J Surg Med. 2021;5(11):1126-1130.
DOI: 10.28982/josam.1014433

Research article

Journal of Surgery and Medicine
e-ISSN=2602-2079

Does muscle stiffness predict early-onset knee osteoarthritis?

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Ethics Committee Approval
Required permissions to carry out the study were obtained from Hacettepe University Clinical Research Ethics Committee and T.C. Ministry of Health Medical Device and Medicine Agency with the decision number 15.03.2018, 2018 / 04-39 (KA-17112).
All procedures in this study involving human participants were performed in accordance with the 1964 Helsinki Declaration and its later amendments.

Conflict of Interest
No conflict of interest was declared by the authors.

Financial Disclosure
The authors declared that this study has received no financial support.

Published
2021 November 23

Abstract

Background/Aim: The precise evaluation of the surrounding soft tissues and documenting it by clinical measurements are extremely important for detecting early-stage knee osteoarthritis (OA). Shear wave ultrasound elastography is the latest technology that directly measures the mechanical properties of a tissue, including muscle stiffness. This study was planned to investigate the relationship between Rectus Femoris (RF) and Biceps Femoris (BF) muscle stiffness and the relevant symptoms observed in OA.
Methods: Thirty-one patients including 21 females and 10 males between 45-67 years of age, diagnosed with early-stage knee OA and 10 healthy individuals were included in this prospective case-control study. Both RF and BF muscle stiffness were evaluated by shear wave elastography (SWE), and the knee range of motion was calculated by a goniometer. The pain intensity was measured by the Visual Analogue Scale (VAS), knee function, with the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and functional performance, using the 6-minute walk test and the step-climbing test.
Results: There was a positive correlation between BF muscle stiffness and WOMAC stiffness (*P*=0.014, r=0.446). There was no difference in Rectus Femoris and Biceps Femoris muscle stiffness between the osteoarthritis patients and healthy individuals (*P*=0.11 and *P*=0.10, respectively).
Conclusion: It can be concluded that the symptom of stiffness seen in early-stage knee OA is caused by BF muscle spasm related to the flexor reflex.

Keywords: Biceps femoris, Muscle stiffness, Osteoarthritis, Rectus femoris, Shear wave elastography

How to cite: Gökşen A, Can F, Yilmaz S. Does muscle stiffness predict early-onset knee osteoarthritis? J Surg Med. 2021;5(11):1126-1130.

Introduction

Early knee osteoarthritis (OA), also known as "gonarthrosis," may cause loss of strength and flexibility in the Rectus Femoris (RF) and Biceps Femoris (BF) [1, 2], as well as an increase in stiffness in these muscles [3, 4]. This loss can be compensatory [5] to protect excessive loads in accompanying joint structures, including the joint cartilage [6]. Shear Wave Elastography (SWE) was previously used to assess the thickness and structural changes of joint cartilage [7, 8]. Shear wave elastography (SWE) is a non-invasive, reliable, and repeatable method that predicts elasticity by measuring the velocity of the speed of tissues [9]. Limited studies evaluated the skeletal muscles of the knee joint using this technology [10-12]. Skeletal muscles and connective tissues are important dynamic and static stabilizers of the knee joint that prevent injuries and progression of the disease, respectively [13]. Two studies revealed that the Quadriceps Femoris (QF) tendon plays a decisive role in the knee flexion range of motion and severity of OA. The stiffness of the QF tendon also affects gait in gonarthrosis, and studies show it plays a decisive role in the knee flexion range of motion and the severity of OA [11, 12]. Structural and functional changes of the QF tendon, but not the other connective tissues of the knee joint, were previously evaluated. None of these studies were conducted in early-stage gonarthrosis. We researched whether SWE could determine structural changes in the QF and the BF muscles in patients with early-stage gonarthrosis and whether there is a relationship between SWE values, function, pain, and knee range of motion, and early-stage knee OA.

