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Short communication

Triceps surae strength balancing as a management option for early-stage knee osteoarthritis: A patient case

Christian Wong [a], Jesper Bencke [a], John Rasmussen [b,*]

[a] Department of Orthopaedic Surgery, Hvidovre Hospital, Kettegårds allé 30, DK-2650 Hvidovre, Denmark
[b] Department of Materials and Production, Aalborg University, Fibigerstræde 16, DK-9220, Denmark

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ABSTRACT

Background: Knee osteoarthritis is a progressive disease that may require management for years before knee arthroplasty can be considered. Previously reported musculoskeletal models suggest that rebalancing the strength of the triceps surae muscles can reduce the joint loads.

Methods: A single patient diagnosed with mild/moderate medial left knee osteoarthritis was treated with botulinum toxin injections in the gastrocnemius muscle of the calf, based on the hypothesis that this would rebalance the triceps surae load distribution and reduce tibiofemoral joint loads. Tests were performed before and 4 weeks after injection to record functional clinical scores and to obtain lower limb joint kinematic and kinetic data of walking, which were subsequently analyzed with a musculoskeletal simulation model.

Findings: The patient experienced a clinically relevant improvement in self-reported pain levels in activities-of-daily-living, stair climbing, 6 minutes' treadmill test, range-of-motion, and in the functional knee questionnaire, KOOS. No improvement was seen when performing lunges. The musculoskeletal simulations showed the expected shift in loads between the muscles, reduced knee loads, and improvement of the load symmetry between the legs.

Interpretation: The case corroborates the hypothesis, and this suggests further tests by randomized controlled trials. If confirmed, this simple and reversible medical intervention can improve the management of early-stage knee osteoarthritis.

1. Introduction

Knee Osteoarthritis (KOA) is a chronic and progressive condition, characterized by a degeneration of articular cartilage leading to abnormal stress transition between the structures of the knee (Kleeman et al., 2005; Loeser et al., 2012). KOA limits activities-of-daily-living and reduces quality-of-life. Reduced ability to engage in social and physical activities can lead to isolation, depression, sedentary lifestyles, and obesity.

Despite the success of total knee arthroplasty, approximately 20% of all operated patients report moderate to severe chronic pain after surgery (Beswick et al., 2012), so there is a strong interest in non-surgical management strategies to postpone or avoid surgery, especially for young KOA patients (Christensen et al., 2005). Weight loss reduces the load on the joint proportionally and has beneficial effects on KOA symptoms (Felson et al., 1992). Muscle forces contribute a dominant part of the tibiofemoral joint loads (Kutzner et al., 2010). Weight loss and exercise therapies with potential influence on muscle strength are therefore considered as the "first choice" of non-surgical intervention (Christensen et al., 2005; Coggon et al., 2000; Felson et al., 1992; Ruiz Jr et al., 2013; Vincent et al., 2012; Waddell and Burton, 2006).

Musculoskeletal models of the knee have performed favorably for the prediction of measured knee joint forces in blinded tests (Fregly et al., 2012; Marra et al., 2015; Richards et al., 2018). Stensgaard Stoltze et al. (2018) quantified the contribution of the gastrocnemius to the knee compressive force, mainly in the second peak of the stance phase of walking gait. Uhlrich et al. (2021) devised a biofeedback training system to reduce the activation of the gastrocnemius in favor of the soleus and reported a reduction of the simulated internal joint forces by 12%. All things equal, rebalancing of the calf muscle forces would offload the joint corresponding to a significant weight loss.

We propose a new method to rebalance calf muscle loads based on

Abbreviations: VAS, Visual Analog Scale; KOOS, Knee Injury and Osteoarthritis Outcome Score.

* Corresponding author.
E-mail addresses: christian.nai.en.tierp-wong@regionh.dk (C. Wong), Jesper.Bencke@regionh.dk (J. Bencke), jr@mp.aau.dk (J. Rasmussen).

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temporary partial paralysis by botulinum toxin (BT). BT treatment of muscles surrounding an affected joint has previously produced encouraging results for hip osteoarthritis patients in a randomized cohort study (Eleopra et al., 2018) based on the idea that pain can be a result of prolonged contraction of the adductor muscles.

