EJVES Extra **12**, 1–5 (2006)
doi:10.1016/j.ejvsextra.2006.04.001, available online at http://www.sciencedirect.com on SCIENCE DIRECT®

SHORT REPORT

Preliminary Evaluation of Recommended Airline Exercises for Optimal Calf Muscle Pump Activity

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Objectives. *A preliminary study to investigate which of the recommended airline exercises for DVT prevention produce optimal calf muscle pump activity.*
Methods. *Four subjects were instructed to carry out ten lower leg exercises based on those recommended by airlines for DVT prevention. An EMG sensor was used to record calf muscle activity and a motion analysis system was used to ensure the exercise was conducted correctly.*
Results. *Statistical analysis showed significant differences in the level of calf muscle pump activity induced by the different exercises. Heel rise foot pumps were shown to induce highest levels of activity while many exercises did not induce any significant calf muscle activity at all.*
Conclusion. *These findings indicate that a further, more detailed examination of the exercises recommended to passengers for DVT prevention on long distance flights should be conducted to determine the potential benefit to the health and safety of the passenger.*

Keywords: Deep Vein Thrombosis (DVT); Prevention; Calf Muscle Pump; Lower Leg; Exercise.

Introduction

The calf muscle and the veins within the leg, both superficial and deep are referred to as the calf muscle pump. Its action may be compared to that of the left side of the heart. The deep veins form the deep compartment containing a pump chamber and outflow tract similar to the left ventricle and aorta of the heart. The large veins within the gastrocnemius and soleus muscles form the main chamber of the pump although all the other deep veins contribute to some extent.[1] Regular contraction of the calf muscles is an essential factor in the circulatory system. Transition from rest to normal rhythmic exercise results in significant changes in pressure and flow in the veins of the lower limb.[2] Continuous contraction of the calf muscle reduces the calf blood volume by up 50 per cent.[1]

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.[3–5] The World Health Organisation (WHO) recommends that passengers at high risk from DVT should exercise on a regular basis whilst on long distance flights.[6] Most airlines provide information on a number of recommended lower leg exercises as a DVT preventative measure. Not all lower leg exercises induce active contraction of the calf muscle pump and therefore may not be beneficial in the prevention of DVT.

We believe that by identifying those lower leg exercises that result in significant contraction of the calf muscles, more useful advice could be provided to passengers allowing them to maximise the benefits obtained from regular in-flight exercise. The aim of this study was

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1533–3167/000001 + 05 $35.00/0

to investigate the varying benefit of different lower leg exercises in inducing calf muscle pump activity (CMPA).

Method

Subjects

Four healthy male subjects were recruited from the Faculty of Electrical Engineering at the University of Ljubljana, Slovenia. Ethical approval was obtained for this investigation from the Medical Ethics Committee of the Republic of Slovenia. The subjects were a mean of 24 years of age, 177 cm in height and 73 kg in weight. All subjects were provided with a volunteer information sheet and asked to give written informed consent to participate in the trial. The information sheet provided both written and illustrated instructions on the exercises that were to be conducted.

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.[7–11] 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 described 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.

Prior to recording, the subject was seated with the thigh horizontal, the knee flexed and the ankle joint in a neutral position of approximately 90 degrees. A single bipolar surface EMG sensor was placed on the gastrocnemius medialis muscle of the active leg to monitor calf muscle activity. The method for positioning electrodes recommended by Rainoldi *et al.*[12] for surface EMG recordings in lower limb muscles was used. The EMG signal was band pass filtered from 20Hz to 400Hz and sampled at 1kHz. During the investigation the movement of the foot and lower leg were recorded using the Northern Digital[1] Optotrak/3010™ 3D motion tracking system. The motion data was used to ensure that the exercises were conducted as prescribed.

Prior to carrying out the exercises the subject was instructed to carry out a maximum voluntary isometric contraction of the calf muscle, required for intersubject normalisation of the EMG signals.

Data processing

The MATLAB computing program was used for all post-trial data processing and analysis. The raw EMG signal was band-pass filtered with a lower cutoff frequency of 20Hz and upper cut-off frequency of 400Hz. The filtered EMG signal was then smoothened to produce a linear envelope using root mean square (RMS) averaging with a window length of 600ms.

