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## DYNAMIC JOINT STIFFNESS AND PERIARTICULAR CO-ACTIVATION PATTERNS AT THE KNEE AND ANKLE BEFORE AND AFTER TOTAL KNEE ARTHROPLASTY

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### SUMMARY

The periarticular antagonistic co-activation (PACoA) and the dynamic joint stiffness at the knee and ankle were assessed during self-selected speed gait on two groups of subjects, patients (N=30) slated for total knee arthroplasty (TKA) and matched controls (N=12). All the subjects had repeated assessments at 3, 6 and 12 months. We aimed to understand the time course of these parameters and evaluate their relationship at each time level. The knee and ankle PACoA indices were evaluated over the same time intervals with the dynamic joint stiffness for each of the joints respectively. ANCOVA was used to account for walking speed differences between individuals and groups. We found no significant time or group x time interaction effects for PACoA and dynamic joint stiffness at neither knee nor ankle. There were significant group main effects for both knee and ankle dynamic joint stiffness and for the knee PACoA, however the ankle PACoA, while higher for the TKA patients, was not significant. The dynamic joint stiffness remained significantly higher at the knee and lower at the ankle for the TKA patients for at least a year postoperatively and the PACoA at the knee remained significantly higher for 6 months. There were no significant correlations between the dynamic joint stiffness and the PACoA at neither knee nor ankle joint, indicating that these measures cannot be used as substitutes for each other. The abnormal patterns observed in knee OA patients persist for a year after TKA are evident during specific sub-phases of the gait cycle, and extend to adjacent joints.

### INTRODUCTION

Total knee arthroplasty (TKA) is a common treatment that reduces pain and improves function in response to the debilitating end-stage osteoarthritis (OA) at the joint. The wear down of the articular cartilage of the knee is not only accompanied by joint instability [1] and decreased proprioception [2], but also by modified muscle activation patterns [3,4], weakness and altered function in the affected joint [5,6] and potentially the adjacent joints of the lower extremity [7]. Post TKA patients often report improvement in the quality of life measurements [8], mainly due to pain reduction and perceived better joint function; however biomechanical gait deviations are reported by many authors persisting for a long time [9]. Typically knee OA patients report joint instability and adopt/learn an analgetic walking

pattern that is characterized by reduced knee joint excursion “stiff-legged pattern” during weight acceptance that is attributed by many investigators to an increased antagonistic co-activation (ACoA) by the knee muscles. This pattern of ACoA can contribute to an increased joint load and is reported to continue after TKA. The purpose of this study was to (1) determine whether the abnormal patterns of increased periarticular antagonistic co-activation (PACoA) and increased dynamic joint stiffness are retained post TKA, (2) understand the time course of these abnormal patterns pre and post TKA, and (3) assess whether the dynamic joint stiffness for the knee and ankle correlates to the PACoA of the corresponding joint.

### METHODS

Kinematic, kinetic and electromyography (EMG) data were collected on 30 unilateral TKA patients and 12 age- and gender-matched controls at pre-, 3, 6, and 12 months post-surgery during self-selected speed gait. All the patients received a unilateral TKA and post-surgery standard physical therapy care, aiming at progressively improvements in strength and ROM. The dynamic joint stiffness was calculated as the slope of the regression line of the linear region of the moment-angle plots for the knee during loading response (between: the peak external flexion moment and the peak knee flexion joint angle) and for the ankle during mid- and terminal-stance (between: the peak plantar- and peak dorsi-flexion joint angles). The joint specific periarticular antagonistic co-activation (PACoA) was calculated, by extending the currently used muscle pair antagonistic co-activation algorithm to include groups of agonist and antagonist muscles that cross the specific joint. Specifically, we calculated the PACoA for the knee by including the EMG activation patterns of the following muscle groups: knee extensor group – rectus femoris, vastus medialis, and vastus lateralis vs. knee flexor group - semitendinosus, biceps femoris and gastrocnemius; and for the ankle PACoA: the plantar flexor group – gastrocnemius and soleus vs. the ankle dorsiflexor - tibialis anterior. Analysis of covariance was used to account for the self-selected walking speed differences of individuals and groups. Two-way ANCOVA to test for group, time and group x time interaction effects and one-way ANCOVA to test for group differences at each time level on the dynamic

joint stiffness and the PACoA indices of the knee and ankle joints (SPSS 18,  $\alpha=0.05$ ).

