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Short communication

Walking with shorter stride length could improve knee kinetics of patients with medial knee osteoarthritis

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ABSTRACT

Walking with a shorter stride length (SL) was recently proposed for gait retraining in medial knee osteoarthritis; however it was never assessed in this patient population. This study tested the hypothesis that shortening SL while maintaining walking speed reduces knee adduction (KAM) and flexion (KFM) moments in patients with medial knee osteoarthritis. Walking trials with normal SL and SL reduced by 0.10 m and 0.15 m were recorded for 15 patients (10 men, 55.5 ± 8.7 years old, 24.6 ± 3.0 kg/m^2). SL was modified using an augmented reality system displaying target footprints on the floor. Repeated one-way ANOVAs and post-hoc paired *t*-tests were performed to compare gait measures between normal and reduced SL. The individual effects of SL reduction were analyzed using descriptive statistics. Group analysis indicated significant decreases in KAM impulse with both SL reductions ($p < 0.05$). No systematic change was observed in the first peaks KAM and KFM when walking with reduced SL ($p > 0.05$). Individually, 33 % of the patients decreased the peak KAM, whereas 20 % decreased the KAM impulse. Among these patients with a decrease in peak KAM or in KAM impulse, 0 % and 33 % had a simultaneous increase in peak KFM, respectively. In conclusion, this study showed that SL shortening can decrease kinetic measures associated with the progression of medial knee osteoarthritis in some patients, demonstrating the importance of considering SL modifications on an individual basis. While further research is necessary, notably regarding dose-response relationships and long-term effects, these findings are particularly encouraging because SL reductions could be easily integrated into rehabilitation protocols.

1. Introduction

Knee osteoarthritis (OA) is a major burden for society, notably because no cure has yet been found (Safiri et al., 2020). In the end stages, it often leads to major surgeries, with results being only partially satisfactory (Halawi et al., 2019; Healy et al., 2013). This situation encourages research to improve conservative treatments, especially those based on mechanical interventions, to delay or avoid major surgery (Arden et al., 2021). Knee machnics during walking have been shown to be an important factor in medial compartment knee OA (Andriacchi et al., 2015; Felson 2013), the most common form of knee OA (Ahlbäck 1968). Specifically, a larger peak knee adduction moment during the first half of stance (pKAM) has been associated with faster progression of medial knee OA (Chang et al., 2015; Chehab et al., 2014). This relationship motivated the development of various interventions to decrease pKAM, including gait retraining, which consists of teaching new ways of walking (Reeves and Bowling, 2011).

Several recent studies have shown clinical improvements in patients with medial knee OA following gait retraining programs with personalized modifications (Cheung et al., 2018; Richards et al., 2018; Uhlrich et al., 2018; Ulrich et al., 2020). To date, gait retraining primarily considers modifications in foot progression angle and step width (Favre et al., 2016; Richards et al., 2018; Simic et al., 2010; Shull et al., 2013). Surprisingly, stride length (SL) modifications have seldom been studied, although SL is a fundamental gait parameter (Murray et al., 1964; Stolze et al., 1997). SL was recently suggested as a parameter that can be modified to reduce pKAM (Edd et al., 2020a; Milner et al., 2018). Specifically, walking with an SL 0.14 m shorter while maintaining gait speed, a modification equivalent to an increase in cadence, was shown to decrease the pKAM in healthy participants. As gait retraining requires

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patient-specific modifications (Cheung et al., 2018; Richards et al., 2018; Uhlrich et al., 2018; Ulrich et al., 2020), increasing the number of parameters that can be modified to reduce pKAM could be useful for identifying individual gait modifications that reduce pKAM for a larger proportion of patients. Consequently, there is interest in characterizing the effect of SL reduction in patients with medial knee OA.

Although gait retraining for medial knee OA started with the sole objective of decreasing the pKAM, more recently, attention has been given to the impulse of the knee adduction moment (iKAM) and the peak knee flexion moment during the first half of the stance (pKFM) (Walter et al., 2010; Bennell et al., 2011; Richards et al., 2018; Ulrich et al., 2020; Van den Noort et al., 2015). These two measures are related to disease progression (Bennell et al., 2011; Chang et al., 2015; Chehab et al., 2014) and their increase has been suggested to counteract the benefits of reducing pKAM (Manal et al., 2015; Walter et al., 2010). Consequently, to obtain a more global view of the kinetic impact of SL shortening, there is an additional need to assess its effects on iKAM and pKFM.