Here, we build on the biomechanical arguments for load rebalancing referred above and hypothesize that BT intervention in the gastrocnemius muscle will offload the tibiofemoral joint, primarily in the second peak of the stance phase, and that this will lead to an improvement of the patient's condition. We report on a KOA patient case with subject-specific musculoskeletal models based on motion data pre and post-intervention to take possible changes in the motion pattern and ground reaction forces into account. This offers a simulation-based insight that is not dependent on an all-things-equal presumption.

2. Methods

The experimental protocol was approved by the Regional Ethical Review Board of Capital Region of Denmark, Journal no. H-19072203.

This study included a female patient, 55 years of age, body weight 66.3 kg, stature 153.2 cm, and BMI 28.3 with bilateral knee pain, which was more severe in the left knee. The pain was activity-related as well as at rest. The patient reported a declining ability for distance walking and participation in leisure activities such as cycling and recreational dancing.

Radiological examination of the knee showed bilateral incipient medial KOA (Ahlbeck grade 1), and 6.0/6.4 degrees varus in the left/right knees respectively. The patient was initially referred to municipal strength training but experienced a deterioration in her functional and pain status. She was then treated with an arthrocentesis with steroid injections in both knees without effect, after which an arthroscopic housecleaning of the left knee was performed. This showed grade 3 osteoarthritis in the medial femoral condyle including the patellofemoral joint. The medial tibial surface had significant grade 3 osteoarthritis. Normal cartilage was found in the lateral joint compartment. The arthroscopy initially relieved symptoms, which returned after 3 months.

The patient was referred for evaluation since she wanted an alternative to surgical treatment with knee arthroplasty. The patient signed a written informed consent form according to local guidelines.

The experimental protocol is summarized in Table 1.

The Treadmill test comprised 6 minutes' level walking and 40 m' fast-paced level walking. Lunges were performed until 90 degrees knee flexion reverting to full extension, repeated in three intervals of ten with VAS scoring after each interval. Stair climbing was performed in five repetitions of 30 s on a normal staircase at self-selected pace. Three-dimensional gait analysis used eight Vicon T40 cameras (Vicon Motion Systems Ltd. UK, Oxford, UK) running at 100 Hz and two AMTI OR6-7 force plates (AMTI, Massachusetts, USA). The marker protocol followed the Conventional Gait Model 2.3 (Horsak et al., 2021). The patient walked with preferred speed along the pathway without regard for the force plates, until five complete hits on the force plates were obtained for each leg. Knee extension and plantar flexion strength were subjectively assessed by a trained clinician on a scale from 0 to 5 according to Hislop et al. (2013).

Botulinum toxin A injections were performed ultrasound-guided and without anesthesia with 150 ie Dysport (300 ie Dysport/1.5 ml NaCl) into both heads of m. gastrocnemius in the left calf, following an established clinical procedure. The drug reaches maximum effect after approximately 4 weeks and gradually wears off after 12–24 weeks.

The musculoskeletal model was developed in the AnyBody Modeling System ver. 7.3 (AnyBody Technology, Aalborg, Denmark) (Damsgaard et al., 2006). The model was built on the Twente Lower Extremity Model ver. 2 (Carbone et al., 2015), which is accessible in open source via the AnyScript Managed Model Repository (Lund et al., 2020). The model was driven by the gait marker data, which also created a subject-specific scaling of segment dimensions (Andersen et al., 2010), and loaded by the force plate data. The post-trials assumed 20% reduced strength in both heads of the left m. gastrocnemius to account for the effect of the injections.

Table 1
Summary of the experimental procedure.

Week	Activity	Measurement
0	Daily living	VAS, KOOS
	Treadmill test	VAS
	Lunges	
	Stair climbing	
	Gait analysis	Optical motion capture, GRF
	Knee extension strength	Subjective clinical assessment
	Plantar flexion strength	
	Range-of-Motion	Goniometer
	Injection	
4	Daily living	VAS, KOOS
	Treadmill test	VAS
	Lunges	
	Stair climbing	
	Gait analysis	Optical motion capture, GRF
	Knee extension strength	Subjective clinical assessment
	Plantar flexion strength	
	Range-of-Motion	Goniometer

VAS: Visual Analog Scale. KOOS: Knee Injury and Osteoarthritis Outcome Score. GRF: Ground Reaction Force.

3. Results

The improvements in KOOS were respectively 39, 11, 37, 5, and 56 for the domains Pain, Other Symptoms, Activities-of-Daily-Living, Sport and Recreation (Sport/Rec), and knee-related Quality-of-Life (QoL) (Fig. 1).

