Benoit and Li of the University of Ottawa. This research was supported, in part, by the Canadian Institutes of Health Research.