

Original Research

Concurrent Force Feedback on Load Symmetry in Total Knee Arthroplasty Patients

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Background and Purpose

Load asymmetry can be present before and after total knee arthroplasty (TKA), which may affect progress during knee rehabilitation in an outpatient sports medicine setting. Current rehabilitation primarily focuses on strength, pain, and range of motion deficits; however, recent evidence suggests the use of movement retraining strategies such as load feedback to address load asymmetry. Therefore, the purpose of this study was to examine how a single session of concurrent force feedback influences load symmetry during the leg-press and body-weight squat exercises in individuals following TKA. Additionally, a secondary purpose was to examine the retention of any changes over the course of a week.

Study design

Case-series study

Methods

This observational, repeated-measures study design examined the effect of concurrent force feedback training on the mean and standard deviation of load symmetry index during the leg press and squat exercises in 26 patients with TKA in an outpatient sports medicine clinic. The load asymmetry was measured with loadpad sensors placed underneath the each extremity during leg press and squat (baseline), after one training session consisting of concurrent force feedback during these exercises within a single physical therapy session (post feedback), and after seven to ten days of a washout period (post retention). Separate 2 x 3 repeated measures analysis of variance was used to compare the mean and standard deviation of load symmetry across exercise (leg press and squat) and across time (baseline, post feedback and post retention).

Results

There was a time effect for the mean load symmetry index ($p=0.027$) but not for the standard deviation ($p=0.441$) during these exercises. The leg press showed a greater mean symmetry index compared to the squat regardless of time ($p=0.001$).

Conclusions

A reduction in the mean load symmetry index following concurrent feedback training suggests improved use of the surgical limb during both leg press and squat exercises during the same therapy session but the more symmetric loading pattern was not

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retained one week later. Overall, the leg press showed greater mean asymmetry than the squat. Standard deviation in the load symmetry index did not change across time or by exercise.

Level of Evidence

3

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INTRODUCTION

As knee OA progresses, individuals often progressively limit their participation in sport and recreational activities.¹ In two separate reviews Barber-Westin & Noyes and Witjes et al. indicated that 34-100% of patients experiencing a TKA return to sport and recreational activities.^{2,3} It is unknown why such large differences exist in whether TKA patients return to sport and recreational activities. Also, despite the reported improvement in mobility and function of individuals following TKA in the literature, abnormal load symmetry (greater loading on the non-surgical limb compared to the surgical limb) has been reported to be present before and after surgical intervention.⁴⁻⁷ Numerous factors such as acquired knee pain on the surgical limb, quadriceps and hamstring weakness in both lower extremities, and acquired habitual movement patterns have been suggested as potential contributors to this abnormal loading symmetry following TKA.^{4,8} This abnormal load symmetry has been suggested to lead to contralateral knee and hip pain, and poor functional outcomes after TKA.^{4,5,9-12} For example, an increased load on the non-surgical limb following TKA could increase knee adduction moment and vertical ground reaction forces on the contralateral side that may lead to or accelerate knee osteoarthritis (OA) and the risk of surgical intervention on the contralateral limb.^{6, 13-16}

Current rehabilitation protocols mostly focus on minimizing shear stimuli, avoiding excessive ligament strain in patients undergoing cartilage repair,¹⁷ minimizing pain, and improving strength, and range of motion in patients after TKA.¹⁸ However, these strategies may not address the habitual movement patterns and movement impairments such as abnormal load symmetry after TKA. Recent suggestions for comprehensive knee rehabilitation include the use of movement retraining strategies that utilize performance-based feedback to address these loading impairments.¹⁸ For example, concurrent feedback has been reported to improve performance during the acquisition phase of motor learning.^{19,20} Concurrent force feedback is a method where the total force from each extremity is displayed on a computer monitor during the performance, such as a leg press and squat. Forces shown may help the patient balance the forces traveling through the joints. Also, squat and leg press exercises, typically part of a current knee rehabilitation regimen, may address strength deficits but not address persistent movement impairments that involve reduced loading on the surgical limb during these exercises. Therefore, targeting and fostering greater load symmetry using concurrent force feedback during leg press and squat in the early stages of rehabilitation follow-

ing TKA may be important. However, the use of force feedback to monitor and regulate load symmetry following TKA has not been extensively reported as part of standard rehabilitation programs.^{5,17}

Therefore, the purpose of this study was to examine how a single session of concurrent force feedback influences load symmetry during the leg-press and body-weight squat exercises in individuals following TKA. Additionally, a secondary purpose was to examine the retention of any changes over the course of a week. The hypothesis was that the load symmetry would improve in individuals with TKA immediately following concurrent force feedback training and persist after one week.