Table 2 summarizes the pre and post-injection test results of VAS pain levels, joint strengths and range-of-motion.

The average daily pain reduction was 3 on the VAS scale, and reductions of 2.5–3 were recorded for the treadmill test. Stair climbing VAS was reduced by 4, while there was no difference for the lunges. The knee range-of-motion was improved by 35 degrees due to reduced swelling around the joint. The ankle range-of-motion was unaffected, and so were the joint strengths, except that the patient did not report pain during the post test.

Of five collected gait trials for each condition, two were discarded due to marker dropouts and other data errors. The remaining three trials were too few for statistical processing, but it is manageable to present them in their raw form in Fig. 2. Notable differences between pre and post-injection are in the medial/lateral direction only. The patient's average self-selected gait speeds pre and post-intervention were 1.14 and 1.16 m/s respectively, i.e. a difference below 2% compared with an intra-test range of 6% and 8% respectively. No significant differences were found in ankle, knee, or hip kinematics between the two

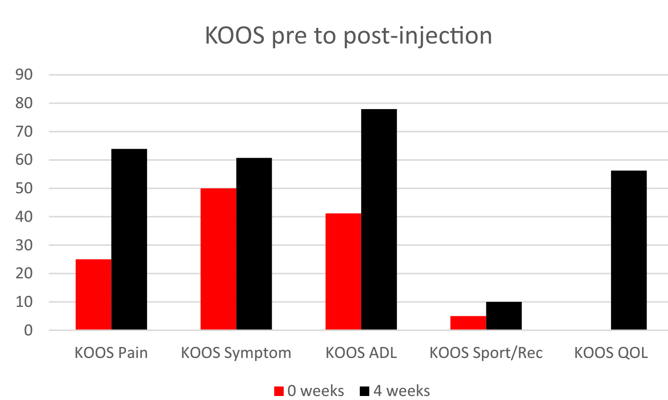

Fig. 1. KOOS evaluation pre and 4 weeks post injection.

Table 2
Test results pre and 4 weeks post-injection.

Activity	Column1	Pre	Post	Difference
Avg daily pain		6.5	3.5	3
Treadmill test	Interval number			
	1	4–5	2	2.5
	2	4–5	2	2.5
	3	4–5	2	2.5
	4	4–5	2	2.5
	5	4–5	2	2.5
	6	4–5	2	2.5
40 m of a fast walking		6	3	3
Lunges	Lunge number			
	10	9–10	9–10	0
	20	9–10	9–10	0
	30	9–10	9–10	0
Stair climbing	Interval number			
	1	9	5	4
	2	9	5	4
	3	9	5	4
	4	9	*	–
	5	9	*	–
Range-of-motion	Knee	10–100	10–135	35
	Ankle	30–60	30–60	0
Joint strength	Knee extension	4 (pain)	4	0
	Knee flexion	4 (pain)	4	0
	Ankle dorsi flex.	5	5	0
	Ankle plantar flex.	5	5	0

Pains scores are on the VAS scale. Knee range-of-motion is in degrees as max extension-max flexion. Ankle range-of-motion is reported in degrees as max dorsi flexion-max plantar flexion. Range-of-motion and strength pertain to the left side, while the VAS scores are not side-speciic. *The patient was exhausted and could not perform the test.

conditions.

Fig. 3 shows the simulated calf muscle forces and proximal/distal knee joint reaction forces for both legs pre and 4 weeks post-injection. In the left leg, the post trials showed more soleus force and less gastrocnemius force as expected. The soleus force was also increased in the right leg post-injection, while the gastrocnemius forces in the right leg were similar pre and post-injection.

The data of Fig. 3 were integrated into impulse in Fig. 4, which reveals that the tibiofemoral joint impulse in the left leg was reduced post-injection. This was also the case for the right leg, albeit to a smaller extent. All impulses appeared to be more evenly divided between the left and right legs post-injection.

The patient reported a reduction of her pain 1 week post injection, improving gradually until the evaluation after 4 weeks. She had resumed her previous level of recreational activities and her walking distance had improved, but problems with stair climbing and squats remained. The patient reported muscle pain consistent with delayed onset of muscle soreness (DOMS) in the soleus in the weeks after the injection. After 2 months, she experienced difficulties sleeping due to knee pain and requested another injection treatment.

