AN INVESTIGATION OF RECOMMENDED LOWER LEG EXERCISES FOR INDUCED CALF MUSCLE ACTIVITY

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ABSTRACT
Active voluntary contraction of the calf muscle is an essential factor in the circulatory system. Failure to exercise the calf muscles for prolonged periods may result in limited or poor blood circulation in the lower leg and increase the risk of deep vein thrombosis (DVT). An association between long distance travel and increased risk of DVT has been established. Most airlines recommend a number of lower leg exercises as a DVT preventative measure. Not all lower leg exercises induce calf muscle pump activity and therefore may not be beneficial in the prevention of DVT. A study was devised to investigate the exercises recommended to passengers for DVT prevention on long distance flights to determine a potential benefit to the health and safety of the passenger. The technique used for the evaluation of recommended airline exercises for optimal calf muscle pump activity is described.

KEY WORDS Deep Vein Thrombosis (DVT); Prevention; Calf Muscle Pump; Lower Leg, Exercise, Joint Coordinate System

Introduction
The calf muscle and the veins within the leg, both superficial and deep, are referred to as the calf muscle pump. Active voluntary contraction of the calf muscle is an essential factor in the circulatory system. Failure to exercise the calf muscles for prolonged periods may result in limited or poor blood circulation in the lower leg. Consequences of poor blood circulation include stasis and venous hypertension due to blood pooling in the leg. Medical conditions associated with calf muscle pump insufficiency include deep vein thrombosis (DVT) and venous ulceration. DVT is a condition in which blood clots; known as thrombi, form in the major veins of the leg or pelvis. Consequences of DVT include venous eczema, pain, swelling, lipodermatosclerosis, and recurrent ulcerations [1]. A further, potentially fatal consequence of DVT is pulmonary thromboembolism (PTE). PTE results when part of the thrombus breaks off (embolises) and travels to the lung circulation, where it lodges in and blocks one of the pulmonary arteries. This in turn can lead to pulmonary hypertension, heart failure, and death [2].

The aeroplane-travelling environment tends to discourage exercise and ambulation with cramped seating conditions, distractions such as in-flight movies and meal services and the tendency of many passengers to sleep. This means that many passengers may remain inactive for prolonged periods, thus increasing the risk of DVT. The World Health Organisation (WHO) recommends that passengers at high risk from DVT should exercise on a regular basis whilst on long distance flights [3]. Most airlines now provide air travel health information on their website, in their in-flight manual or during their pre-flight briefing which includes preventative measures for travel related DVT. Some airlines present illustrations on different types of lower exercises while others simply suggest periodic exercise. Not all lower leg exercises induce active contraction of the calf muscle pump. Should a passenger rely on an exercise that does not induce calf muscle pump activity (CMPA) in an effort to reduce stasis in the lower leg, they may remain at increased risk of DVT due to the fact that the calf muscle pump remains inactive.

An evaluation of the lower leg exercises recommended to passengers for DVT prevention was carried out to investigate which exercises induce optimum calf muscle pump activity. The evaluation can provide information that is beneficial to the health and safety of passengers on long distance flights. The technique used in the evaluation includes EMG activity monitoring of the calf muscle and a 3D motion analysis of the lower leg and foot, allowing ankle joint orientation angles to be derived.

Method

Procedure
The health and safety section of eleven international airline websites were reviewed for information on suggested exercises to assist in the prevention of DVT.
Five of the websites provided detailed information including illustrations on recommended lower leg exercises [4-8]. During the investigation the subject was instructed to carry out 6 repetitions of 10 different exercises recommended by these five airlines. While the prescribed exercises were based on those presented by the five airlines, the information sheet for the experiment prescribed the investigators interpretation of each exercise. For two of the suggested exercises (knee extension and knee flexion), the reviewed airline websites provided no recommendation for the movement of the foot and so two variations of each of these exercises was prescribed, one with minimal foot movement and the other with plantar flexion. Exercises were performed using the right leg only. The 10 exercises investigated were:

1. Heel rise foot pumps
2. Toe rise foot pumps
3. Knee flexion with minimal foot movement
4. Knee flexion with plantar flexion
5. Knee extension with minimal foot movement
6. Knee extension with plantar flexion
7. Clockwise ankle rotation
8. Anti-clockwise ankle rotation
9. Lateral foot rotation
10. Medial foot rotation

These exercises are illustrated in Fig. 1.