METHODS

STUDY DESIGN

In this repeated measures design, participants performed both body-weight squat and leg press, in a random order, as load symmetry were collected without providing feedback (baseline). Participants performed bodyweight squat in standing with self-chosen foot width. During the leg press, participants were seated with the seat adjusted to the proper length such that their knees could be fully extended and the leg press load was chosen based on their perceived exertion. Both exercises were performed at a set rate of movement and the body-weight squat was performed to 80° of knee flexion. The perceived exertion for both exercises were based on verbal indication by each participant not exceeding 5/10 on a Rated Perceived Exertion (RPE)²¹ scale (A scale that measures subjective reporting of effort that ranges from no exertion to maximum exertion experienced during an exercise or a physical activity) for all participants. No specific instructions were provided regarding body position or exercise form during these two exercises other than the rate and depth during baseline assessment.

Then, each participant received concurrent force feedback training (force feedback from each extremity) while performing both the leg press and body weight squat in a randomized order. They subsequently completed other weight-bearing exercises within a typical 20-minute physical therapy session without any feedback. Immediately after completion of this physical therapy session, participants were asked to perform the same leg-press and squat exercises while load symmetry data was collected with participants were blinded (load from each extremity was not shown or displayed) to concurrent force feedback (post feedback). Then, after seven to ten days of a washout period, the load symmetry data was collected similar to the baseline and post feedback testing conditions during the

leg press and squat in a randomized order (post retention) prior to a standard physical therapy session.

PARTICIPANTS

Twenty six patients (mean age 63.8 years, range 58-76) who desired to return to being recreationally active in sport and recreational activities after TKA were recruited as participants. Patients were included in this study if they were post TKA and were able to safely and independently perform an unsupported squat, ambulate without an assistive device, and complete seated leg press with a knee flexion angle of at least 80°. The mean time from surgery was 7.5 weeks (range from three weeks and two days to 14 weeks with no weight-bearing restrictions). All of the participants were actively participating in a supervised post-operative rehabilitation in an outpatient sports medicine setting at a regional medical center. Participants provided their written informed consent prior to participation in this study, and the study protocol was approved by the Ethics Committee on the use of human subjects in research at the University of Wisconsin – La Crosse. The IRB for this protocol was #17-TK-173.

INSTRUMENTATION

Two loadpad sensors (Novel GMBH, Munich, Germany), inserted in a protective cover, were placed on the ground or affixed to the base plate of a leg press machine (Eagle NX, Cybex, Rosemont, IL, USA) to measure and/or provide concurrent force feedback during the training session (Figure 1).

Force data from each extremity were collected using the sensors at 62.5 Hz that was streamed to an iPad (Apple Inc., Cupertino, CA, USA). Similar technology to the loadpad, the loadsol in-shoe sensors, developed by the same manufacturer, has been reported to have excellent reliability for determining peak ground reaction force with data collected simultaneously with a force platform for hopping (ICC=0.96), walking (ICC=0.89) and for running (ICC=0.92-0.94) on an instrumented treadmill as reported by Burns et al.²²

PROCEDURE

Prior to baseline testing, subjects were provided with a verbal explanation and demonstration of the study protocol. For each testing scenario, the knee flexion angle was limited to 80° as measured by a hand-held goniometer. For the seated leg press, the machine was set to limit the knee flexion angle at 80° with a subject-specific weight based on their RPE. An adjustable stool was placed behind the subjects to maintain appropriate knee flexion angle while performing the body-weight squat. An auditory metronome (Seiko quartz metronome, Mahwah, NJ) was set at 36 beats per minute to constrain movement velocity to a set rate during both the leg press and squat for consistency between subjects. Each beat of the metronome occurred when the extremities were most flexed or extended. Participants were allowed several repetitions in each testing condition to fa-

miliarize themselves with the task. The subjects were not allowed to use any assistive device or their hands for support during the testing or training.