4. Discussion

The patient experienced a gradual and considerable improvement of clinical scores following the injections. The results indicate that the inflammation-related excitation of the pain system was reduced, while the KOA problem persisted and caused pain in high-load situations. Reduced inflammation was documented by the increase of the knee range-of-motion by 35 degrees. There were no side effects reported except for temporary DOMS.

The quantitative experimental data showed rather subtle changes in the kinematics and ground reaction forces for the vertical and anterior/posterior directions, while the differences in muscle force and impulse simulations were considerable. The impulse reduction in the left knee post-injection was 16%, corresponding to a weight loss of the same magnitude. Given the assumed gastrocnemius strength reduction, the results support the value of calf muscle rebalancing, but it is surprising that the reduction of knee joint force (Fig. 3) was mainly in the initial part of the stance phase rather than at toe-off. This indicates a complex interplay between inflammation, pain, muscle strength and movement patterns, and is possibly explained by reduction of the medial/lateral component of the ground reaction force (Fig. 2), indicating improved ambulation stability. Fig. 4 shows that the post-injection distribution of loads was better balanced between the left and right knees, and it could be speculated that the results support a vicious circle interpretation of KOA, where pain causes unstable ambulation, which increases the cumulative biomechanical loads, resulting in further joint degeneration and pain. No clinical investigation was protocolled for the situation after the effect wore off. This should be included in future studies.

In the interest of patient compliance, the pharmaceutical approach

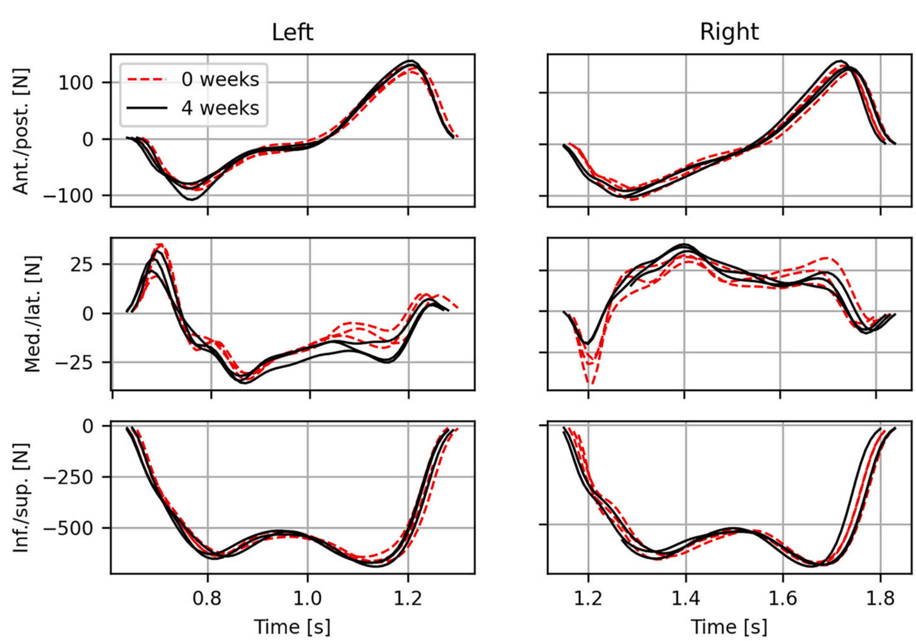

Fig. 2. Gait trial ground reaction forces, pre-injection and 4 weeks after. Graphs in each plot have been time-synchronized between trials by cross correlation.