This study aimed to evaluate the effects of SL reduction at constant walking speed in patients with medial knee OA. Specifically, we tested the primary hypothesis that a shorter SL results in decreases in pKAM. The secondary hypotheses of decreases in iKAM and pKFM with shorter SL were also tested. Following our previous work in healthy subjects (Edd et al., 2020a), SL reductions of 0.10 and 0.15 m were analyzed. Furthermore, in accordance with the observations of patient-specific responses to gait retraining (Cheung et al., 2018; Richards et al., 2018; Uhlrich et al., 2018; Ulrich et al., 2020), this study also described kinetic changes at the individual level.

2. Methods

Fifteen patients (10 men, 55.5 ± 8.7 years old, 1.74 ± 0.12 m, and 74.5 ± 15.3 kg) were enrolled in this IRB-approved study after providing written informed consent. Individuals aged between 20 and 70 years who were diagnosed with medial knee OA of Kellgren-Lawrence grades I to III based on an examination, including radiography, performed by their physicians in the previous 12 months, were eligible. Exclusion criteria were BMI > 30 kg/m^2, history of lower limb surgery, neurological disorders, or use of walking aids, as these characteristics have been shown to affect patients' gait (Harding et al., 2012; Kemp et al., 2008; Robbins et al., 2019). A sample size calculation indicated a minimum of 14 participants to detect pKAM changes of large effect size (expected Cohen's d of 0.85 (Edd et al., 2020a)) in a study testing two SL modifications, with a power of 80 % and an alpha level of 5 % (G*Power, DE).

Patients performed 10 m-long walking trials in a laboratory equipped with a motion capture system (Vicon, UK) and floor-embedded force plates (Kistler, CH), recording synchronously at 120 and 1200 Hz, respectively (Bennour et al., 2018). Two projectors were used to display target footprints on the ground (Bennour et al., 2018) to induce SL modifications as explained below. Following a standard protocol (Chehab et al., 2017), reflective markers were fixed to the patients and a standing reference pose was captured before the gait trials. pKAM, iKAM, and pKFM were calculated following a common inverse dynamics procedure (Chehab et al., 2017) and expressed as external moments normalized to percent bodyweight and height (%BW × Ht). Footprint parameters, including SL, step width, and foot progression angle, as well as walking speed and cadence, were computed according to previously described methods (Favre et al., 2016). All biomechanical calculations were performed using the BioMove software (Stanford, US).

The protocol first included capturing five trials at a self-selected normal walking speed without footprints displayed on the floor. The average footprint parameters and speed of these trials were defined as the normal footprint parameters and speed for the rest of the experiment. Then, the target footprints were displayed on the ground, and patients were provided time to get used to walking on them (Bennour et al., 2018). Once the patients felt confident walking according to the target footprints, footprints corresponding to their normal footprint parameters were displayed on the ground, and three trials were recorded. Subsequently, the target footprints were modified to induce SL reductions of 0.10 and 0.15 m bilaterally and three trials were recorded for each condition. The reductions were selected according to the range of modifications previously reported as acceptable for everyday walking (Edd et al., 2020a). The target footprints remained at the patients' normal step widths and foot progression angles. Patients were free to practice each footprint configuration as many times as they wanted and the trials that they felt were improperly executed were recorded again. Patients were asked to maintain their normal walking speed during the trials, with footprints displayed on the floor, and trials with speeds differing by>10 % from the normal speed were repeated.

2.1. Statistics

All gait measures were averaged over the three trials recorded for each SL condition to have one value per measure, SL condition, and patient. Repeated one-way ANOVA was performed to determine whether SL had an effect on the other measures. When appropriate, post-hoc paired *t*-tests were performed to compare the values with both SL shortening and values in the normal condition. The percentage of patients with changes exceeding natural variability was calculated to report the effects of SL reduction at the patient level. Natural variability was determined by computing the coefficient of variation for each measure and patient based on normal walking trials. Separately, for each measure, the coefficients were then averaged over all patients, and the natural variability defined as two times the average coefficient (i.e., 11.0 % for pKAM, 13.9 % for iKAM, and 29.1 % for pKFM). Data were tested for normality using Kolmogorov − Smirnov tests before using parametric statistics. The significance level was set a priori at $p < 0.05$, with a Bonferroni correction for multiple testing (effective $p < 0.017$).

