Original Article

The effects of a semi-rigid soled shoe compared to walking barefoot on knee adduction moment

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ABSTRACT

Background/Purpose: On a background of literature suggesting that certain rigid soled shoes may increase the knee adduction moment during gait this study was performed to look at specific postoperative shoe – the Medishoe. This shoe is used on a daily basis in a district general hospital orthopaedic department for patients post-operatively to protect wounds and fixations.

Methods: Using force plates and an opto-electronic motion capture system with retroreflective markers the knee adduction moment was estimated in ten healthy subject both with and without the shoe during normal gait. The angle at which the ground reaction acted with respect to the ground in the coronal plane as well as the tibiofemoral angle were also calculated using the Qualsys software – both with and without the Medishoe.

Results: Two-tailed paired t-tests using a 95% confidence interval showed that there was no significant difference between the two groups in the estimated knee adduction moment ($p = 0.238$), tibiofemoral angle ($p = 0.4952$) and the angle of the ground reaction force to the ground ($p = 0.059$).

Conclusion: There was no significant difference in the estimated knee adduction moment between the two groups, although there was a statistical trend to an alteration in the angle of the ground reaction force. Further work involving a greater number of subjects and a three dimensional model would further answer the question as to whether these or other post-operative shoes have a significant effect on the knee adduction moment.

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1. Introduction

Knee osteoarthritis is a widespread and debilitating disease that can have potentially devastating effects on peoples work and quality of life. Choice of footwear is playing a crucial role in the prevention of arthritis progression. Footwear and its vast variety of modifications has long been thought to be related to certain orthopaedic problems.¹ Recent studies have looked at the effect of a variety of different types of shoes had on the peak knee adduction moment,² with clogs and stability shoes leading to greater knee adduction moments which has been shown to increase in the progression of osteoarthritis.³

The knee adduction moment is defined as the product of the ground reaction force (GRF) and its perpendicular distance from

the centre of rotation of the knee. Its value varies during the different phases of the gait cycle (Fig. 1).

In order to reduce the knee adduction moment, there must be either a reduction in magnitude of the ground reaction force, or a reduction in length of the moment arm.

It is common practice for shoes to be used post-operatively following foot or ankle surgery in order to encourage mobilization and make early weight-bearing comfortable. However, in post-operative patients who also happen to have pre-existing knee medial compartment osteoarthritis, any potential increase in knee adduction moment could exacerbate their condition. This effect could be augmented even further if the patients had a pre-existing varus deformity, which would further increase the moment arm of the ground reduction force. The use of inexpensive, minimalistic and flexible shoes as close to barefoot in design have been suggested,^{5,6} but even these could be detrimental to any pre-existing osteoarthritis when compared to walking purely barefoot.⁷ In the post-operative patient, a compromise must be made between controlling the knee

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Fig. 1. Dynamic variation of the knee adduction moment during the gait cycle. Simplified from Deluzio et al.⁴

adduction moment and protecting the surgical wound and fixation.

This study looks at a specific post-operative shoe (Medishoe, Promedics Orthopaedics) which is a semi-flexible, rigid non-slip sole (Fig. 2). The aim was to see whether the shoe had an effect on the knee adduction moment in normal subjects. Knee adduction moments were compared in subjects walking barefoot and then with the shoe.

2. Methods

Ethical approval was obtained for this study from the University of Surrey. Ten healthy volunteers were recruited. The entry criteria for the study were males and females between the ages of 18 and 60 who had no previous history of lower limb operations or pathology. Written consent was obtained from all subjects.

For each subject the gait was analysed with and without the Medishoe. This was done with motion capture 3D with 10 high resolution cameras (ProReflex, Qualisys, Göteborg, Sweden) and two force-platforms (AMTI Force and Motion, Massachusetts, USA). Each camera had an array of diodes that were able to emit infrared radiation that can be reflected back off spherical reflective markers. The cameras capture the movement of the reflective markers at a frequency of 100 Hz in two-dimensions.

An optoelectronic system was used to measure the peak knee adduction moment with retro-reflective markers on subjects arranged in a particular configuration, to create a model consisting of rigid bodies moving with six degrees of freedom. When used in conjunction with force plates, the knee adduction moment could be calculated by exporting data into software that is able to analyse and interpret moments in any desired plane. The set-up was similar to that previously described with three retro-reflective skin markers were attached to the greater trochanter, lateral epicondyle of the femur and the lateral malleolus of the ankle.⁹ All markers were attached directly on skin using hypoallergenic double-adhesive tape. Markers were attached directly onto skin as opposed to trousers or clothes in order to prevent their relative movement with respect to the bony landmarks.