Materials and methods

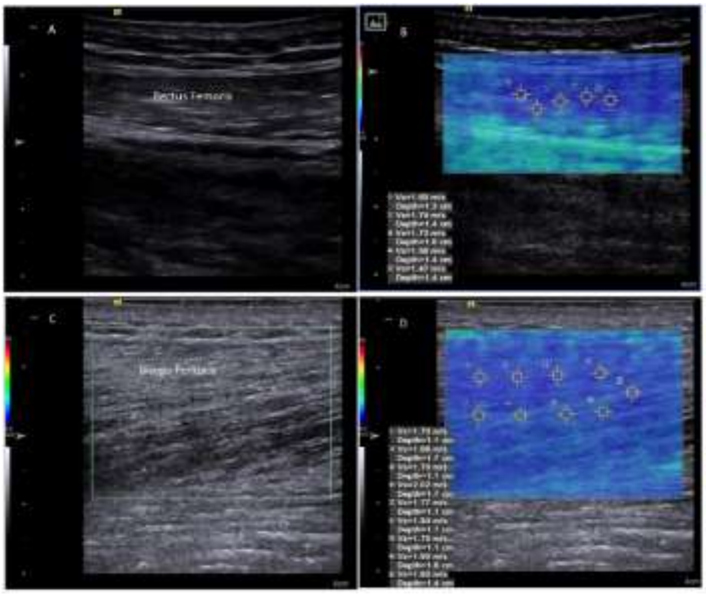
In this prospective case-control study, the G*Power statistical analysis software was used to calculate the minimum sample size for the Spearmen Correlation test, based on the effect size of a similar previous study [10]. The minimum total sample size was 30 individuals. The association of RF and BF muscle stiffness with pain levels, range of motion, knee function, and functional performance was examined using the appropriate statistical methods. In the second G*Power analysis, Quadriceps Femoris muscle stiffness was the main outcome. Bidirectional hypothesis design was used to achieve an 80% working power. A minimum of 20 adults was needed for each group, for a significant difference of 50% and 5% type 1 error. Initially, the study began with a total of 40 osteoarthritis patients and 20 healthy individuals; however, it was completed with 31 patients and 10 healthy individuals who were suitable for orthopedic examination, radiological and magnetic resonance evaluations. It was highly difficult to find healthy adults between 45-60 years of age without any orthopedic problems in the knee. Therefore, the study evaluated 31 (21 females, 10 males) osteoarthritis patients and 10 healthy individuals admitted to Beytepe Hospital, Hacettepe University. Patients were diagnosed with Stage 1–Stage 2 knee OA according to the Kellgren-Lawrence classification system based on prior examinations performed by the relevant physician, and the absence of any previous surgery or concomitant ligament or meniscus injuries. Individuals who voluntarily agreed to participate in the study and signed the informed consent form were included. Age (years), height (m), and weight (kg) of the patients were recorded, and Body Mass Index (BMI) (kg/m²) was calculated by dividing the total body weight by the square of height.

Pain intensity was evaluated with the Visual Analogue Scale (VAS) measured at rest and during activity, in which the patient marked the intensity of their pain on a 10 cm-long line containing marked indicators on either side ranging from '0', indicating no pain, to '10', indicating unbearable pain.

The knee flexion range of motion was evaluated with a goniometer in the prone position, which is a widely used, valid, and reliable method [14].

RF and BF Shear Wave velocity were evaluated by a single physician using SWE, an ultrasonography-based imaging method that shows the soft tissue changes in the early stages of the disease. SWE provides numerical information on the stiffness and flexibility of both the superficial and the deep soft tissues. Since the measurements are independent of the examiner and repeatable, SWE is considered a valid and reliable method for evaluating the stiffness of the skeletal muscles [15]. Shear wave elastography of RF and BF muscles was performed with the Acuson S3000 ultrasound system (Siemens Medical Solutions, Mountain View, CA) equipped with a 9L4 (4–9-MHz) linear array ultrasound transducer. The RF SWE measurement was performed in the supine position on the distal one-third of the anterior superior iliac spine and patella. The ultrasound transducer was placed longitudinally on the muscle fibers with the knee flexed at 30 degrees [15]. The biceps femoris long head SWE measurement was performed in the prone position on the distal one-fourth point between the posterior superior iliac spine and the fibular head. The ultrasound transducer was placed longitudinally on the muscle fibers with the knee flexed at 30-45 degrees [16]. The mean muscle stiffness was calculated from the radio frequency data using customized software, Virtual Touch Tissue Imaging Quantification, Siemens Medical Solutions. The measurement was repeated thrice for each muscle, the average of the three measurements was taken and recorded with a calculator in meters per second (m/s). Images of muscle stiffness measurements are depicted in Figure 1.

