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RESEARCH ARTICLE

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Tricompartment offloader knee brace reduces contact forces in adults with multicompartment knee osteoarthritis

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Abstract

The levitation tricompartment offloader (TCO) brace is designed to unload all three knee compartments by reducing compressive forces caused by muscle contraction. This study aimed to determine the effect of the TCO on knee contact forces and quadriceps muscle activity in individuals with knee osteoarthritis. Lower limb kinematics, kinetics, and electromyography data were collected during a chair rise-and-lower task. A three-dimensional inverse dynamics model of the lower leg and foot was used with a sagittal plane knee model to compute knee joint forces. TCO brace use significantly decreased forces in the tibiofemoral [$p = 0.001$; mean difference, MD (97.5% confidence interval, CI) −0.62 (−0.91, −0.33) body weight (BW)] and patellofemoral [$p = 0.001$; MD (97.5% CI) −0.88 (−1.36, −0.39) BW] compartments in high-power mode. Significant reductions in quadriceps tendon force [$p = 0.002$; MD (97.5% CI) −0.53 (−0.83, −0.23) BW] and electromyography intensity of the vastus medialis [$p = 0.018$, MD (97.5% CI) −30.7 (−59.1, −2.3)] and vastus lateralis [$p = 0.012$, MD (97.5% CI) −26.2 (−48.5, −3.9)] were also observed. The TCO significantly reduced tibiofemoral and patellofemoral contact forces throughout chair lower, and when knee flexion was greater than 50° during chair rise in high power. These results demonstrate that the TCO reduces contact forces in the tibiofemoral and patellofemoral joint compartments and confirms that the TCO unloads the joint by reducing compressive forces caused by the quadriceps. Clinical significance: The magnitude of knee joint unloading provided by the TCO is similar to that achieved by clinically recommended levels of bodyweight loss and is therefore expected to result in clinical benefits for knee osteoarthritis patients.

KEYWORDS
electromyography, joint loading, knee brace, knee osteoarthritis, musculoskeletal model

1 | INTRODUCTION

Osteoarthritis (OA) is the most common joint disease in adults.[1] OA causes pain, disability, and reduced quality of life for those affected, and represents a major financial burden internationally.[2,3] The prevalence of OA is rising due to an aging population and demands for increased joint function with age.[4] Knee OA is the most common form of OA[5] and can affect all three joint compartments, including the medial tibiofemoral (TF), lateral TF, and patellofemoral (PF), individually or in combination. Of those individuals with knee OA, more than 80% have multicompartment or PF knee OA, while the rates of unicompartment TF knee OA are comparatively low (4%–20%).[6–8] There is currently no cure for OA and total knee replacement (TKR) surgery is the most common treatment option for end-stage knee OA. However, knee replacements have a finite lifespan, not all individuals are suitable candidates for TKR and many individuals continue to have pain and disability following surgery.[9,10] There is a continuing and growing need for safe, efficacious, and cost-effective conservative management strategies for knee OA patients to manage painful symptoms and help delay or avoid knee replacement surgery.

It is well established that altered joint loading is associated with the initiation and progression of knee OA.[11,12] Specifically, increased joint loads and changes in the loaded region of the joint are associated with cartilage degeneration.[12,13] Current evidence also indicates that excess joint loading induces symptoms of knee pain.[14] Therefore, many conservative management strategies for mild to moderate knee OA focus on unloading the knee joint to reduce pain, improve function, and prevent disease progression. Braces for knee OA are designed to reduce joint loading and pain, as well as improve symptoms and joint function.[15] The majority of knee OA braces are designed to mechanically realign the joint in the frontal plane (e.g., to control varus/valgus alignment), offloading the diseased TF compartment (typically medial) by transferring the compressive load to the opposing TF compartment (typically lateral).[16] These unicompartment offloader braces have been shown to be beneficial in a small subset of knee OA patients with unicompartment TF OA.[17] However, they are not designed or intended for patients with multicompartment or PF knee OA. A bracing solution capable of unloading both the TF and PF compartments would provide a solution to address symptoms for the broader knee OA population for the first time. Since lower limb muscle contraction is responsible for the majority of knee joint loading,[18] muscle forces may provide an alternative target for unloading multiple compartments within the knee joint.