Baseline testing consisted of participants performing six repetitions of a body-weight squat and during self-selected, moderate-load, leg press exercises. The participants were blinded to their load symmetry during these two exercises and the order of exercises were randomized for each participant during this baseline assessment.

Then, all the participants performed one set of six repetitions of the leg press and body-weight squat exercises while receiving concurrent force feedback from the two loadpad sensors. The order of the exercises was randomly assigned. The force feedback data (from force measured each foot) were continuously displayed via a separate bar graph for each extremity measured in N (Figure 2) on the iPad display in front of the participant during each exercise so they could see the bar graph display.

The refresh rate on the iPad display from the loadpad sensors was 4.16 Hz. Before the training, the subjects were given verbal reminders to attempt to keep these two bars as equal as possible on the iPad which was placed on a stand in front of the participant during the squat and leg press exercise performance. After completing this feedback training, the participants completed 20 repetitions of each of the following supervised exercises during a standardized 20 minute physical therapy (PT) session: terminal knee extensions in standing, bipedal rocker board tilts forward-backward and side to side, and standing hip abduction bilaterally. Immediately after the 20-minute supervised PT session, the participants performed six repetitions of body-weight squat and leg press exercises in a randomized order without any force feedback while we collected load symmetry data (post feedback). After seven to ten days of a washout period, the load symmetry data were collected (post retention) similar to baseline and post feedback testing conditions with no force feedback prior to a standard physical therapy session.

STATISTICAL ANALYSIS

A sample size calculation performed using G-power (version 3.0.10, Germany) determined that at least a sample size of 16 was required for this study based on Zeni et al. 2013²³ based on the mean and standard deviations for vertical ground reaction force symmetry values from presurgical to six months postsurgical with alpha set to 0.05, beta to 0.2 and a calculated effect size of 1.07.

Force data were smoothed with a low-pass Butterworth filter (2nd order, dual-pass, 7 Hz cut-off frequency) and clipped to the beginning and end of the six squat or leg press repetitions from data recorded on the iPad. The load symmetry index (LSI) based on the bilateral force was determined based on the following formula as described elsewhere²⁴:

$$LSI = \frac{(Force\ on\ the\ non- surgical\ limb - Force\ on\ the\ surgical\ limb)}{\frac{1}{2} (Force\ on\ the\ non- surgical\ limb + Force\ on\ the\ surgical\ limb)} \times 100\%$$

A load symmetry index of 0 indicates a perfect symmetry.⁹ All data processing were completed using the force values