A simple three-marker technique was used as shown in Fig. 3. Once the trials were completed, a statistical analysis was

performed to see how peak knee adduction moment, defined as the varus/valgus alignment of the femur with respect to the tibia, changed with the use of the Medishoe. Using trigonometry the angle at which the peak ground reaction force in the coronal plane acts to the horizontal was then calculated, to see whether the direction of the force was changed by a shoe - a possibility that was suggested by Lidtke.¹⁰

Prior to the experiments, a calibration frame was used for static calibration of the system and to define the co-ordinates of the system. They consisted of an 'L'-shaped metal limb with the reflective markers pre-attached. Each limb of this calibration frame represented the 'x', 'y' and 'z' axes. The frame was placed so the long limb of the 'L' was parallel to the long axis of the force platforms and the position of the markers were recorded with the cameras. Dynamic calibration was then performed by waving a 'T'-shaped wand with reflective markers attached within the work space. This was done so as to allow the camera to view the wand in as many orientations as possible, to allow each camera to be individually calibrated in all directions. This was done for ten seconds at a camera capture frequency of 100 Hz in order for each camera to capture 1000 frames. Prior to beginning the experiments it was checked that the calibration test was passed.

Fig. 2. The Medishoe (Promedics Orthopaedic).⁸

Fig. 3. Figure showing markers on the greater trochanter, lateral condyle of tibia and lateral malleolus.

Three different shoe sizes (small, medium and large) were selected to fit all subjects. In order to maintain balance and as normal gait as possible shoes were used on both feet of the subjects despite the knee adduction moment only being measured on one side.

The force plates measured 400×600 mm in area – two were aligned in a walkway in the middle of the workspace surrounded by the 10 cameras. Each force plate consisted of two slabs of metal separated by four piezo-resistive strain gauges – one at each corner of the plate. These were designed to measure displacement of the pad around its centre when the pad is depressed. Prior to its use the position of the force plate in the workspace was defined by placing markers at the corner and performing a one second capture. This was done in order to view the force vectors in the same coordinate system as the motion captured by the cameras. In order to ensure normal gait was maintained throughout the subjects were requested to walk as normally as possible over the platforms. This was required in order for the subject not to consciously alter their gait over the force plates. Foot placement was carefully watched during the trials to ensure a subjects entire foot was contained within the area of the force platform to achieve an accurate ground reaction force reading. If subjects were not able to fully place their foot during a trial, this trial would be repeated until it was observed that the subject had successfully planted their foot within the boundaries of a force platform. The subject would not be told as to why the trial was being repeated in order to prevent them from consciously attempting to place their foot over the middle of the force platform and thus, altering their stride length and normal gait pattern.

The software used was Qualsys Track Manager or QTM (Qualisys, Sweden). This was a Windows-based software that acquired and processed information that had been captured by the cameras. Using the output from the AMTI force plates, the three orthogonal vectors that comprise the ground reaction force could be monitored and plotted on a graph against time in QTM. From this graph the peak vertical ('z') and horizontal ('x') components of the ground reaction force during the stance phase could be identified. These were the two components of the ground reaction

force in the frontal plane. Using trigonometry these two components were resolved to calculate magnitude of the ground reaction force in the frontal plane. Two angles were calculated. The first was the angle at which the GRF acted to the horizontal (referred to as θ in the results). The second was the angle between the three markers in the coronal plane (tibio-femoral angle). QTM was used to plot both angles against time. Both angles were recorded when the GRF was at its peak. The experiment was repeated both with and without the shoe and any change was noted. Both force and angle measurements were measured directly off the graphs on QTM by stopping the captured motion at the appropriate frame and magnifying the part of the curve of interest.

The peak knee adduction moment was estimated by multiplying the peak ground reaction force in the front plane by 63 mm, as specified by Weidenhielm et al.¹¹ This was done both with and without the stiff post-operative shoes on for all ten subjects. Statistical analysis was carried out using Medcalc 11.2.1.0 (MedCalc Software bvba, 9030 Mariakerke, Belgium) to compare all acquired data with paired and non-paired t-tests.

