Influence Of Gastrocnemius-soleus Muscle Force On Ankle Stress Distribution During Triple Arthrodesis

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Introduction: The muscle forces during the gait cycle can be as large as 1000N. Thus, the effect of muscle forces on the contact stress distribution might be significant. The dominant extrinsic plantar flexor is the gastrocnemius-soleus (G-S) muscle complex, and it likely has a considerable effect on the stress distribution of ankle joint in normal and abnormal subjects. In this study, a three-dimensional musculoskeletal FE model of the ankle joint is presented to determine the influence of gastrocnemius-soleus (G-S) muscle force on the stress distribution in tibio-talar joint in normal and arthrodesised subjects.

Methods: Gait analysis tests were performed on ten subjects. Five patients with bilateral triple arthrodesis (two females, three males) (age = 31.6 ± 3.2 years; BMI = 23.42 ± 3.79) were recruited for this study. The mean duration of follow-up after surgery was 2.7 years. Five normal persons (two females, three males) (age = 26.4 ± 1.5 years; BMI = 21.59 ± 2.9) years participated in this study. During the gait analysis tests, surface EMG signals of 4 muscles (tibialis anterior, soleus, lateral gastrocnemius-soleus and peroneus brevis) were recorded for all subjects. Also, the subjects performed three trials of MVC at one minute intervals. Description of MVC testing method was reported in the literature [1]. Then, filtered kinematic and kinetic data were imported to a gait model according to Vaughan [2] that has been generated in the AnyBody Modelling System V5.3.1 to calculate ankle muscle forces. Individual muscle forces were validated with EMG signals using the BioProc software V3.10 (Canadian Society for Biomechanics). Ankle muscle forces were then imported to a finite element model of the ankle joint, which was verified with the experimental data related to the tibio-talar contact stress [3, 4], in three different stages of the gait cycle. CT data of the right foot of a healthy 47 years old male was used to create the geometry of 3D models of 6 bony segments including the distal segments of the tibia and fibula, talus, calcaneus, cuboid, and navicular bones. The solid models of the different segments were assembled in the finite element package ANSYS Workbench V14.5.7 (ANSYS Inc, Pittsburgh, PA, USA). Muscle forces were applied on the insertion point detected from the MRI [5]. FE model of the ankle joint complex was used for all subjects, and for each subject, the boundary conditions were applied to the FE model in three different stages of gait cycle.

Results: Four different muscle forces obtained by AnyBody (Figure 1) showed a good similarity with the trend of their EMG signals (Figure 2). Correlation coefficient, as a measure of the similarity of EMG and muscle force, of 4 ankle muscles for all subjects can be found in Table 1. Comparison of ankle muscle forces in normal subjects and triple arthrodesis patients reveals that peroneus brevis forces in arthrodesis individuals were more compared to those of normal subjects during the early stance phase. In addition, correlation coefficients between ankle muscle forces and EMG of arthrodesis individuals were lower compared to normal subjects (Table 1). Also, maximum EMG amplitude and maximum muscle force of G-S accrued later than in normal subjects. This finding is in agreement with a previous study (Fig 1, 2) [6]. The von Mises stress patterns of the tibio-talar joint for all subjects in the stance phase and in the lateral side of inferior surface of tibio-talar joint show a good agreement with a previous study (Fig. 3A) [3]. This is due to the fact that the ankle muscles are not very active in stance
phase, thus results of the stress distribution in stance phase agrees well with the results in cadavers (Fig. 3A). The effect of gastrocnemius-soleus (G-S) muscle force on the stress distribution in tibio-talar joint in the heel rise phase of the gait cycle for one patient is shown in Fig. 3B. By increasing the G-S muscle force, von Mises stress of the tibio-talar joint will reduce, especially on the medial surface of tibio-talar joint. Also, in the case of an increase in the G-S muscle force, von Mises stress on the tibio-talar joint for patients were shifted to the lateral side of the inferior surface of the joint (Fig. 3B).

**Discussion:** In all subjects, a good similarity was seen between EMG and forces of ankle muscles (Fig. 1, 2 and Table 1). M. peroneus brevis is more active in the early stance phase in all patients compared to that of normal subjects. This is due to the fact that all arthrodesis patients, who took part in the gait cycle tests, had an extreme initial eversion of ankle joints in early stance phase and the one action of peroneus brevis muscle is ankle eversion. Considering that increasing G-S muscle force will cause a change in the stress distribution pattern on the medial malleolus (compare Fig. 3B right with Fig. 3B left), in arthrodesis subjects, these patients need physiotherapy to make their muscles stronger and consequently prevent them from making extreme eversion in their ankle joints.

**Significance:** Considering muscle forces in the FE models of ankles of normal and arthrodesis subjects was the main scope in this study. The results give input to the physiotherapy rehabilitation process and may contribute to the development of implants, improvement of ankle arthroplasties and surgical procedures.
Figure 1. The muscle forces obtained using AnyBody. Colored lines indicate patients with triple arthrodesis and black lines indicate normal subjects.

Table 1. The mean and standard deviation of the correlation coefficients between muscle forces that obtained by AnyBody and EMG of muscles for patients with triple arthrodesis and for normal subjects.

<table>
<thead>
<tr>
<th>Muscle's name</th>
<th>Correlation coefficients</th>
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<tbody>
<tr>
<td></td>
<td>Patients</td>
</tr>
<tr>
<td>Soleus</td>
<td>0.8884±0.0577</td>
</tr>
<tr>
<td>Gastrocnemius-soleus</td>
<td>0.8916±0.0268</td>
</tr>
<tr>
<td>Peroneus Brevis</td>
<td>0.7598±0.0733</td>
</tr>
<tr>
<td>Tibialis Anterior</td>
<td>0.8996±0.0502</td>
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Figure 2. The mean and standard deviations of muscle activities (EMG signal normalized to a maximum voluntary contraction (MVC)) for the subjects of (a): patients with triple arthrodesis, and (b): normal subjects.

Figure 3. (A) Comparison of results of this study with Anderson et al.'s study [3] (a): Anderson et al.'s study, (b): results of this study stress distribution in tibio-talar joint in normal subjects in stance phase. (B) The effects of increasing G-S muscle force on the stress distribution in tibio-talar joint. Right figure shows the effect of increasing the G-S muscle force, compared to the left figure, on the stress distribution in tibio-talar joint in patients with triple arthrodesis.

References:

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