The Correlation Between Gastrocnemius Muscle Thickness 
And Activity Limitations In Patients With Severe OA

Aseel Ghazwan\textsuperscript{1\textdagger}, Waleed A Alsaadan\textsuperscript{2}, and Nadia Rany\textsuperscript{1}

\textsuperscript{1}Biomedical Engineering Department, Al-Nahrain University, Baghdad, Iraq.
\textsuperscript{2}Training program director of Arab Board of Orthopaedic Surgery in Iraq, Medical City, Baghdad, Iraq

\texttt{*aseel\_ghazwan@yahoo.com}

**Abstract.** Muscle thickness offers an excellent indicator of maximal force generating capacity, and, accordingly, a reduction in muscle thickness may contribute to muscle weakness; this in turn may be related to functional limitations in patients undergoing total knee replacement. The purpose of this study was to correlate the morphologic changes in the gastrocnemius muscle in relation to muscle activity in subjects with severe knee osteoarthritis (OA), in order to establish an objective means of measuring muscle function and muscle recovery. Two subject groups participated in this study, one group of 10 non-pathological subjects (NP) and a separate group of 10 subjects with severe OA. The muscle thickness (MT) and EMG muscle activity (MA) of the medial gastrocnemius (MG) and lateral gastrocnemius (LG) were assessed using ultrasonography (US) and electromyography (EMG), respectively. The correlation between MA and MT was thus investigated, and linear regression analysis performed to determine prediction equations for muscle activity. The results showed that MA is highly related to MT for both MG and LG in NP subjects. The MA prediction equation based on linear regression analysis resulted in R\textsuperscript{2} values of 0.90 and 0.95 (p<0.05) for LG and MG, respectively, while in OA subjects, a good correlation was shown between MA and MT within the MG, with R\textsuperscript{2} = 0.80, though a more moderate correlation was found for LG, with R\textsuperscript{2} = 0.52. The thickness of the MG was not significantly increased during maximum voluntary contraction (MVC) as compared with the resting state, while the thicknesses of LG significantly increased, from 15 to 22 mm, on moving from resting to MVC. This study thus demonstrated that MG is more useful parameter than LG for the prediction of muscle force generating intensity in patients with severe OA.

1. Introduction

Osteoarthritis (OA) is a common chronic disease that affects an estimated 10\% of males and 13\% of females over the age of 60 suffering from regular knee symptoms OA [1]. OA progression is frequently accompanied by muscle weakness, decline in muscle strength [2, 3], and functional disability [4]. Such muscle weakness has been attributed to muscle atrophy and impaired activation [5], though selective atrophy of type 2 fibres may contribute to the development and/or progression of OA as a cofactor [6]. The selective motor control effects of the disease make it difficult to assess the strength of muscles in OA patients; thus, quantifying the morphologic changes of the gastrocnemius muscle in relation to muscle activity may provide an indirect means of measuring muscle function and potential muscle recovery. There is also reliable evidence that the muscle size in the affected limb, as assessed by means of muscle thickness, offers an indicator of maximal force generating intensity [7], being reduced in cases...
of reduced function as compared to normal muscles. However, the impacts of the muscle structure on motor control have not been seriously examined in patients with severe OA.

The relationship between EMG activity and muscular architecture has been examined in the literature in other cases, however, with relationships between the change in EMG and muscle thickness of the abdominal muscles [8], quadriceps in soccer players [9], erector spinae [10], and gastrocnemius in healthy adults [11] having been investigated. No study has used muscle thickness (MT) and EMG muscle activity (MA) in the medial gastrocnemius (MG) and lateral gastrocnemius (LG) to assess muscle function and muscle recovery in patients with severe OA, however, and the current study thus aimed to quantify morphologic changes of the gastrocnemius muscle in relation to muscle activity in patients with severe OA.

2. Materials and Method
Electromyography (EMG) and ultrasonography data were collected in the motion analysis laboratory of the Biomedical Engineering Department at Al-Nahrain University and Medical City, respectively, from twenty subjects, divided into two groups: ten subjects with no knee pathology (NP) and ten subjects with severe OA.