Statistical analysis

The first repetition of each exercise was discarded from the analysis, as suggested by Cram and Kasman.[13] Data obtained from the 3D motion tracking system were analysed and any repetitions of an exercise that were performed incorrectly were discarded. EMG data were 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. 2 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

[1]Northern Digital Inc, 103 Randall Drive, Waterloo, Ontario, Canada.

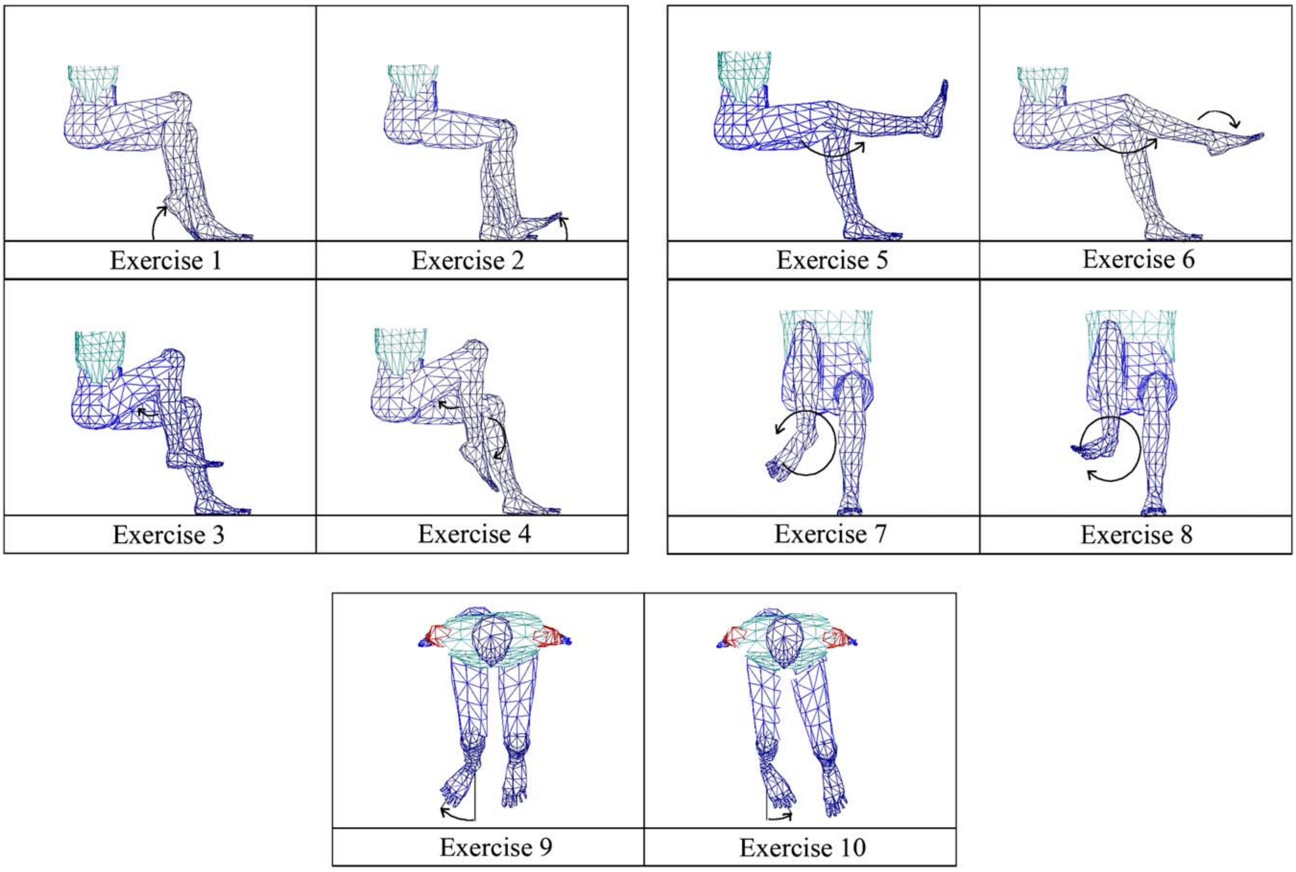

Fig. 1. Exercises evaluated during the experiment.

line illustrates median values, inter-quartile ranges (IQR) are illustrated by the upper and lower limits of the boxes, full ranges are illustrated by the upper and lower limits of the vertical lines and the small circles illustrate outliers.