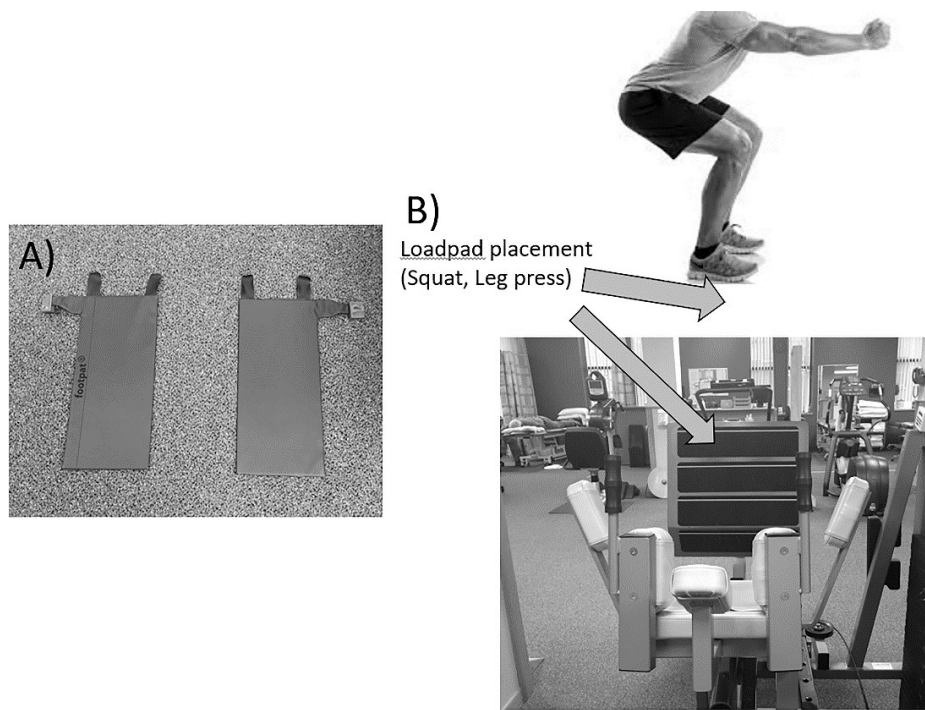


Figure 1. A) Loadpad sensors used in the investigation were placed in a protective covering. B) During the squat performance and leg press performance, the loadpad sensors were placed under each foot. For the squat, the sensor was placed on the floor and for the leg press, it was affixed via double-sided tape to the foot plate of the leg press machine.

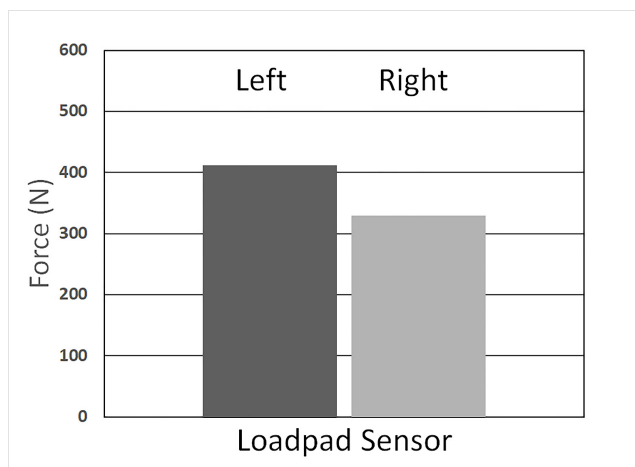


Figure 2. Concurrent feedback of force (N) displayed on the iPad in front of a representative subject during the squat and leg press exercises. Right indicates the right lower extremity and Left indicates the left lower extremity.

from each sensor within MATLAB® (Mathworks, Natick, MA). Mean load symmetry index is the mean value measured from the continuous force measurements from each force sensor at 62.5 Hz during the six repetitions of the squat and leg press exercises. Standard deviation of the load symmetry index was calculated and is used as an indicator of the variation in the load symmetry index during the continuous force measures from each sensor during the same timeframe for each exercise.

A 2 x 3 repeated-measures analysis of variance was performed on exercise (Squat, Leg press) and time (baseline, post feedback, post retention) to determine the mean and standard deviation of load symmetry index ($\alpha=0.05$) using SPSS 28 (IBM, Inc., Armonk, NY). Follow-up tests using the Bonferroni procedure were performed as warranted. Partial η^2 was used to determine effect sizes within SPSS. A small effect was based on partial η^2 equal to 0.01, medium equal to 0.06, and large equal to 0.14.²⁵

RESULTS

MEAN LOAD SYMMETRY INDEX

The mean and standard deviation of the load symmetry index was shown in [Table 1](#) for each time point (baseline, post feedback, post retention) for leg press and squat exercises ([Table 1](#)). The mean load symmetry index for the squat showed a 42.7% decrease from baseline to post feedback but returned to baseline values post retention. The leg press exercise showed a 5.9% decrease in mean load symmetry index from baseline to post feedback but then showed an increase of 12.5% that depicted a regression in mean load symmetry index greater than the baseline. The mean load symmetry index was always greater due to greater loads being placed on the non-surgical limb (indicating an increased load compared to the non-surgical limb).

[Figure 3](#) depicts the mean load symmetry index for all subjects across time points between the two exercises. There was an effect of time on the mean load symmetry in-

Table 1. Means ± standard deviation of load symmetry index (LSI) for leg-press and squat exercise across the time points. Values closer to zero indicates perfect symmetry.