2.1. Participants
Ten patients with severe knee OA were recruited from Medical city, having been diagnosed by a consultant orthopaedic surgeon. The control group consisted of ten non-pathological (NP) subjects with no self-reported symptoms or history of activity-limiting conditions. The mean age, mass, and height were 60 years, 84 kg, and 1.65 m and 28 years, 64 kg, and 1.72 m for OA and NP, respectively.

2.2. Data acquisition
Each participant underwent rest and maximum voluntary contraction (MVC) measurements of EMG signal for the medial gastrocnemius (MG) and lateral gastrocnemius (LG) muscles using the MyoTrace system, with muscle thickness measurements taken using ultrasound.

2.3. EMG Measurement
Muscle electromyographic (EMG) data, for the MG and LG were collected using the Noraxon Myotrace400 Wireless EMG (MyoTrace system). Electrodes were placed longitudinally over the muscle belly after standard preparation of the skin, as recommended by SENIAM [12], which involved shaving, exfoliation, skin cleaning, and finally electrode gel was used to reduce electrode-skin impedance [13]. EMG data for the MG and LG were recorded during maximum voluntary contraction (MVC); to achieve this, subjects were asked to stand up with full plantar flexion and to contract their gastrocnemius muscle as hard as possible for three seconds [14], as shown in Figure 1. Two trials were recorded for each participant.
2.4. Morphological Measurement
Real time B-mode ultrasonography (US) was used to measure MG and LG muscle thickness. Gastrocnemius muscle thickness was assessed by measuring tibia length (TL) from the most prominent point of the lateral malleolus to the fibular head. Following the recommendations of Bénard et al [15], the US image was obtained at a marked point on the top 25% of the TL. The longest distance from the upper to lower muscle fascia visible on the image was used to define MT. Gastrocnemius muscle assessments were taken over the middle of the muscle belly during both resting and MVC phases.

2.4.1. Resting Position. US measurement of the gastrocnemius muscle was based on [16]: “The participants were rested comfortably in the supine position with the knee joint near the natural resting position of 10°; furthermore, a towel roll was placed under the knee as required for positioning or to aid in comfort and muscle relaxation. The transverse images of the gastrocnemius muscle were taken at 25% of the tibial length from the popliteal fossa. The subjects were positioned prone on the examination table, with their feet hanging over the edge enabling a resting ankle position”, as shown in Figure 2. The US probe was held close to the skin, with a beam perpendicular to the skin surface, then the medial cross section of the MG was checked, and the largest cross-section area identified as the standard section, marking the corresponding body surface. Extreme care was taken to keep participants in a standardised position through the session, and a generous amount of contact gel was used to minimise pressure from the transducer to eliminate the negative impact of excess compression causing distortion of the skin and subcutaneous tissues.
2.4.2. Maximum voluntary contraction (MVC). The second set of US measurements was taken during the MVC of the gastrocnemius muscle. Subjects were asked to stand up with full plantar flexion and contract their gastrocnemius muscle as hard as possible [14], as shown in Figure 3. The US probe was then held close to the skin over the middle of the muscle belly to measure MT during MVC.

![Figure 3: US Measurement during MVC.](image3)
2.5. Data Processing
The raw EMG data was filtered through a Butterworth 4th order filter at 10 to 450 Hz, with a band-pass filter added to remove movement artifacts; this was then rectified and finally filtered with a low pass filter, 4th order Butterworth filter at 6 Hz to create a linear envelope. EMG data was then analysed in MATLAB (version R2016b, MathWorks Inc.). The EMG processing steps are presented in Figure 4.

![Figure 4: Transformation of raw EMG to muscle activation data.](image)

2.6. Statistical Analysis
Statistical analysis was undertaken within Excel, with all significance levels set to P < 0.05. To determine the correlation between MA and MT in NP and OA subjects, a Pearson correlation test was performed, while to quantify the strength of any such correlations, linear regressions were applied as required.

3. Results
The results of the linear regression models are presented in Figures 5 and 6; these show the correlation between EMG muscle activity and muscle thickness during MVC. The results of the correlation are plotted over the groups in a unit scale, so that the differences between groups can be easily observed. MA is highly related to MT for both MG and LG in NP subjects; based on the linear regression analysis, the equation for MA predictions shows R² values of 0.90 and 0.95 (p<0.05) for LG and MG, respectively. In OA subjects, a good correlation was shown between MA and MT on the MG, with R² = 0.80, while only moderate correlation was identified on the LG, with R² = 0.52.