Tricompartment offloader (TCO) knee braces are designed to reduce joint forces related to knee pain in all three compartments of the knee for individuals with multicompartment OA by providing an assistive moment, rather than mechanically realigning the knee. The levitation TCO brace (Spring Loaded Technology) incorporates a spring-loaded hinge that provides this assistive moment at the knee during flexion and extension movements,[19] targeting compressive joint forces caused by quadriceps muscle contraction. The assistive moment increases as the TCO brace flexes, providing higher levels of assistance during deeper knee flexion when joint contact forces are highest.[20,21] User survey evidence indicates significant and clinically relevant improvements in knee pain and function following TCO brace use in individuals with symptomatic knee OA.[22,23] Using computational analysis, Budarick et al.[22] demonstrated that the TCO is capable of providing clinically meaningful[24] unloading in both the TF and PF compartments of the knee, equivalent to losing up to ~20 kg of body weight (BW), or 22% of BW for the average knee OA patient. More recently, McGibbon et al.[25] simulated knee joint force reductions of as much as 30%–50% with the TCO during a deep knee bend movement using a sagittal plane knee and ideal TCO brace model. While the results of these studies provide promising evidence on the joint unloading capabilities of the TCO, they only considered the results of computer simulations based on unbraced human movement data and ideal brace performance (e.g., perfect force transmission and brace alignment). Changes in knee kinematics and kinetics associated with TCO brace wear have been previously quantified[26]; however, the resultant forces were not distributed to the internal joint components.[24] There is a need to quantify the TCO's joint unloading effect in patients with knee OA wearing the brace during a dynamic motion.

The objective of this study was to determine the in vivo biomechanical effect of the TCO brace on knee joint contact forces and quadriceps muscle activity in individuals with knee OA. It was hypothesized that the use of the TCO brace would decrease TF and PF contact forces and quadriceps tendon (QT) forces, as well as decrease quadriceps muscle activity while worn during a repeated chair rise-and-lower movement in patients with multicompartment knee OA.

2 | METHODS

2.1 | Participants

Nine participants were enrolled in this ethics-approved study (ID REB 18-1865) following informed consent. One participant was excluded due to a protocol violation identified during data analysis. Eight participants (six male, two female) with unilateral knee OA (age 63.4 ± 6.1 years; body mass index [BMI]: 30.9 ± 4.0 kg/m^2) are included in this analysis. Participants had Kellgren-Lawrence[27] grades 2–4 combined medial TF and PF OA diagnosed by an orthopedic surgeon (M. C.). Participants were excluded if they could not walk without walking aids or stand from a seated position unassisted, had a BMI greater than 35 kg/m^2, or had contraindications for knee bracing. Participants who received corticosteroid injections in the affected knee within 3 months before the start of the study and those with a history of knee trauma, rheumatoid arthritis, or knee surgery (excluding arthroscopy) were also excluded.

2.2 | Data collection

Participants were fitted with a levitation 2 TCO knee brace (Spring Loaded Technology) by a trained member of the research team (E. B.)

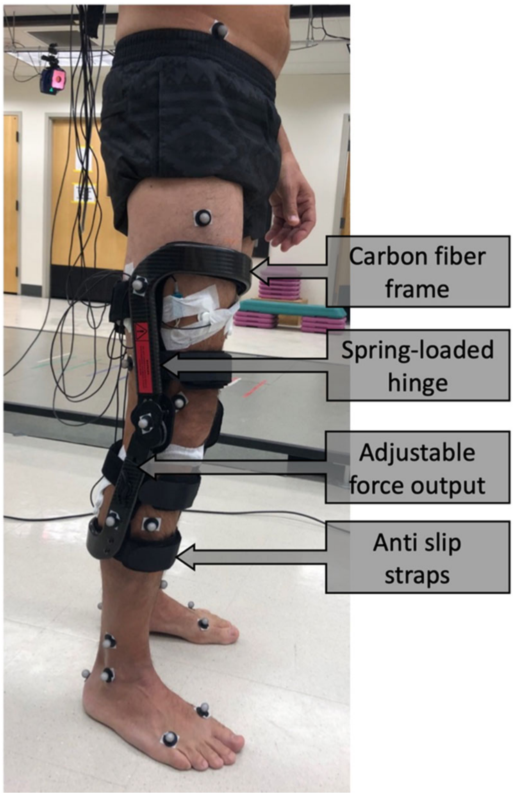

FIGURE 1 Study participant wearing the tricompartment offloader (TCO) brace with reflective markers on the lower limbs and pelvis and electromyography (EMG) electrodes on the lower limb muscles. The TCO consists of two light-weight carbon fiber frames with adjustable antislip straps to secure the brace to the thigh and shank. The embedded spring-loaded hinge provides an adjustable (rotary switch) extension moment at the knee through the contributions of the liquid spring.

following manufacturer guidelines. The TCO brace has two power modes providing different levels of passive spring assistance: (1) low power where the brace spring engages from 45° to 120° knee flexion, and (2) high power where the spring engages throughout the entire range of motion (0°–120°). Participants were provided with the brace to wear during their daily activities for a minimum of 48 h before data collection to become accustomed to wearing the brace.

Lower limb kinematics, kinetics, and electromyography (EMG) were collected for a repeated chair rise-and-lower task to determine differences between three bracing conditions: (1) without the brace (OFF); (2) with the brace worn in low power (LOW); and (3) with the brace worn in high power (HIGH). Participants were asked to sit on a stool, and the stool height was adjusted for each participant to ensure a seated knee flexion angle of 90°. Participants were instructed to rise to a fully upright standing position and to sit back down on the stool with their arms crossed over the abdomen. Each movement trial consisted of five consecutive repetitions from sitting to standing and subsequent return to a seated position. Participants performed one movement trial of five repetitions for each bracing condition in a randomized order determined using a random sequence generator.