Figure 1: A: 2D sonogram of the rectus femoris muscle. B: SWE images of the rectus femoris muscle C: 2D sonogram of the biceps femoris muscle D: SWE images of the biceps femoris muscle. Squares marked on B and D are region of interest from where SWE measures were obtained



Knee function was evaluated by the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire scores, the 6-minute walk test, and the step-climbing test. WOMAC questionnaire evaluates function in the knee and hip osteoarthritis under three headings of pain, stiffness, and function, and its validity and reliability studies on hip and knee OA were performed both in Turkey and abroad [17, 18].

Other assessment measures, such as the 6-minute walk test and the step-climbing test, are reliable and easily applicable tests for evaluating functional performance and mobility [19]. In the 6-minute walk test, the maximum distance the patient can travel in a fixed corridor for 6 min is recorded in meters. The step-climbing test involves asking the patient to climb up and down the 10-step ladder as quickly and safely as possible without holding on and the elapsed time is recorded in seconds [20].

Statistical analysis

Statistical analysis was conducted with the SPSS version 21 (Armonk, NY: IBM Corp). The G*Power statistical analysis software was used to calculate the sample size for the Spearmen Correlation test based on the effect size of a similar study [10], which revealed a minimum sample size of thirty individuals. The association between RF and BF muscle stiffness and pain levels, range of motion, knee function as well as functional performance was examined using the appropriate statistical methods. The normality of the data distribution was determined with the Shapiro-Wilk test and histogram evaluations. The association of the data variables with each other was evaluated with the Spearman rank correlation test. A *P*-value of less than 0.05 was considered significant.

Results

The mean age and the mean body mass index of 31 patients (21 females, 10 males) were 54.58 (1.27) years, and 30.60 (4.61) kg/m^2, respectively. The mean pain intensity was 5.77 (2.56) cm (2–10) at rest and 5.00 (4.29) cm (0–10) during activity. The mean knee flexion range of motion, step climbing test scores and 6-minute walk test scores of all individuals included in the study were 119.83 (15.02) (91–140) degrees, 12.31(4.96) (5.70–25.00) seconds, and 449.22 (95.28) (287–748) meters, respectively. The WOMAC pain, stiffness, function, and total scores were 7.31(3.01) (2–12) points, 2.34 (2.51) (0–7) points, 27.51 (10.35) (45–10) points, and 36.62 (12.84) (63–12) points, respectively. The mean RF and BF Shear wave velocity values of all patients were 1.84 (0.25) (1.43–2.42) m/s and 1.71 (0.32) (1.14–2.32) m/s, respectively (Table 1). There was no difference in muscle stiffness between the osteoarthritis patients and the control group (*P*>0.05) (Table 2). RF Shear Wave velocity and rest pain, activity pain, range of motion, step climbing test, 6-minute walk test, WOMAC pain, stiffness, function, and total scores in early-stage knee osteoarthritis were not related *(P*>0.05) (Table 3, 4).

Although BF muscle stiffness was not correlated with rest pain, activity pain, joint range of motion, step climbing test, the 6-minute walk test, or the WOMAC pain, function, and total scores (*P*>0.05), it was positively correlated with the WOMAC stiffness score (*P*=0.014, r=0.446) (Table 4).

Table 1: Detailed data on individuals with knee osteoarthritis

		Early Knee OA Mean (SD) (Min-Max)
Pain intensity level	Activity (cm)	5.77 (2.6) (2–10)
	Rest (cm)	5 (4.29) (0–10)
Knee Flexion Range of Motion (degree)		119.83 (15.02) (91–140)
Step Climbing Score (sec)		12.31 (4.96) (5.70–25.00)
6-minute walk score (m)		449.22 (95.28) (287–748)
WOMAC (score)	WOMAC Pain (points)	7.31 (3.01) (2–12)
	WOMAC stiffness (points)	2.34 (2.51) (0–7)
	WOMAC Function (points)	27.51 (10.35) (45–10)
	WOMAC Total (points)	36.62 (12.84) (63–12)
RF Muscle Shear wave velocity (m/sec)		1.84 (0.25) (1.43–2.42)
BF Muscle Sear wave velocity (m/sec)		1.71 (0.32) (1.14–2.32)