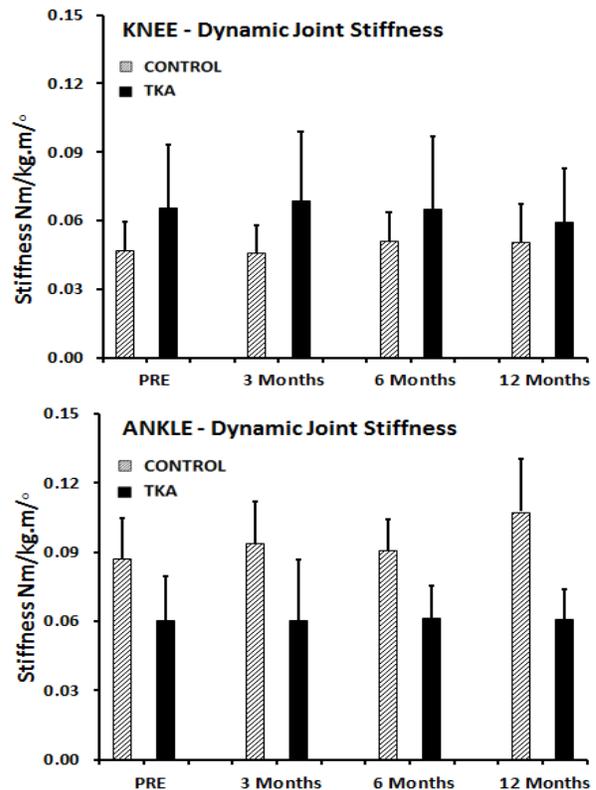
## RESULTS AND DISCUSSION

The TKA patients walked significantly slower than the controls  $0.92 \pm 0.17$  m/s vs.  $1.22 \pm 0.14$  m/s (pooled over time:  $p=0.000$ ), respectively. We found no significant time or group  $\times$  time interaction effects for either knee or ankle dynamic joint stiffness. There were significant group main effects for both knee and ankle dynamic joint stiffness. The knee dynamic joint stiffness was significantly ( $p=0.000$ ) higher for the TKA patients  $0.064 \pm 0.028$  Nm/kg.m<sup>o</sup> vs.  $0.049 \pm 0.011$  Nm/kg.m<sup>o</sup> for the controls. Interestingly, the ankle dynamic joint stiffness was significantly ( $p=0.000$ ) lower for the TKA patients  $0.061 \pm 0.019$  Nm/kg.m<sup>o</sup> vs.  $0.094 \pm 0.018$  Nm/kg.m<sup>o</sup> the controls. The knee and ankle PACoA indices were evaluated over the same time intervals with the dynamic joint stiffness for each of the joints, respectively. The knee PACoA index during loading response showed a significant group main effect ( $p=0.000$ ) with higher co-activation for the TKA group  $45.5 \pm 11.3\%$  vs.  $35.3 \pm 12.0\%$  for the control. However, while the ankle PACoA was higher for the TKA group ( $19.3 \pm 14.3\%$ ) than the control ( $16.7 \pm 12.2\%$ ) during mid- and terminal-stance, this difference was not significant. To better understand the timeline of these differences, one-way group ANCOVA analyses were done at each time level. The dynamic joint stiffness remained significantly higher at the knee and lower at the ankle for the TKA patients throughout the 12 month post-operative period. Similarly the higher PACoA observed for the knee periarticular muscles was found to remain significant through the six months, post-surgery. There were no significant correlations observed between the dynamic joint stiffness and the PACoA at neither knee nor ankle joint. Our results are consistent with the growing evidence in support that subjects that receive standard care post TKA surgery exhibit high knee dynamic joint stiffness for a long time after the surgery. Since we did not collect strength and range of motion data, we were unable to assert the specific reasons of retention of this abnormal pattern with respect to physiological deficiencies or the pre-surgical learned antalgic habitual patterns. The increased PACoA at the knee in the TKA patients during the same phase of the gait cycle at first seems to explain this retained abnormality as the potential cause; however, since we found no correlation between dynamic knee joint stiffness and knee PACoA this justification does not seem plausible. The dynamic joint stiffness of the ipsilateral ankle joint, on the contrary, was significantly lower in the TKA patients during the subsequent phases of the gait cycle (mid-stance and terminal stance). This was an unexpected finding, especially since the ankle PACoA for the TKA group was marginally higher.

## CONCLUSIONS

The results of the present study show that knee OA patients retain the stiff-knee walking pattern for a year post unilateral TKA. Contrary to our expectations the increased dynamic joint stiffness was not related to the increased antagonistic co-activation at the knee. The increased dynamic joint stiffness at the knee seems to reduce the dynamic joint stiffness of the ipsilateral ankle. These findings may be indicative of changes in neuromuscular recruitment patterns,

the pathophysiology of the disease, or the ineffectiveness of usual post TKA care in terms of addressing pre-operative learned movement patterns. The implications of these findings are unknown with respect to the longevity of the prosthesis; however, the decrease in knee dynamic joint stiffness as well as the reduction of the co-activation of the knee periarticular muscles should be an additional focus of the post-surgical rehabilitation protocols.



**Figure 1:** Dynamic joint stiffness for the knee (top) during loading response and for the ankle (bottom) during mid-terminal-stance in TKA patients and controls at Pre, 3, 6, and 12 months post-surgery.

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