Six-degree-of-freedom kinematics were acquired using an 8-camera motion capture system (Motion Analysis; 240 Hz). Forty-one spherical reflective markers (Ø = 9 mm) were attached to the right and left legs, as well as the pelvis of each participant, and a further eight markers were attached to the brace (Figure 1). Ground reaction forces (OR6-6, AMTI; 2400 Hz) and surface EMGs (Biovision; 2400 Hz) were collected for the brace leg during movement trials. EMG was used to measure muscle activation in the quadriceps. Bipolar Ag/AgCl EMG electrodes (Ø = 10 mm, interelectrode distance 20 mm; Noraxon) were attached to the skin overlying the vastus medialis (VM) and vastus lateralis (VL) and secured using medical tape. The skin was shaved and cleaned with rubbing alcohol before attachment. Electrode placements were informed by SENIAM guidelines (http://www.seniam.org). A maximum voluntary contraction (MVC) protocol was completed before movement trials using a dynamometer (Biodex Medical Systems) to enable EMG signal amplitude normalization. Participants performed three trials of knee extension at 45° knee flexion with 60 s rest between trials. Participants were instructed to extend their leg against the dynamometer arm using maximal effort and were provided visual feedback and verbal encouragement.

2.3 | Biomechanical model

A three-dimensional (3D) inverse dynamics model of the lower leg and foot was used with a sagittal plane model of the knee to compute knee joint forces during the repeated chair rise-and-lower task. The model workflow is shown in Figure 2 and has been previously described.[25] Briefly, an inverse dynamics knee model was used, where the tibia was acted upon by ankle forces and moments and center of mass inertia. Therefore, the loads estimated in joint structures took into account segmental dynamics. The knee model, however, does not consider viscoelastic properties of tissues and the internal force solutions should be considered "quasi-static." Independent tracking of the leg and brace enabled potential differences in the alignment of the brace with the human leg to be included in the model (Figure 2A).

For the no brace condition (or if the brace is ignored), the inverse dynamic solution (Figure 2B) yields the net forces and moments at the anatomical knee joint. In this condition, dynamic stability is provided by the knee muscles alone. With the two brace conditions, the lower brace arm and cuff were modelled as a moment and force couple (Figure 2C). The moment was a function of the brace flexion angle based on mechanical testing information provided by the manufacturer (in flexion or extension for LOW and HIGH braces; Figure 3). The brace moment arm (r_B) was set at a fixed distance from the brace axis. The known position of the brace on the leg allowed the force transmitted to the tibia $F_B{}'$ to be computed as the component of $-F_B$ in the sagittal plane and perpendicular to the shank long axis with an effective moment arm (r_K) relative to the anatomical joint axis (Figure 2D). The sagittal plane knee model[25] was used to resolve TF and PF contact forces, and QT forces, as well as cruciate ligament forces (Figure 2E).