OA: Osteoarthritis, WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index, SD: Standard deviation, Min: Minimum, Max.: Maximum, sec: second, m: meter, RF: Rectus femoris, BF: Biceps femoris, cm: centimeter

Table 2: Comparison of muscle shear wave velocity between individuals with early-stage knee OA and healthy individuals

		RF Muscle Shear Wave velocity (m/sec)	BF Muscle Shear Wave velocity (m/sec)
Early Knee OA	Mean Rank	22.68	19.29
Healthy Group	Mean Rank	15.80	26.30
z		-1.57	-1.61
P-value		0.11	0.10

OA: Osteoarthritis, RF: Rectus Femoris, BF: Biceps Femoris, Mann-Whitney Test*, p<0.05 was considered statistically significant, m: meter, sec: second

Table 3: The relationship of muscle stiffness with pain, range of motion, and knee functional performance

		Pain in Rest (0–10 cm)	Pain at Activity (0–10 cm)	Range of Motion (degree)	Stair Climbing Test (sec)	6-Minute Walk Test (meter)
RF Muscle Shear wave velocity (m/sec)	*P*	0.090	0.488	0.134	0.442	0.641
	r	-0.309	-0.129	0.275	-0.143	-0.087
BF Muscle Shear wave velocity (m/sec)	*P*	0.213	0.327	0.339	0.761	0.134
	r	-0.230	-0.182	-0.178	-0.057	0.275

RF: Rectus Femoris, BF: Biceps Femoris, Spearman Correlation Test*, p<0.05 was considered statistically significant, m: meter, sec: second, cm: centimeter

Table 4: The relationship of muscle stiffness with knee function

		WOMAC Pain (Point)	WOMAC Stiffness (Point)	WOMAC Function (Point)	WOMAC Total (Point)
Mean (SD) (Min-Max)		7.31 (3.01) (2–12)	2.34 (2.51) (0–7)	27.51 (10.35) (45–10)	36.62 (12.84) (63–12)
Rectus Femoris Muscle Shear Wave velocity (m/sec)	*P*	0.139	0.101	0.178	0.093
	r	0.277	0.305	0.253	0.312
Biceps Femoris Muscle Shear Wave velocity (m/sec)	*P*	*0.79*	0.01*	0.82	0.88
	r	-0.05	0.44	-0.04	0.02

Spearman Correlation Test, *p<0.05 was considered statistically significant. SD: Standard deviation, WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index, m: meter, sec: second