Movement and Variable	Baseline	Post feedback	Post retention
Squat Mean LSI (%)	28 ± 16	16 ± 04	28 ± 22
Squat SD LSI (%)	22 ± 04	12 ± 02	12 ± 04
Leg Press Mean LSI (%)	34 ± 12	32 ± 12	36 ± 20
Leg Press SD LSI (%)	22 ± 06	20 ± 06	20 ± 06

Note: A load symmetry index of 0 indicates a perfect symmetry, as described in Christiansen et al.⁹

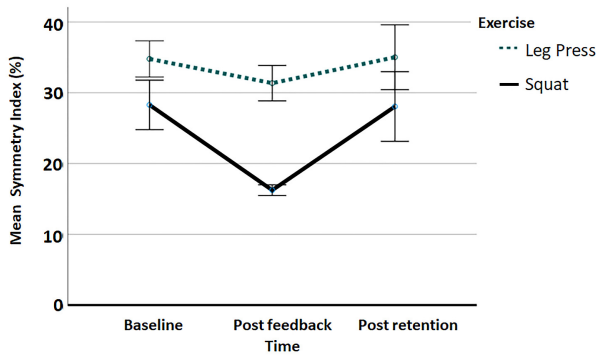


Figure 3. Mean load symmetry index based on time and exercise. The zero axis represents equal loading symmetry on each extremity. Error bars indicate ±1 standard error.

dex ($p=0.027$, partial $\eta^2=0.17$) in both squat and leg press exercises. The exercises (squat vs. leg press) were different for both the mean load symmetry index ($p=0.001$, partial $\eta^2=0.422$) for all time points. There was no interaction between time and exercise ($p=0.165$, partial $\eta^2=0.091$).

STANDARD DEVIATION FOR LOAD SYMMETRY INDEX

There was no time effect for the standard deviation in load symmetry index ($p=0.441$, partial $\eta^2=0.042$) for both squat and leg press exercises. The exercises were different for standard deviation of load symmetry index ($p=0.000$, partial $\eta^2=0.785$) for all time points (baseline, post feedback, post retention). There was no interaction between time and exercise ($p=0.401$, partial $\eta^2=0.047$).

DISCUSSION

This study examined the effects of concurrent force feedback training on load symmetry in individuals with TKA in sports medicine outpatient setting. The results of this study

partly supported the hypothesis by showing a difference in the mean load symmetry index in both leg press and squat exercises immediately following concurrent feedback training. In addition, there was a large effect size observed in mean load symmetry index due to feedback for both exercises. These changes suggest that the participants showed a shifting of their load from the non-operated limb to the operated limb as evidenced by the decrease in load symmetry index from baseline to post feedback may be due to concurrent feedback training. However, this effect was not observed after a week (post retention) indicating a poor retention of the effects of concurrent feedback using force over the course of a week. At the same time, standard deviation of load symmetry index did not change. The lack of change in the standard deviation of LSI suggests that the chosen performance pattern of force on extremity based on the variation in load symmetry index was largely consistent during these same time periods (baseline, post feedback, and post retention). This study results relate to suggestions provided in Bade et al.,¹⁸ regarding the concept that movement retraining and motor control principles can be used for a comprehensive knee rehabilitation in individuals with TKA. However, this study findings appear to show that a single session of concurrent force feedback may not be enough to produce longer term changes in load symmetry beyond a single session.

Also, numerous studies^{4,6,7,18} have reported abnormal load symmetry (i.e., reliance on the non-surgical limb) during weight-bearing activities such as walking in individuals following TKA that have been shown to be associated with contralateral hip pain and contralateral TKA. Interestingly, the load symmetry index data shown in this study also agrees with these investigations, evidenced by higher than 0 load symmetry index values at all time periods during both the leg press and squat exercise. A load symmetry index of 0 indicates perfect symmetry, in other words equal weightbearing on each extremity. For example, 28% mean LSI observed during the squat indicates a 72% asymmetrical force on the extremities. However, in this investigation, improved loading on the surgical limb was observed from baseline to post feedback in both exercises. This suggests that one may be able to improve loading on the operated limb temporarily with concurrent force feedback within a single rehabilitation session but this appeared not to persist to the next therapy session. Perhaps, the use of concurrent feedback training that offered in a faded manner throughout rehabilitation may improve the retention of symmetry as shown in other studies. If load symmetry was improved, one may then consider investigating if greater load symmetry would transfer over to other tasks like sit to stand and gait activities where abnormal symmetry has been reported.^{4,6,7,18} Future studies appear warranted in this area. In addition, it is unknown how such loading asymmetry may influence participants return to sport and recreational activity which was the outcome goal of these participants.