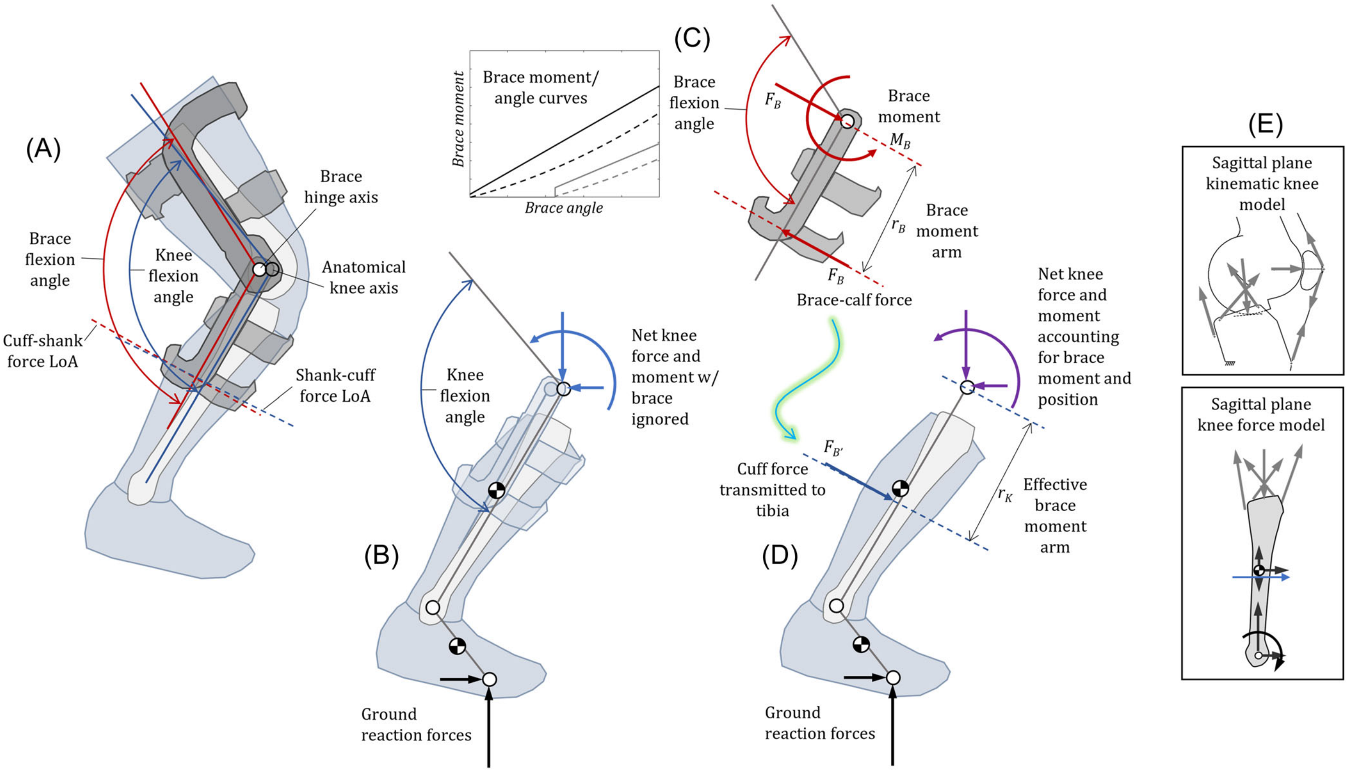

FIGURE 2 Three-dimensional (3D) inverse dynamics model of the lower leg, tricompartment offloader (TCO) brace and foot (A–D) and sagittal plane model of the knee (E) used to compute knee joint forces.

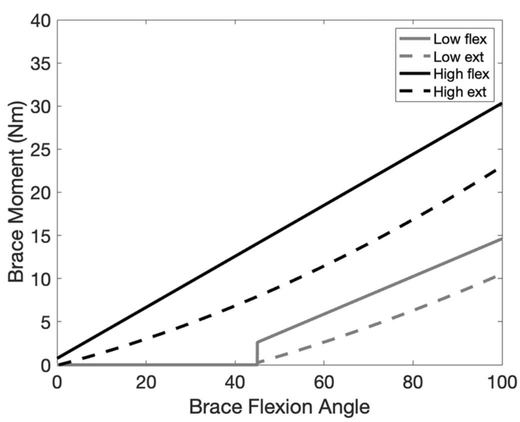

FIGURE 3 Tricompartment offloader (TCO) brace moment (Nm) as a function of brace flexion angle (degrees) for low power (gray) and high power (black) modes during brace flexion (solid line) and extension (dashed line).

2.4 | Data analysis

Kinematic and kinetic data collected during the chair rise-and-lower movement was used with the biomechanical model to calculate knee forces for each participant and bracing condition (OFF, LOW, and HIGH). While the model solves for knee forces in all tissues, the current analysis focuses on TF and PF contact forces as well as QT force. For the LOW and HIGH brace conditions, joint forces were also computed without considering the extension assistance provided by the TCO brace, hereafter referred to as the "unassisted" condition. This approach isolates the effect of the TCO within a brace condition and provides an estimate of the knee joint burden without an external source of support (i.e., the external knee moment provided by the TCO brace). Time intervals for the rise-and-lower phases of the movement task were determined using the velocity of the knee flexion angle. The start or end of a movement phase was identified with a velocity threshold of 0.05°/s. Peak joint forces were calculated separately for the rise (knee extension) and lower (knee flexion) phases of the chair task.

EMG signals were analyzed using a wavelet analysis approach.[28] Before wavelet transformation, the EMG amplitude of each trial was normalized to the maximum EMG amplitude of the MVC. Signal intensities for each muscle were then summed across wavelets and time for chair rise and chair lower separately. The resultant total EMG intensities are analogous to the total power of the muscle activation.

2.5 | Statistical analysis

Statistical analysis was performed using SPSS software (v26; IBM). Knee forces and EMG data were averaged across the middle three repetitions for each participant. Data were assessed for normality using the Shapiro–Wilk test. Paired t-tests were used to determine differences in outcomes between the three bracing conditions. Peak TF, PF, and QT forces for the LOW and HIGH braced conditions were compared with the OFF condition for each movement phase (chair rise and lower). Total VM and VL EMG intensity for the LOW and HIGH braced conditions were compared with the OFF conditions for each movement phase. A Bonferroni correction was used to account for the false discovery rate with multiple testing ($\alpha = 0.025$).