Discussion

This is the first study to investigate and explore the importance of muscle stiffness in early-stage knee OA. Many studies emphasized the importance of RF muscle strength in patients with knee OA [21-24] and reported that RF muscle strength decreased as the severity of the disease increased [24]. In addition to decreased muscle strength, pain, loss of function, and range of motion are the most common problems encountered by the patients in knee OA [5, 24, 25]. Although many factors cause these symptoms in knee OA, muscle stiffness may cause a gradual decrease in the intrinsic shock absorption feature; thus, resulting in decreased knee function in early-stage knee OA [2]. Muscle stiffness is an important parameter for joint stability and control of movements [26, 27]. The initial degeneration that starts in the cartilage tissue gradually reaches the bone tissue [28]; therefore, musculoskeletal problems may also be responsible for pain and loss of function in early knee OA [29]. For this reason, it is imperative to evaluate the surrounding soft tissues in early knee OA. In this study, the WOMAC stiffness parameter was correlated with Biceps Femoris muscle stiffness. According to the results of our study, we think that stiffness seen in OA is related to the flexor reflex. In early-stage knee OA, unlike advanced-stage knee OA, stiffness and other symptoms are not continuous, though symptoms that increase with activity levels are present [6]. The flexor reflex that protects the knee joint may be responsible for symptoms that increase with activity in knee injury [29]. In the case of the flexor reflex, flexor muscles are activated, and extensor muscles are inhibited to protect the knee joint. This increase in activation of the flexor muscles can increase muscle stiffness by causing nutritional deficiency in that area due to overuse. Additionally, in the presence of pain, gamma motor neuron-muscle spindle sensitivity and reflex activity may be impaired due to the activity of group III and group IV afferent nociceptors. Gamma motor neuron stimulation can increase muscle stiffness by causing an increase in muscle spindle activity [29-31]. Many studies evaluated joint stiffness rather than muscle stiffness in individuals with early-stage knee OA, and to date, no study has evaluated the changes associated with muscle stiffness in early knee OA [32, 33]. However, previous studies reported that increased muscle activation in musculoskeletal problems increases muscle stiffness [34, 35]. According to our study results, RF and BF muscle stiffness was not associated with knee pain, range of motion, and knee function, as assessed by step-climbing test and 6-minute walk test. RF muscle stiffness was also not associated with knee function according to the WOMAC index. However, in their study conducted on individuals with neurological diseases, Lee et al., reported that a decrease in knee joint range of motion and knee function was due to the deterioration of the mechanical properties of the muscle [36]. Since RF muscle stiffness in early knee OA does not deteriorate enough to negatively affect knee function, such a relationship was not found in our results. We believe that the symptom of joint stiffness seen in early-stage knee OA, also frequently studied in the literature [30, 32, 33, 37], is caused by BF muscle stiffness. In the study of Langan et al. [38] on healthy individuals, BF muscle stiffness was associated with isotonic muscle performance, evaluated with the Biodex System. BF muscle stiffness may lead to improved dynamic muscle performance, which in turn may have implications for injury prevention. However, this study has not incorporated any performance-based tests, such as the step test. Since SWE is a recent evaluation method, there are no past literary insights that have evaluated the mechanical properties of the muscle in early-stage knee OA except for a few studies about muscle flexibility [39-41]. A study evaluating the muscle flexibility in osteoarthritis by measuring the passive knee extension range of motion reported that muscle flexibility decreased in patients with osteoarthritis as compared to patients without [40]. Various studies that evaluated how the mechanical properties of the muscle affect the knee joint reported that RF and H muscle stiffness decreases with age and is crucial for the control of knee joint movement [10, 26, 42]. In a study evaluating muscle stiffness after ACL surgery, muscle stiffness was associated with muscle strength [43]. As seen in the previous studies, muscle stiffness can be interpreted as muscle spasms as well as muscle strength. In our study, muscle stiffness was interpreted as a spasm because it was associated with stiffness. More studies are needed to correlate muscle stiffness with symptoms and function in early OA.

No correlation was found between pain and muscle stiffness, which was another evaluation parameter in our study. The increase in muscle stiffness is an intrinsic compensatory mechanism to reduce pain. Studies report that an increase in pain is generally associated with muscle stiffness [30, 44]. However, this relationship was not demonstrated because the pain associated with early knee OA increases with activities that put a load on the knee joint. Also, muscle stiffness was evaluated in the resting position of the muscle. In shear wave ultrasonography, muscle stiffness was evaluated passively at the time of relaxation of the muscle as suggested by many studies in the literature [15, 45, 46]. Additional follow-up studies should be planned accordingly to reveal the relationship between muscle flexibility and pain in early knee OA by involving the measurements of muscle stiffness during both rest and submaximal contractions. In our study, no correlation was found between muscle stiffness and pain in patients with early-stage knee OA. Even though RF muscle stiffness was not associated with function and range of motion, BF muscle stiffness was associated with WOMAC stiffness. To sum up, a decrease in BF muscle flexibility is directly associated with joint stiffness, as observed in early-stage OA.

Conclusion

We think that the inclusion of flexibility exercises for the Hamstring muscle group in the rehabilitation program might minimize the symptoms associated with stiffness. Further evaluation of muscle flexibility, as well as muscle strength in early-stage knee OA, may also reduce the rate of progression of the disease by reducing the risk of injury. Future studies examining the changes in muscle stiffness in all stages of osteoarthritis will enable us to understand the muscle stiffness seen in osteoarthritis better.

Limitations

According to the results of radiological magnetic resonance and orthopedic examination, it was very difficult to find a healthy individual without any orthopedic problems and complaints in the knee, so we could not reach a higher number of healthy individuals for comparison.

Acknowledgment

I would like to thank Prof. Dr. Feza Korkusuz, Dr. Ömer Özkan, Associate Professor Dr. Serkan Taş, Şahap Karaman, and Nahit Gökşen for contributing to the provision of a suitable environment for work.

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