Very low levels of CMPA 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 CMPA 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 CMPA and was found to be significantly different from all exercises except exercise 7.

In exercise 1 (heel rise foot pump), reaching the objective position involved active plantar flexion of the foot thus inducing high CMPA at a reasonably consistent level (median = 0.65, IQR = 0.28). For exercise 2 (toe rise foot pump) reaching the objective position required active dorsiflexion, while returning to the neutral position involved only passive plantar flexion thus minimal CMPA was induced (median = 0.11, IQR = 0.09). Very little CMPA was induced during exercise 3 (knee flexion with minimal foot movement, median = 0.07, IQR = 0.06) since no foot movement was prescribed for this exercise. The median peak EMG for exercise 4 (knee flexion with plantar flexion)

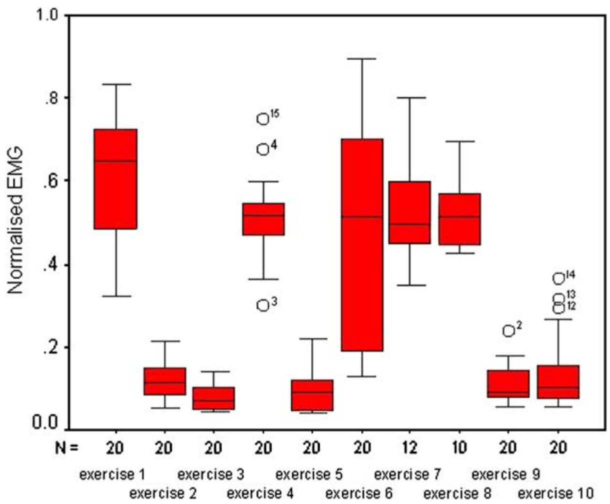

Fig. 2. Peak normalised calf muscle EMG for each of the 8 exercises. Median values, inter-quartile ranges (IQR), full ranges and outliers are illustrated.

was comparatively high (median = 0.52), while this exercise also proved to be consistent in inducing CMPA (IQR = 0.08). No foot movement was prescribed for exercise 5 (knee extension with minimal foot movement) and the CMPA was correspondingly low (median = 0.09, IQR = 0.08). Exercise 6 (knee extension with plantar flexion) achieved high levels of CMPA (median = 0.51), however this was not very consistent throughout (IQR = 0.52). The median peak EMG for exercises 7 and 8 (clockwise and anti-clockwise rotations respectively) was relatively high (median = 0.50 for clockwise, median = 0.51 for anti-clockwise), and these exercises also produced reasonably consistent levels of CMPA (IQR = 0.15 for clockwise, IQR = 0.13 for anti-clockwise). Both exercises 9 and 10 (lateral and medial foot rotations respectively) induced low levels of CMPA (median = 0.09, IQR = 0.07 for lateral and median = 0.1, IQR = 0.10 for medial).

A bonferroni analysis on subject-to-subject variability also found some significant differences across subjects. This may be explained by variability in the contractile effort induced by different subjects whilst performing the prescribed exercises.

Discussion

The failure of exercises 2,3,5,9 and 10 to induce significant levels of calf muscle activity is as expected since these exercises did not involve active plantar flexion of the foot, while the exercises that did induce significant levels of calf muscle activity involved active plantar flexion. The fact that exercise 1 induced highest levels of calf muscle activity is to be expected as the exercise involved simple plantar flexion, while exercise 4 (knee flexion combined with plantar flexion) also performed well.

Exercise 6 (knee extension with plantar flexion) at times achieved high levels of calf muscle activity; however this was not very consistent throughout. 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 were not always induced.

It is suggested that during this exercise plantar flexion may at times 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. Should a passenger on a long distance flight rely on such an exercise 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 involving both maximal plantar flexion and maximal dorsiflexion from the starting orientation.

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 Fig. 2 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. The results of this study have outlined which lower leg exercises induce highest levels of CMPA. 'Heel rise foot pumps', 'knee flexion combined with plantar flexion' and 'ankle rotations' may be considered as the most suitable exercises for optimal CMPA. We believe that these findings warrant an examination of 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.

Acknowledgements

The authors would like to thank the Irish Research Council for Science, Engineering and Technology for their sponsorship of this project.

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Accepted 6 April 2006