Statistical parametric mapping (SPM) was used to determine the portion of the chair rise-and-lower task when the TCO brace significantly reduced TF and PF joint contact forces (i.e., the effective region), similar to the approach used by McGibbon et al.[25] SPM operates analogous to standard *t*-tests and analysis-of-variance tests but enables comparison of time series data, identifying timepoints where the waveforms are significantly different from one another. The SPM analog of the paired *t*-test was used to compare TF and PF contact forces between the unassisted and actual brace conditions within each of the LOW- and HIGH-braced conditions. The effective region was defined by the region where the continuum of *t*-scores across the waveform comparison exceeded the critical *t*-score ($t*$) at $\alpha = 0.05$.

3 | RESULTS

3.1 | Knee joint forces

With the TCO brace worn in high-power mode, peak TF contact forces were significantly reduced during both chair rise and chair lower, by 0.64 BW (18%, $p = 0.008$) and 0.62 BW (23%, $p = 0.001$), respectively, compared to the OFF condition (Figure 4 and Table 1). Peak PF contact forces were significantly reduced by 0.88 BW (26%, $p = 0.001$) with the TCO worn in high power during chair lower, but not during chair rise ($p = 0.027$), compared to the OFF condition (Figure 4 and Table 1). Peak QT forces were significantly reduced during both chair rise and chair lower, by 0.44 BW (17%, $p = 0.023$) and 0.53 BW (26%, $p = 0.002$), respectively, compared to the OFF condition (Figure 4 and Table 1). In low-power mode, joint forces were significantly reduced during chair lower in the TF compartment, by 0.33 BW (12%, $p = 0.002$), the PF compartment, by 0.36 BW (10%, $p = 0.004$), and the QT, by 0.22 (11%, $p = 0.004$) (Figure 4 and Table 1). Knee joint forces were not significantly reduced in low-power mode during chair rise.

3.2 | Quadriceps EMG intensity

EMG intensity was significantly decreased with the brace worn in HIGH during chair rise for both the VM ($p = 0.019$) and VL ($p = 0.019$) compared to the OFF condition (Table 1). During the chair lower, EMG intensity was significantly decreased with the brace worn in HIGH for both the VM ($p = 0.018$) and VL ($p = 0.012$) compared to the OFF condition (Table 1). Reductions in mean EMG intensity ranged from 41% to 55% for the VM and 30%–39% for the VL with the brace worn in HIGH during the chair rise-and-lower task. There were no significant differences in EMG intensity with the brace worn in LOW for the VM or VL during either the chair rise or chair lower.

3.3 | Effective region of TCO brace

In low-power mode, the TCO brace significantly reduced both TF and PF joint contact forces with knee flexion greater than 77.9° during chair rise, and with knee flexion greater than 67.9° during chair lower, compared to the unassisted brace condition (Figure 5). In high-power mode, the TCO brace significantly reduced both TF and PF joint contact forces throughout the duration of chair lower (Figure 5),

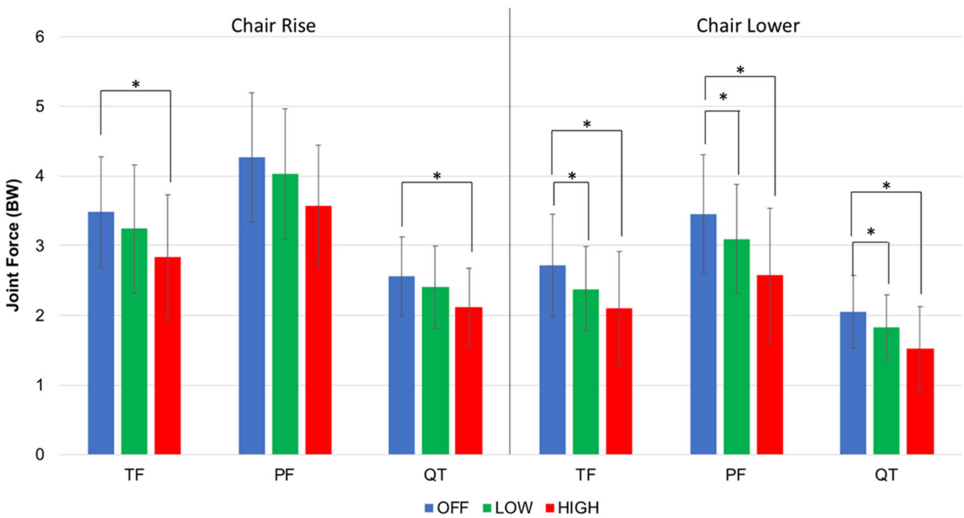

FIGURE 4 Mean peak tibiofemoral (TF), patellofemoral (PF), and quadriceps tendon (QT) forces (error bars represent standard deviation) during the chair rise (left panel) and chair lower (right panel) phases of the task under three different brace conditions: no brace (OFF), brace in low power mode (LOW), and brace in high power mode (HIGH). *Significance at the 0.025 level.