3. Results

The average (±SD) SL, cadence, and gait speed in the normal walking condition were 1.48 ± 0.17 m, 114.0 ± 8.3 steps/min, and 1.42 ± 0.21 m/s, respectively. The patients achieved the requested SL reduction with an error of 0.004 ± 0.022 m.

The ANOVA indicated an effect of SL on iKAM ($p = 0.002$), cadence ($p < 0.001$) and speed ($p = 0.007$), but not on pKAM ($p = 0.057$) and pKFM ($p = 0.43$). Post-hoc analyses indicated a decrease of 6.7 ± 13.0 % ($p = 0.017$) and 8.2 ± 14.6 % ($p = 0.005$) in iKAM when the patients walked with SL shortened by 0.10 m and 0.15 m, respectively (Table 1). Additionally, cadence was found to be increased with both SL reductions ($p < 0.001$), and gait speed decreased when the patients walked with SL 0.15 m shorter ($p = 0.012$).

Individual analysis of the kinetic changes exceeding natural variability indicated a decrease in pKAM for 20 % of the patients (3 out of 15) with a SL reduction of 0.10 m (Fig. 1). A pKAM decrease was also observed in 20 % of the patients (3 out of 15) with a SL reduction of 0.15 m and in 33 % of the patients (5 out of 15) with a SL reduction of either 0.10 m or 0.15 m. Shortening the SL by 0.10 m and 0.15 m resulted in an iKAM decrease for 13 % (2 out of 15) and 20 % (3 out of 15) of the patients, respectively. An iKAM decrease was also observed in 20 % of the patients (3 out of 15) with a SL reduction of either 0.10 m or 0.15 m. A simultaneous decrease in pKAM and iKAM was observed in 7 % of the participants (1 out of 15), with both SL reductions. Among the patients with a pKAM decrease or an iKAM decrease with either SL reduction, 0 % (0 out of 5) and 33 % (1 out of 3) had a simultaneous pKFM increase, respectively.

4. Discussion

The present study demonstrates that, on average, SL modifications

Table 1
Gait measures of the 15 patients for the three stride length (SL) walking conditions.

		Absolute values of the kinetic measures	Relative changes with respect to the normal SL condition	
		Mean ± SD	Mean ± SD	P-value
Normal SL	SL	1.48 ± 0.16 m	n/a	
	Cadence	114.0 ± 8.3 steps/min	n/a	
	Speed	1.42 ± 0.21 m/s	n/a	
	pKAM	3.21 ± 0.80 %BW*Ht	n/a	
	iKAM	0.99 ± 0.34 %BW*Ht*s	n/a	
	pKFM	2.85 ± 1.78 %BW*Ht	n/a	
SL reduced by 0.10 m	SL	1.38 ± 0.16 m	**−6.65 ± 1.29 %**	**p < 0.001**
	Cadence	120.7 ± 11.6 steps/min	**+5.77 ± 4.13 %**	**p < 0.001**
	Speed	1.41 ± 2.23 m/s	−1.21 ± 3.8 %	p = 0.31
	pKAM	3.06 ± 0.86 %BW*Ht	−5.12 ± 9.53 %	p = 0.095
	iKAM	0.92 ± 0.34 %BW*Ht*s	**−6.67 ± 12.96 %**	**p = 0.017**
	pKFM	2.71 ± 1.92 %BW*Ht	−5.42 ± 26.08 %	p = 0.41
SL reduced by 0.15 m	SL	1.38 ± 0.16 m	**−9.83 ± 1.03 %**	**p < 0.001**
	Cadence	122.4 ± 11.8 steps/min	**+7.30 ± 4.49 %**	**p < 0.001**
	Speed	1.38 ± 0.23 m/s	**−3.39 ± 4.50 %**	**p = 0.012**
	pKAM	3.02 ± 0.79 %BW*Ht	−5.37 ± 11.15 %	p = 0.075
	iKAM	0.90 ± 0.33 %BW*Ht*s	**−8.17 ± 14.59 %**	**p = 0.005**
	pKFM	2.63 ± 1.74 %BW*Ht	−9.62 ± 27.71 %	p = 0.24