Two assumptions were made; that peak knee adduction moment occurred precisely where the ground reaction force was at its peak, and peak moment arm of the ground reaction force was 63 mm with a co-efficient of variation of 7.9%.¹¹

3. Results

The average age, weight and height of subjects was 333.8 months, 70.0 kg and 1.73 m, respectively. The peak knee adduction moments with and without the Medishoe are shown in Table 1. There was no significant difference found in knee adduction moment or tibio-femoral alignment between subjects wearing Medishoe and subjects who were barefoot ($P = 0.2380$).

Table 2 demonstrates that there was no significant difference found in θ angle between subjects wearing Medishoe compared to barefoot subjects ($P = 0.0590$). It can also be seen that there was no significant difference found in tibio-femoral angle between subjects wearing Medishoe compared to barefoot subjects ($P = 0.4952$).

Table 1

Table showing each subjects change in peak knee adduction moment and tibio-femoral alignment when barefoot and in the Medishoe.

Subject	Peak knee adduction moment barefoot (Nm)	Peak knee adduction moment in Medishoe (Nm)	Change in peak knee adduction moment with shoe (Nm)	Change in tibio-femoral alignment with shoe (degrees)
1	37.56	39.12	1.56	−0.45
2	40.66	39.07	−1.59	1.02
3	52.16	52.48	0.32	0.66
4	38.69	39.39	0.70	3.23
5	71.06	69.98	−1.08	−3.70
6	48.47	54.30	5.83	−1.80
7	42.40	43.31	0.91	−1.24
8	58.16	59.20	1.04	−3.05
9	67.00	67.15	0.15	1.49
10	34.69	34.87	0.18	−0.094

Nm Newton metres.

Table 2

Comparison of peak knee adduction moment, angle of ground reaction force and tibio-femoral angles of subjects barefoot and wearing the Medishoe.

	Peak knee adduction moment (Nm)		θ angle of ground reaction force to horizontal (degrees)		Tibio-femoral angle (degrees)	
	Barefoot	Medishoe	Barefoot	Medishoe	Barefoot	Medishoe
Mean value	49.0850	49.8870	86.8144	87.5760	174.9240	175.4020
S.D	4.0274	3.9813	1.2638	1.1856	4.0514	3.6589

Nm Newton metres.

4. Discussion

This study aimed to determine whether the Medishoe altered the biomechanics of the knee during normal gait in normal subjects. It was determined that there was no difference in the peak tibio-femoral angle and knee adduction moments between the two groups. However, although not statistically significant, there was a trend towards a smaller θ angle when wearing the shoe ($p = 0.059$). The net result of this would be to increase the moment arm of the GRF and therefore the true knee adduction moment. This suggests that the Medishoe altered lower limb biomechanics so as to alter the vector of the GRF. This may be as a result of relative restriction of the subtalar and chopart joints within stiff soled shoes that are firmly attached.

With regards to future studies, a more accurate method of calculating the centre of rotation could be used. Using software such as Visual3D (C-motion Inc, USA) in conjunction with Qualsys allows for a more accurate knee adduction moment to be calculated. A further method of monitoring the kinematics would be the use of an electromagnetic tracking system. One such system of human motion tracking involves the placement of 3-axis magnetic sensors on subjects joints, whereby movement can be detected by a fixed source emitting an electromagnetic pulse.¹² In comparison to the optoelectronic method this is far simpler as it does not involve numerous cameras and still gives information about all the degrees of freedom of a joint. Unfortunately, difficulty could possibly arise from interference with the electromagnetic fields from metallic implants when analysing prostheses. Chang et al described a 3D base tracking algorithm that utilises a video camera filming several points on a moving subject.¹³ The computer algorithm is able to estimate the position of all the points based on the observed video images, and converts these to digital images creating an articulated digital model. The clear advantage over other techniques is that no markers nor cameras nor any form of radiation are required.