TABLE 1 Mean peak TF, PF, and QT forces (BW), and mean VM and VL EMG intensity under three different brace conditions: no brace (OFF), brace in low-power mode (LOW), and brace in high-power mode (HIGH).

	Activity phase									
	Chair rise					Chair lower				
Brace condition	Mean	SD	MD	97.5% CI	*p* Value	Mean	SD	MD	97.5% CI	*p* Value
TF contact force (BW)										
OFF	3.47	0.80	–	–	–	2.71	0.73	–	–	–
LOW	3.24	0.92	−0.24	−0.60, 0.12	0.097	2.38	0.60	−0.33	−0.53, −0.13	0.002*
HIGH	2.83	0.89	−0.64	−1.14, −0.15	0.008*	2.10	0.82	−0.62	−0.91, −0.33	0.001*
PF contact force (BW)										
OFF	4.26	0.93	–	–	–	3.45	0.85	–	–	–
LOW	4.03	0.94	−0.24	−0.64, 0.16	0.136	3.10	0.78	−0.36	−0.60, −0.11	0.004*
HIGH	3.57	0.88	−0.70	−1.41, 0.01	0.027	2.58	0.96	−0.88	−1.36, −0.39	0.001*
QT force (BW)										
OFF	2.55	0.57	–	–	–	2.05	0.52	–	–	–
LOW	2.41	0.59	−0.15	−0.39, 0.10	0.128	1.83	0.47	−0.22	−0.38, −0.07	0.004*
HIGH	2.12	0.56	−0.44	−0.87, −0.01	0.023*	1.52	0.60	−0.53	−0.83, −0.23	0.002*
VM EMG Intensity										
OFF	99.4	69.0	–	–	–	55.8	45.1	–	–	–
LOW	77.8	60.7	−21.6	−59.9, 16.7	0.153	31.3	19.2	−24.5	−54.6, 5.7	0.055
HIGH	58.4	58.1	−40.9	−79.5, −2.4	0.019*	25.1	18.8	−30.7	−59.1, −2.3	0.018*
VL EMG Intensity										
OFF	110.5	62.6	–	–	–	66.5	37.3	–	–	–
LOW	92.6	62.5	−17.9	−44.6, 8.8	0.099	49.9	23.2	−16.6	−41.6, 8.4	0.101
HIGH	77.1	49.9	−33.4	−64.7, −2.0	0.019*	40.3	20.9	−26.2	−48.5, −3.9	0.012*

Note: MD and *p*-values from the paired *t*-tests (LOW/HIGH vs. OFF) are presented.

Abbreviations: CI, confidence interval; EMG, electromyography; MD, mean differences; PF, patellofemoral; QT, quadriceps tendon; TF, tibiofemoral; VL, vastus lateralis; VM, vastus medialis.

*Significance at the 0.025 level.

compared to the unassisted brace condition. During chair rise with the TCO worn in high-power mode, the TF joint contact force was significantly reduced with knee flexion greater than 20.8° and the PF joint contact force was significantly reduced with knee flexion greater than 48.6° (Figure 5), compared to the unassisted brace condition.

4 | DISCUSSION

The results of this research indicate that the assistive extension moment provided by the TCO brace reduces forces in both the TF and PF knee compartments in individuals with knee OA during a chair rise-and-lower movement. Results also showed reduced QT force and decreased quadriceps muscle activity with TCO brace use. These findings support the study hypothesis and demonstrate that the TCO brace reduces joint contact forces by reducing compressive forces generated by the quadriceps muscles during weight-bearing knee flexion.

Wearing the TCO brace in high-power mode significantly reduced peak contact forces in both the TF and PF knee compartments during chair lower, and in the TF compartment during chair rise. The mean peak PF force was also reduced during chair rise; however, this difference did not reach the adjusted level of statistical significance. There were significant reductions in total VM and VL EMG intensity, indicating decreased effort from the quadriceps with the TCO worn in high power during chair rise and chair lower. There were also significant reductions in QT force predicted by the biomechanical model. The EMG results, therefore, support the biomechanical model QT force predictions, providing confidence in the model predictions of reduced TF and PF contact forces. Importantly, these results confirm that the TCO brace unloads both the TF and PF compartments of the knee by reducing compressive quadriceps forces in knee OA patients.