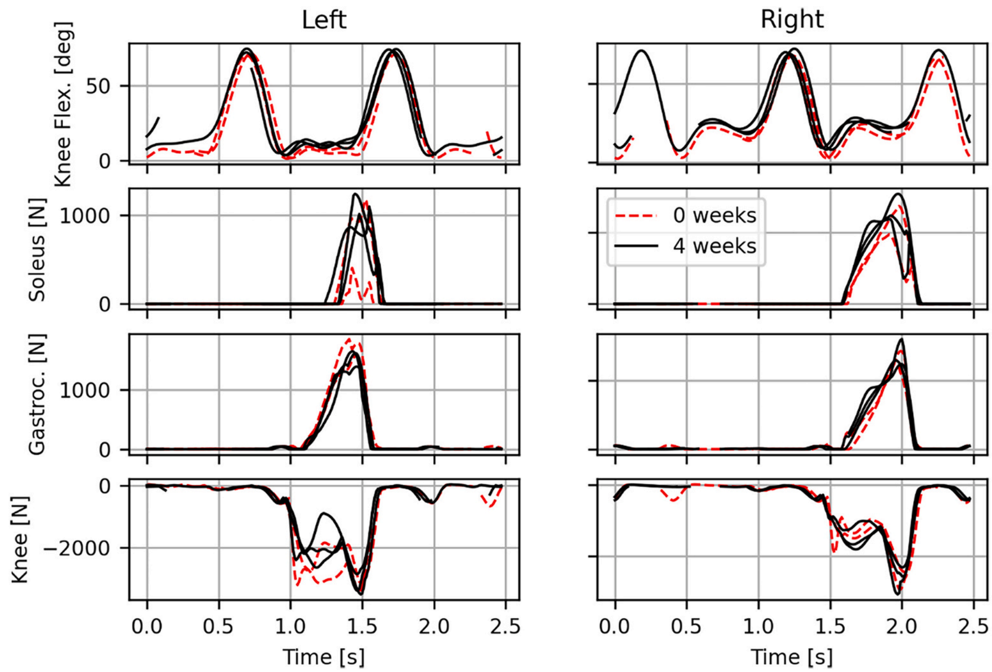

Fig. 3. Knee flexion angles and simulated soleus and gastrocnemius muscle forces and knee joint compression forces pre-injection and 4 weeks post-injection. Graphs in each plot have been time-synchronized between trials by cross correlation.

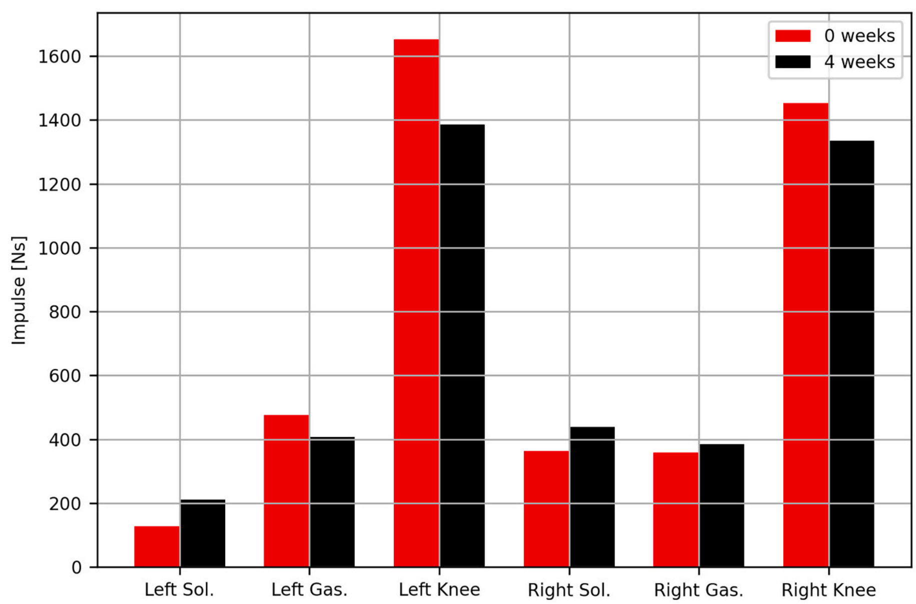

Fig. 4. Average muscle and joint force impulses for the three pre and post-injection trials, respectively.

described here is clinically attractive compared with training regimes aimed at strengthening m. soleus. The patient's experience of post injection DOMS in m. soleus indicates that the weakening of m. gastrocnemius may strengthen m. soleus. A combined treatment protocol with injections followed by targeted soleus exercise could therefore be considered.

5. Conclusions

The results, when combined with the biomechanical basis of the hypothesis, are promising and suggest further investigation by a randomized study. If confirmed, this simple and reversable medical intervention can improve the management of early-stage knee osteoarthritis.

Contributions

- Christian Wong protocolled the project, treated, and performed patient evaluations.
- John Rasmussen performed computer simulations to recover the effect of strength balancing on knee compressive loads and processed data.
- Jesper Bencke performed clinical tests and gait analysis.
- All authors contributed to the discussion of the results and the preparation of the manuscript.

Competing interests

The authors have no competing interests.

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