Different types of shoes can also be researched. Hinman already looked at the effect of lateral wedged shoes affecting the knee adduction moment.¹⁴ Although this may have the effect of reducing the knee adduction moment by reducing its moment arm, this type of shoe would not necessarily be appropriate post-operatively. This would particularly be the case for post-lateral ray surgery or even a subtalar fusion where there is no ability for the hindfoot to go into valgus. Sole et al performed a systematic review of which showed that high heels, sneakers, dress shoes and even clogs all had the effect of increasing the external knee adduction moment.¹⁵ Based on this study it would seem that certainly the thickness and the stiffness of a heel of a shoe can increase the knee adduction moment. In a certain type of shoe that comes in various heel thicknesses it would be interesting to see how the knee adduction moment varies with heel thickness and stiffness. One type of post-operative shoe that has increased in popularity for forefoot surgery is the reverse camber shoe. The purpose of this particular type of shoe is to offload the forefoot following surgery such as a Scarf osteotomy, to correct hallux valgus deformity. Hook et al stated that the reverse camber shoe was a popular post-operative shoe used in their practice and it could be used for up to seven weeks post-operatively for symptomatic control with no significant increase in complications.¹⁶ However, more recently following a questionnaire based study by Sarmah et al pointed out that, particularly in the elderly, compliance with the reverse camber shoe was poor, possibly due to *“poor adaptation in the presence of pre-existing arthritis”*, and that *“compliance may be affected due to the altered gait pattern that is conferred”*.¹⁷ This potentially altered gait pattern and increased pain due to the pre-existing arthritis may well be due to an increased knee adduction moment that would exacerbate pre-existing medial compartment

knee osteoarthritis. The design of the reverse camber shoe certainly is less minimalistic compared to the Medishoe in terms of heel thickness and design. It would be interesting in the future to do a randomised trial involving a similar questionnaire based survey, assessing satisfaction and compliance of the Medishoe and the reverse camber shoe in an elderly cohort of patients post-surgery. This would ideally be in parallel with a study comparing their respective knee adduction moments.

There are several limitations of the study. Firstly, it is a small snapshot of a particular problem with a small number of healthy subjects. Furthermore, the Medishoe is designed for use in post-operative patients. These patients could potentially have antalgic gaits, oedematous tissues or bulky dressings that may alter their kinetics and kinematics, dependant on what type of lower limb surgery they have undergone. Therefore the effect that the shoe has on the knee adduction moment in normal subjects could well be different for a particular cohort of post-operative patients, and is likely to be affected by significant varus deformity at the knee. Indeed, it would be of interest to see what effect these particular shoes have on the knee adduction moment of patients with pre-existing varus osteoarthritis. If that study was to be performed then an assumption on the consistency of the moment arm length could not be made, as this would be dependent on the degree of varus deformity.

The use of a 3D model as opposed to looking at a moment in the frontal plane would allow for the true centre of rotation of the knee. The peak moment arm of the GRF is an oversimplification, although it has been used in a previous study.¹¹ The previous study also demonstrated that the variability of the length of the peak moment arm in the frontal plane was not as high as that of the sagittal plane, or indeed in the hip.

A second assumption that was made was that the peak knee adduction moment during the gait cycle occurred when the vertical component of the ground reaction force was at its maximal. This would be a reasonable assumption to have made as the majority of the magnitude of the ground reaction force in the coronal plane would have been derived from the vertical component. However, the assumption that the peak varus or valgus angulation coincided with the peak vertical ground reaction force, may not necessarily have been accurate. It would be interesting to see how the peak tibio-femoral angle and how the average tibio-femoral angle throughout the stance phase varied in response to using the shoe.

5. Conclusion

The results indicate that the Medishoe had no significant effect on the knee adduction moment or the tibio-femoral angle. Although the ‘p’ value in the two-tailed t-test for the θ angle ($P = 0.059$) was not low enough to demonstrate significance, this particular measurement was trended towards demonstrating difference between the two groups. The implication of this would be that the shoe acted to change the direction of the ground reaction force to be further away from the centre of the knee and thus increasing its moment arm about the knee. However, it is likely that the power of the study was not high enough to demonstrate a significant difference between the two groups.

It is also possible that there was no real difference between the two groups and that the knee adduction moment is not significantly affected by the shoe. It should be taken into account that compared to the reverse camber shoe, the Medishoe has a thin semi-flexible sole. This may make it closer to barefoot in terms of its effect on the knee – however, this particular study was not powerful enough to demonstrate this. This study suggests further avenues of research with regards to this shoe. A more accurate method of determining the knee adduction moment with three-dimensional models

and software to calculate inverse dynamics, in combination with a larger number of subjects, would be a natural development from this study.

Conflicts of interest

All authors have none to declare.

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