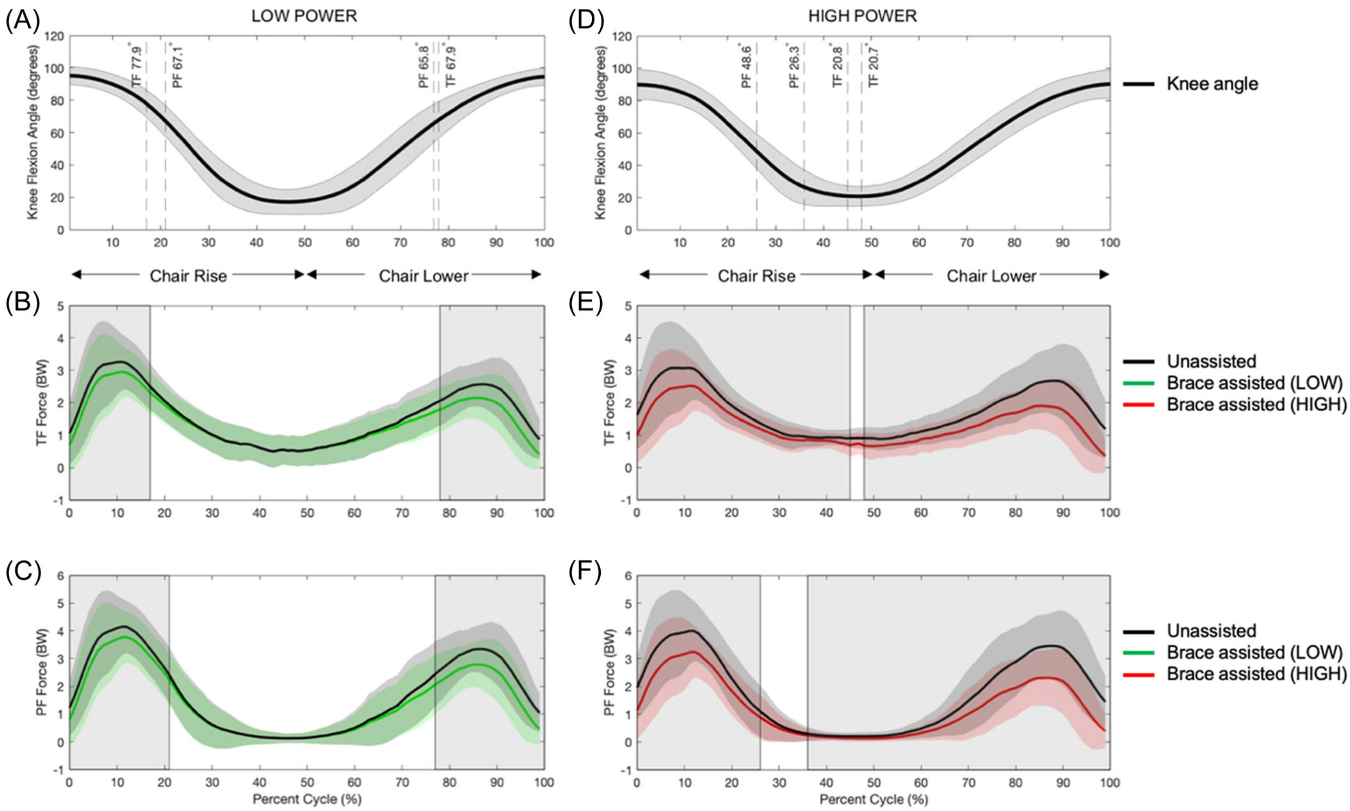

FIGURE 5 Effective region of the tricompartment offloader (TCO) brace during the chair rise-and-lower in LOW (A–C) and HIGH (D–F) power modes. Mean knee flexion angles (degrees), and their standard deviations, are shown in A and D. Dashed vertical lines indicate cutoff angle values corresponding to the effective region of the brace for PF and TF contact forces. Mean TF and PF contact forces (BW), and their standard deviations, are shown in B/E and C/F, respectively. Unassisted contact forces are shown in black, while those with brace use are shown in green (LOW) and red (HIGH). Shaded rectangular regions for contact force graphs represent statistically significant differences in contact forces between conditions ($\alpha = 0.05$).

The TCO brace significantly reduced both TF and PF joint contact forces throughout the chair lower movement when worn in high power. During the chair rise movement, TF and PF contact forces were significantly reduced with the TCO worn in high power when the knee flexion angle was greater than 50° (i.e., when joint forces were highest and increased beyond approximately 1 BW). In high-power mode, the TCO provides assistance via a knee extension moment throughout its range of motion that increases as the brace flexes (Figure 3). These results demonstrate that the amount of assistance provided by the brace in high-power mode was sufficient to significantly reduce knee joint loading throughout the greater part of a chair rise-and-lower task, a movement requiring weight-bearing knee flexion and extension to a knee flexion angle of 90°.

In low-power mode, the TCO brace provided significant reductions in peak TF and PF contact forces, as well as QT force, during the chair lower. However, joint forces did not differ significantly during the chair rise, and quadriceps EMG intensity did not differ during the chair rise or lower movements. The TCO had a comparatively larger unloading effect during the chair lower due to higher brace assistance during brace flexion (Figure 3) and lower joint contact forces during chair lower compared to chair rise (Figure 4). While EMG intensity for the VM and VL were not significantly reduced with the TCO worn in low power during chair lower, seven of eight and six of eight participants showed a reduction in VM and VL EMG intensity, respectively. Furthermore, QT force was significantly reduced with the TCO worn in low power during chair lower, suggesting that the TCO had a significant effect on the quadriceps. The TCO brace worn in low power significantly reduced both TF and PF joint contact forces at the start and end of the chair rise-and-lower movement when joint contact forces peaked. In low power mode, the TCO begins providing assistance when the brace reaches 45° of flexion (Figure 3), so it was expected that the TCO's unloading effect would only be realized at higher knee flexion angles. Overall, these results demonstrate that in low-power mode, the TCO brace has a larger joint unloading effect during knee flexion compared to knee extension, acting to support BW as the user lowers their center of mass.