In addition, a higher load symmetry index (higher load on the non-surgical limb) was observed during the leg-press exercise compared to the squat exercise at all time pe-

riods in this study. In other words, the participants relied more on the non-surgical limb during the leg-press than the squat exercise at all time periods. This finding may relate findings of Zheng et al., that reported a higher peak tibiofemoral compressive force (via analytical model) during a leg press compared to a squat exercise.²⁶ Maybe to avoid increased tibiofemoral compressive force that could produce knee pain, the participants in this investigation relied more on the non-surgical limb for weight bearing during leg press than the squat. It is possible that one could manage their own body weight during squat but may not manage externally applied load during the leg press exercise. Another plausible reason for this difference in mean load symmetry may be imposed by the constraints necessary for maintaining postural control during each exercise. When one is seated during a leg press, a more similar contribution of force may not be required for success. However, when maintaining a standing position, postural control during a squat may require the performer's center of gravity to be more centered between the legs compared to being seated during the leg press.

Regarding the absence of persistence of improved loading symmetry after the one week of washout period as evidenced by the return of load symmetry index to near baseline for both the exercises, this is not surprising and may be attributed to how concurrent feedback improves immediate practice performance but may not be sustained once the concurrent feedback has been removed.^{27,28} Chang et al.²⁷ and Yamamoto & Ohashi²⁸ suggested that considerable feedback must first be provided and then feedback frequency should be reduced to avoid dependency to promote long-term motor skill learning. A portion of this study results supported this training effect by showing an immediate increase in mean load symmetry immediately in a single session of training but then returned toward baseline levels after a short washout period.

Finally, the authors wanted to highlight that no observed difference in standard deviation of load symmetry index for both squat and leg press exercises over time periods indicated that minimal variation in the load symmetry performance pattern occurred in this study's participants. This may be an indication of a repeatable pattern of loading symmetry in both exercises. Incorporating this study results and other literature related to the use of feedback suggest that using more practice may be needed with concurrent force feedback (increase the frequency of concurrent feedback training over more than one therapy session) to improve loading symmetry over time. Also, it may be then necessary to use different types of feedback (terminal: feedback provided as a summary after the completion of an action or performance and faded: reducing the feedback frequency over time) to translate the short-term improvements to a longer-term retention for improved function and return to sport and recreational activity.

Clinicians, such as physical therapists, may want to consider utilizing movement retraining strategies such as using concurrent force feedback training to promote improved load on the surgical limb following TKA when appropriate. With the dramatic projected increase of TKA from 85%²⁹ in 2025 to 110%³⁰ in 2030 to as high as 401% in 2040³⁰ and their association with future TKA in the uninvolved limb,^{6, 13} the use of a movement retraining strategy with concurrent force feedback to address movement system impairments may be warranted.

STUDY LIMITATIONS

This study has several limitations, such as TKA subjects with varying Body Mass Index (BMI), variable time from surgery (three weeks to 14 weeks), pain levels, gender, and medication schedules that may have influenced findings and study participation. The status or level of participation in sport and recreational activities of each patient prior to TKA other than each had expressed a goal to return to such activities was unknown. Also, this study did not have a control or a comparison group that would have helped to delineate the influence of regular physical therapy exercises on the results. The loadpad device is likely not perfectly valid in measuring peak force but is reliable during the less dynamic tasks used in this study such as the squat and leg press. This preliminary investigation was solely to determine how force related feedback might be implemented in an outpatient sports medicine clinical setting. At present, there is no follow up data on each patient's ability to return to sport and recreational activity.

CONCLUSION

Concurrent feedback training using load sensors may be used to improve the load symmetry during a single session of knee rehabilitation following TKA. Improvements were only shown in the short term and did not persist over the following week.

CONFLICT OF INTEREST

None declared.

FUNDING

None.

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