Bold values indicate statistically significant changes compared to the normal SL walking condition ($p < 0.017$). pKAM, peak knee adduction moment; iKAM, impulse of the knee adduction moment; pKFM, peak knee flexion moment.

can improve some, but not all, key measures of knee joint loading associated with medial knee OA. When analyzing the patients as a group, walking with a shorter SL decreased the iKAM but not the pKAM or pKFM. These results partially differ from those of earlier studies on young healthy subjects, where reductions in all three kinetic measures were observed with shorter SL (Edd et al., 2020a; Milner et al., 2018). Consequently, the data available to date indicate that SL modifications are worth considering in gait retraining for medial knee OA. However, further research on larger populations, preferably of patients with medial knee OA, as the biomechanical response could vary with age and disease, will be necessary for a more precise characterization of the effects of SL modifications.

While there was no pKAM decrease for the group of patients, one-third of the patients showed a decrease in pKAM by a magnitude larger than the natural variability when walking with a shorter SL. This result is all the more important as there is a trend for personalized gait retraining in knee OA, meaning that an intervention does not need to work with the majority of patients to be of interest (Felson et al., 2019; Richards et al., 2018; Uhlrich et al., 2018). From this perspective, obtaining a pKAM decrease in one-third of patients without individually optimizing the SL modification is promising (Erhart et al., 2010; Felson et al., 2019). Moreover, all the patients decreasing the pKAM did it without increasing the pKFM, and a small proportion of patients (i.e., 7 %) even decreased both the pKAM and iKAM without increasing the pKFM. These findings suggest that SL modifications contribute to a global improvement in knee loading, at least in some patients (Manal et al., 2015; Walter et al., 2010). The findings also highlighted that group statistics alone could be misleading and encourage the analysis of individual responses, which might better reflect the future clinical use of gait retraining for medial knee OA.

Patients with medial knee OA followed footprint instructions on the floor with an accuracy comparable to that previously reported for healthy individuals (Edd et al., 2020b). This finding supports the use of floor-displayed instructions, which represents an easy and intuitive way to modify footprints simultaneously in terms of SL, foot progression angle, and step width. While the augmented reality system used in this study is not adequate for routine practice, treadmills with projection on