The reduced level of muscle activity in OA compared to NP was accompanied by a reduction in the range of MT.

![Figure 5: Relationship between EMG muscle activity during MVC and muscle thickness for medial gastrocnemius muscle in Non-pathologic (NP) and OA subjects.](image)
Figure 6: Relationship between EMG muscle activity during MVC and muscle thickness for lateral gastrocnemius muscle in Non-pathologic (NP) and OA subjects.

Muscle thickness of the two subject groups both resting and at MVC is presented in Figure 7. The results show thicknesses of MG at rest of 16.1±1.5 and 12.3±0.80 mm in NP and OA subjects, respectively, which did not change significantly in response to MVC. LG muscle thickness increased (p < 0.05) in NP during MVC as compared with resting values, however.

Figure 7: Muscle thickness (MT) for NP and OA subjects during Resting and MVC positions. Values represent means, with standard deviation bars.

4. Discussion
The key finding of this study was that the MG is more useful parameter than the LG for predicting the force generating intensity of muscle in OA subjects. In the published literature [16], US assessment of MT has been shown to be a valid and reliable measure of muscle volume. The current results confirmed that ultrasound is indeed useful in quantifying configurational differences between the relaxed and contracting state of the gastrocnemius muscle, specifically the MG in severe OA patients.
The findings of the current study suggest that as gastrocnemius muscle thickness increases, muscle contraction level also increases, further revealing that the relationship between MT and contraction level is linear in NP subjects, with significant correlations for the MG and LG (p < 0.05), with R² values of 0.95 and 0.90, respectively. However in OA subjects, the MG showed the strongest relationship with contraction levels, with an R² value of 0.80 for muscle thickness regression equations as used to predict contraction level. This is supported by the previous literature [11], which has reported a linear relationship between muscle activity and changes in muscle geometry for MG.

For the LG, the relationship between muscle thickness and level of contraction is also fairly linear in OA subjects, though only a moderate significant correlation (p < 0.05) was identified, with an R² value of 0.52. The OA group was formed of patients with medial knee OA, and thus these patients have malalignments, with weight shifted to the medial side of the knee. This means that the lateral muscles of the knee joint are highly co-activated, forming a compensatory load reduction mechanism on the medial side of the joint to compensate for joint instability and subsequent pain. This might be destructive for the long-term integrity of the joint, as it induces atrophy of muscle fibres [17], and the LG may have undergone permanent configuration changes in this group due to the higher and more prolonged muscle co-activation. Looking at Figure 7, it can be noted that the change in MT from resting to MVC positions in OA patients is lower than that in NP subjects. The functional importance of the changes in muscle activity of the LG can be seen in its contribution to total force production to stabilise the joint.

The findings concerning changes in muscle thickness in response to the contraction levels were not always predictable, as they appear to be muscle specific, in line with Maganaris et al. [18]. In NP subjects, the thickness of MG did not significantly change in response to contraction levels (16.1±1.51 to 16.6±1.51 mm from resting to MVC, respectively) while the thicknesses of LG did change (15.91±1.84 to 21.52±1.86 mm from resting to MVC, respectively). This is in agreement with the findings of [18], which reported that no significant differences were observed in the thickness of MG (about 17 mm) while the thicknesses of LG significantly increased, from 15 to 22 mm from resting to MVC, respectively.

The results of this study suggest that changes in muscle activation appear to be muscle specific in the context of symptomatic knee OA, and that these changes are influenced by morphological severity. Further studies will be required to examine whether these changes are causal or in response to the development of OA, however.

5. Conclusion
Both MG and LG muscles are strongly correlated to muscle activity in NP subjects, while in OA subjects who have undergone greater morphological changes than NP subjects, the MG muscle is a more useful parameter than the LG in terms of predicting the force generating capacity of the muscle. Statistical analysis of the relationship between EMG muscle activity and the morphologic parameters of the MG and LG also revealed a significant association between degenerative muscle changes and activity limitations.

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