An experimental protocol and data analysis system were established to record 3D motion analysis of the lower leg and foot and the EMG signal from calf muscle during the exercises. The experimental set-up is shown in Figure 2.

A single bipolar surface EMG sensor was placed on the gastrocnemius muscle to monitor calf muscle activity. The method described by Rainoldi et al [9], for positioning electrodes during surface EMG recordings in lower limb muscles, was used. The EMG signal was passed through a band-pass filter with a lower cut-off frequency of 20Hz (for the removal of movement artefact) and upper cut-off frequency of 400Hz (for the removal of unwanted higher frequency components and to prevent aliasing). It was then sampled at 1 kHz and logged to a PC using a MATLAB\textsuperscript{1} Simulink™ interface.

The Northern Digital\textsuperscript{2} Optotrak/3010\textsuperscript{TM} 3D motion tracking system was used to record the motion of the markers on the foot and lower leg. The Optotrak marker signals were sampled at 100 Hz and logged to a PC using a MATLAB Simulink™ interface.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{exercises.png}
\caption{Exercises evaluated during the experiment}
\end{figure}

\textsuperscript{1} The MathWorks Inc., 3 Apple Hill Drive, Natick, MA 01760-2098, U.S.A.
\textsuperscript{2} Northern Digital Inc, 103 Randall Drive, Waterloo, Ontario, Canada
Target markers were attached at three locations on the foot and at three locations on the lower leg. Two markers (A and B) were placed on an approximate distal-proximal axis on the front of the lower leg, and the third target (C) was placed on the tip of the lateral malleolus. All three markers on the foot were placed on an approximate transverse plane. Two of the markers (D and E) were placed on an approximate anterior-posterior axis with one marker placed at the posterior of the foot on the heel, and the other placed on the superior surface of the foot. The third marker (F) was placed at the lateral side of the foot below the lateral malleolus. Care was taken in the placement of all markers to follow anatomical lines.

Prior to carrying out the recommended exercises the subject was seated as in Fig 2, with the thigh horizontal, the knee flexed and the ankle joint in a neutral position. The subject was instructed to carry out a maximum voluntary isometric contraction (MVIC) of the calf muscle, required for inter-subject normalisation of the EMG signals. This is the most commonly used normalisation procedure for EMG amplitude estimation [10]. The subject was then instructed to carry out 6 repetitions of the 10 different recommended exercises.

![Fig. 2. Experimental set-up](image)

**Data Processing**

The MATLAB computing program was used for all post-trial data processing and analysis. The raw EMG signal was digitally processed for time domain analysis using a five stage process. Stages one to four are based on those outlined by Clancy et al [11]. In the first stage the raw EMG signal was band-pass filtered with a lower cut-off frequency of 20Hz and upper cut-off frequency of 400Hz. The EMG signal was also notch filtered at 50Hz for the removal of electrical interference. The second stage was the demodulation stage where the EMG signal was rectified and raised to the power of two. The third stage creates a linear envelope of the rectified EMG signal using a midpoint moving average window (non-causal) of length 600ms. The fourth stage inverts the power law applied during the demodulation stage to the smoothened EMG signal. Stages two to four may be summarised under the title of root mean square (RMS) averaging. The fifth stage of the process was signal normalisation. The mean peak amplitude of the MVICs for a particular subject was calculated as the normalisation factor for that subject. The EMG signals for each subject were then divided by the normalisation factor for that subject.

The Optotrak marker signals were low pass filtered with a cut-off frequency of 20Hz. Each triad of markers formed the basis for the development of a local coordinate system on each of the two body segments. A joint coordinate system having unit coordinate vectors $e_1$, $e_2$ and $e_3$ was formed by selecting $e_1$ to coincide with the Z-axis of the lower leg, $e_3$ to coincide with the y-axis of the foot and the floating axis $e_2$ the common axis perpendicular to $e_1$ and $e_3$ (see Fig. 3). The three different angles of rotation (dorsiflexion/plantar flexion, internal/external rotation and inversion/eversion) were calculated to monitor the movement of the foot relative to the lower leg.