Joint contact force reductions resulting from TCO use in this study were lower than those reported by McGibbon et al.[25]; that is, 44% and 47% in the TF and PF compartments, respectively, at 90° knee flexion. In comparison, the current study reported peak reductions of 23% and 26% in the TF and PF compartments, respectively, with the TCO worn in high-power mode. McGibbon's joint force estimations represent an idealized scenario for healthy participants, where the brace tracks the leg perfectly and the torque output from the TCO is consistent between flexion and extension. In contrast, the results presented here represent a real-world use case for knee OA patients wearing the brace during an activity of daily living and account for imperfect tracking of the brace on the leg as well as losses in TCO torque output during brace extension. The TF unloading effect observed in the current study is similar to that of unicompartment offloader brace studies reporting TF joint contact force reductions ranging from 11%–17%[29] to 24%–30%[30] during walking.

While the magnitude of knee joint force reduction required to realize clinical benefits in knee OA patients has not been well established, sustained weight loss of at least 10% BW is reported to result in significant clinical improvements for obese and overweight knee OA patients.[24] Messier et al.[24] reported an average reduction of 306 N in peak TF compressive force in knee OA patients who lost at least 10% BW, and a 550 N reduction in those who lost at least 20% BW. They showed substantial corresponding improvements in knee pain, function, and health-related quality of life for those who lost at least 10% BW, with additional clinical benefits for those who lost more than 20% BW.[24] In the current study, average (nonnormalized) peak TF and PF contact force reductions ranged from 200 to 300 N with the brace worn in low power, and from 500 to 700 N with the brace worn in high power during the chair rise-and-lower. Joint force reductions with the TCO in low power are comparable in magnitude to those observed in the 10% BW reduction group, and reductions with the TCO in high power are comparable to those observed in the 20% BW reduction group in Messier's study.[24] We can therefore conclude that the joint contact force reductions resulting from TCO use are similar to those that would be achieved with weight reduction that has been shown to be clinically effective for knee OA patients. Furthermore, while the TCO has a larger unloading effect in high power compared to low power mode, the reduction in joint contact forces with the brace worn in low power is still expected to be clinically beneficial for knee OA patients.

4.1 | Limitations

The study selection criteria excluded individuals with a BMI greater than 35 kg/m^2 and outside the age range of 45–75 years. Participants were recruited from an orthopedic clinic requiring a referral from a primary care physician. Given the study selection criteria and limited sample size, the study population may not be representative of the average person with symptomatic knee OA, and therefore the findings may not be generalizable across all brace users with knee OA. Knee joint forces were calculated with a simplified sagittal plane model of TF and PF joint kinematics, which may overestimate forces in higher flexion angles due to neglecting the influence of posterior stabilizing tissues of the knee. Further, participants were given a limited amount of time to familiarize themselves with TCO brace wear and it is feasible that the current results could differ from those for long-term brace use.

5 | CONCLUSION

This is the first time that the effect of the TCO brace on knee joint contact forces has been evaluated in patients with multicompartment knee OA. The study demonstrates that the TCO effectively reduces contact forces in both the TF and PF compartments of the knee during a chair rise-and-lower, a movement requiring significant strength and control[31–33] that is affected by joint pain in knee OA patients.[34] Further, the findings confirm that the TCO unloads the joint by reducing compressive forces caused by the quadriceps muscles. By unloading both the TF and PF compartments of the knee, the TCO brace offers a conservative management solution for patients who suffer from multicompartment or PF knee OA, populations that have been largely excluded from prior bracing research. The magnitude of joint unloading provided by the TCO when worn in both low- and high-power modes is similar to that achieved by clinically recommended levels of BW loss, and is therefore expected to result in clinical benefits for knee OA patients.

AUTHOR CONTRIBUTIONS

Emily L. Bishop: Research design; data acquisition; data analysis; data interpretation; drafting and critically revising the paper. **Chris A. McGibbon**: Data analysis; data interpretation; drafting and critically revising the paper. **Gregor Kuntze**: Data acquisition; data analysis; data interpretation; critically revising the paper. **Marcia L. Clark**: Participant recruitment; data interpretation; critically revising the paper **Chris Cowper-Smith**: Research design; critically revising the paper **Janet L. Ronsky**: Research design; data interpretation; critically revising the paper. All authors have read and approved the final submitted manuscript.

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CONFLICTS OF INTEREST STATEMENT

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