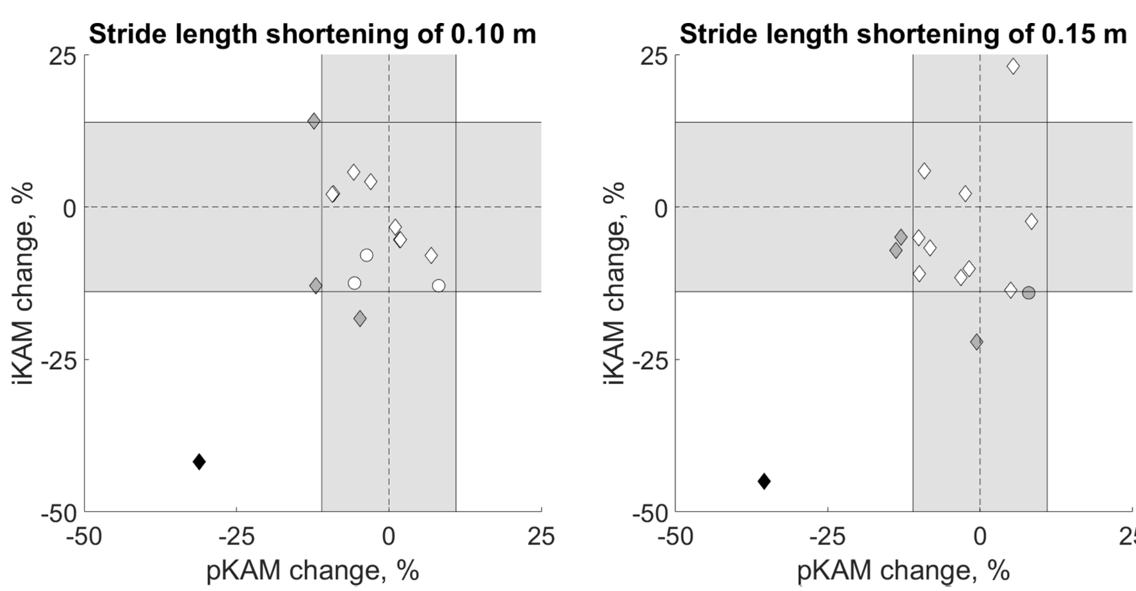

Fig. 1. Graphical representation of the individual kinetic changes with stride length reductions of 0.10 (left) and 0.15 (right) m. Each mark corresponds to one patient. Changes in the peak (pKAM) and impulse (iKAM) of the knee adduction moment are reported along the horizontal and vertical axes, respectively. Changes in the peak of the knee flexion moment (pKFM) are indicated by symbols (circles: increases of larger magnitude than the natural variability, diamonds: increases of lower magnitudes than the natural variability or decreases). Continuous black lines correspond to the natural variability and the white zones outside these lines indicate the areas where the changes exceed the natural variability in pKAM and iKAM. Black, grey, and white marks indicate patients with decreases exceeding the natural variability in both pKAM and iKAM, with a decrease in either pKAM or iKAM exceeding the natural variability, and without any decrease in KAM measures exceeding the natural variability, respectively.

the belt are already used in clinics (Schlick et al., 2016; Tuijtelaars et al., 2021) and could be adapted for the purpose of treating knee OA.

Another advantage of enhancing knee kinetics through SL modifications is that SL modifications, or equivalent cadence modifications, can be easily taught to patients with simple wearable devices. For example, a simple smartphone app measuring walking speed with a built-in GPS and producing auditory or haptic feedback at the desired cadence could be a simple option to help patients learn and maintain a new SL (cadence) (Fortmann et al., 2012; Nascimento et al., 2015; Yang and Li, 2012).

Since this study has confirmed the potential of SL modifications in the rehabilitation of medial knee OA, further research is required to characterize the dose–response relationships. Previous studies have shown the benefit of combining modifications, for example, in the foot progression angle and step width (Edd et al., 2020a; Richards et al., 2018). The added value of mixing SL with other modifications also needs to be explored. In this regard, it is worth mentioning that while improvements in clinical outcomes have been reported following gait interventions primarily aimed at reducing the pKAM (Felson et al., 2019; Shull et al., 2013), there are no guidelines regarding kinetic changes that should be sought. For instance, regarding the pKAM, prior studies aimed at gait modifications of any magnitude to decrease by at least 10 % (Shull et al., 2013; Ulrich et al., 2020). It is interesting to note that the targeted pKAM decreases in previous research were generally lower than the natural variability threshold of 11 % used in the present study to identify the responders to a SL shortening. This suggests that the analysis presented herein is conservative.

This exploratory study was limited by the small sample size. As discussed above, additional research with larger populations and analysis of wider ranges of modifications or even combinations of modifications is necessary for a more comprehensive description of the effects of SL modifications. Second, although variations in gait speed were controlled, patients walked slower when they were asked to reduce the SL by 0.15 m. To isolate the effects of SL, future studies are encouraged to use more rigorous speed control than in the present work. Third, longitudinal work is required to determine the long-term effects of SL modifications on ambulatory mechanics and clinical outcomes. Finally, walking with a shorter SL required more steps to cover the same distance. Further research is necessary to determine wether this could mitigate the benefits of changing knee kinetics.

5. Conclusion

This study confirmed the potential of SL reduction to enhance mechanical loading on the knee in patients with medial OA. While further research is necessary to determine the dose–response relationships and long-term effects, this finding is particularly encouraging because modifying SL seems simple enough to be considered in the routine treatment of knee OA.

CRediT authorship contribution statement

Baptiste Ulrich: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Luís C. Pereira:** Writing – review & editing, Investigation. **Brigitte M. Jolles:** Writing – review & editing, Resources, Project administration, Funding acquisition, Conceptualization. **Julien Favre:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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