![Fig. 3. Derivation of the ankle joint coordinate system](image)

**Statistical Analysis**

EMG data was expressed as the peak normalised EMG for each correctly performed repetition of each exercise. A bonferroni analysis was performed on the data to detect differences across the exercises.
Results
Fig. 4 shows a box plot of the peak normalised EMG magnitude for each correctly performed repetition of the 10 exercises for all four subjects. The horizontal line illustrates median values, inter-quartile ranges (IQR) are illustrated by the upper and lower limits of the boxes and full ranges are illustrated by the upper and lower limits of the vertical lines.

Discussion
Very low levels of calf muscle EMG were induced by exercises 2, 3, 5, 9 and 10. No significant statistical differences were found between these exercises while these exercises were found to be significantly different from all other exercises. Relatively high levels of calf muscle EMG were induced by the other five exercises. No significant differences were found between exercises 4, 6, 7 and 8. Exercise 1 induced highest levels of calf muscle EMG and was found to be significantly different from all exercises except exercise 7.

The failure of exercises 2,3,5,9 and 10 to induce significant levels of calf muscle activity is of no surprise since these exercises do not involve active plantar flexion of the foot. Also the fact that exercise 1 (heel rise foot pump) induced highest levels of calf muscle EMG and was found to be significantly different from all exercises except exercise 7.

Exercise 6 (knee extension with plantar flexion) at times achieved high levels of calf muscle activity; however this was not very consistent throughout as may be observed from figure 4. Plantar flexion of the foot was prescribed as part of this exercise and therefore consistently high levels of calf muscle pump activity may be expected. From the 3D motion analysis it was observed that even when plantar flexion was performed as part of the exercise, high levels of calf muscle pump activity was not always induced.

It is suggested that during this exercise plantar flexion may also have been achieved passively by allowing gravity to carry the front of the foot downwards in a free fall manner as the leg was raised. This may explain the wide range of calf muscle EMG activity observed. This passive plantar flexion was also observed somewhat in exercise 4 (knee flexion with plantar flexion) although to a much lesser extent. Should a passenger on a long distance flight rely on such exercises for DVT prevention it may be beneficial to advise the passenger that active plantar flexion of the foot is important.

From the 3D motion analysis it was observed that exercises 7 & 8, which were prescribed as ankle rotations, were at times performed without a complete rotation which would involve both maximal plantar flexion and maximal dorsiflexion from the starting orientation.
Figure 5 shows the normalised EMG activity and the corresponding angle of flexion for 1 repetition of exercise 7 (ankle rotation) for subjects 1 and 2. It may be observed that calf muscle activity was high when the ankle rotation exercise was carried out with a large amount of plantar flexion from the neutral position (as in Fig. 5a, subject 1), however very little calf muscle activity was induced when the ankle rotation exercise was carried out with little plantar flexion from the neutral position (as in Fig. 5b, subject 2). This could be interpreted as the failure of the subject to carry out the exercise correctly however it also highlights the point that when prescribing ankle rotations for DVT prevention, it should be emphasised that a complete rotation which includes maximal active plantar flexion should be conducted. Such instances, where the ankle rotation was performed without any significant plantar flexion were removed prior to the statistical analysis and are not included in the data presented in figure 4 as it was deemed that the exercise was not conducted correctly.

**Conclusion**

Decreasing venous stasis through active voluntary contraction of the calf muscle pump is beneficial in the prevention of DVT. Major airlines provide information in various forms on a number of lower leg exercises recommended for decreasing the risk of DVT however; they do not indicate which exercises optimise CMPA. This study was designed to investigate which lower exercises produce maximum activity of the calf muscle and hence optimise CMPA.

‘Heel rise foot pumps’ were found to produce most consistently high levels of calf muscle activity and may be the exercise which is most beneficial to the passenger in optimising CMPA. While ‘ankle rotations’ were found to produce similarly high levels of calf muscle activity it is suggested that in order for the passenger to benefit fully from this exercise, emphasis should be placed on the need for a complete ankle rotation which includes maximal plantar flexion. Both the ‘knee extension with plantar flexion’ and to a lesser extent ‘knee flexion with plantar flexion’ can produce high levels of calf muscle activity but may fail to benefit the passenger should they neglect the need for active plantar flexion. All other exercises produced little or no calf muscle activity. We believe that these findings highlight the need for a further examination of the exercises recommended to passengers for DVT prevention on long distance flights to ensure correct information is provided to maximise the benefit to the health and safety of the passenger.

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