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ORIGINAL RESEARCH

Knee Compression Loading When Lying Supine: Effects of Foot Position on Mattress

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Abstract

Purpose: Knee loading from standing for long periods has been shown to cause degenerative effects in knee cartilage, and this has been linked to the onset and progression of osteoarthritis. When lying supine because the heel protrudes 'outwards' from the back of the leg, contact forces are concentrated at the heel and act to 'push' the knee into full extension. The resulting knee-moment (compression loading) can be experienced for prolonged periods. The current study determined the magnitude of the knee-extension moment when lying supine and whether the moment was effected by how the feet were supported.

Methods: Ten healthy participants laid supine on a flat surface with feet on surface or hung over the end of it. A motion capture system and force platform was used to determine knee-moments.

Results: Knee-moments (extension) were comparable to those previously reported for standing but when the feet were hung over the end of the support the extension moment was all but eliminated ($P < 0.001$).

Conclusion: Findings suggests that for those who sleep supine, a change in sleeping position so that the feet hang over the end of the mattress will eliminate knee compression loading, and this simple intervention may provide temporary pain relief in those with knee-osteoarthritis.

Keywords

Knee osteoarthritis, Knee compression loading, Knee moments, Knee pain, Lying supine

Introduction

Static compressive varus loading of 100% bodyweight in the rat knee has been shown to produce degenerative changes in the medial compartment joint cartilage, including a decrease in cartilage modulus and thickness and an increase in matrix loss [1]. Additionally, it has been shown in the rabbit knee, that fifty minutes of isometric loading for 3 days a week over multiple weeks will cause the cells (chondrocytes) that produce and maintain cartilage matrix to die at a higher rate compared to that following comparable concentric loading [2]. Matric loss and chondrocyte death are features that have been shown to be risk factors in the onset and progression of osteoarthritis (OA) [3,4]. The above findings [1,2] suggest that prolonged excessive static joint loading may be a factor in knee-OA. Prolonged knee-joint loading may occur from involvement in certain occupations or daily activities, which could explain why such have been shown to be risk factors in knee-OA. For example, it has been shown that daily activities such as prolonged squatting [5] and occupational activities such as lifting, doing heaving work while standing or simply standing [6] are factors associated with knee-OA. It is worth noting that the study by Dahaghin and colleagues [5] found that routine prolonged standing was not a risk factor in knee-OA.

When humans lie supine, because the heel protrudes 'outwards' (posteriorly) from the back of the leg, contact forces (reaction to the weight of the leg) are mostly experienced at the heel and act to 'push' the knee into full extension. When lying in such a position the liga-

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ments of the knee act to prevent hyperextension, and the induced ligament tension together with the applied knee-extension moment will result in knee compression. As we spend many hours in bed, the knee-moment experienced when lying supine will produce prolonged knee compression loading, however, to date the knee extension moment associated with lying supine has not previously been reported.

It is apparent that the knee compression induced by lying supine can be problematic for those suffering knee-OA and/or chronic knee pain, as those with such conditions often place wedged cushioning under the knees when in bed in an attempt to alleviate the night time knee pain and discomfort they experience. Essentially the cushion prevents the knee from being in full extension and thus acts to reduce compression loading when lying supine. An alternative approach would be to sleep on a mattress that has a step-down or downward slope at the foot end in which the feet are placed when lying supine. Use of such a mattress should eliminate any contact force being experienced through the heel when lying supine, which should minimize the resulting knee-extension moment.

The aims of the current study were to determine the magnitude of knee extension moment experienced when lying supine, and how such moment is affected by hanging the feet off the end of the support surface (which simulated lying supine on a mattress with step-down or downward slope at the foot end). Trials were repeated with participants lying supine on a solid surface with feet at the same level as hips or slightly elevated above the hips, which is what happens when lying on a soft or sunken mattress. We hypothesised that lying with feet hanging off end of support will significantly reduce the knee-extension moment experienced. Although lying on a wooden surface does not simulate resting on real mattresses and more flexible beds, we chose such as it would mean most/all of the contact forces would act through the heel and this would represent a worst case scenario. In addition, this approach meant we could eliminate mattress design effects, which given there are countless designs available, this was desirable; particularly as this was a preliminary 'proof of concept' study.

Methods

Participants

Ten healthy individuals (6 male, 4 female; age 22.3 (2.1) years, height 1.74 (0.11) m, weight 72.4 (11.76) kg) took part, all giving written informed consent. The tenets of the Declaration of Helsinki were observed and ethical approval was obtained from the institutional ethics committee.

Experimental protocol and data collection

Participants laid supine on a flat surface (15 cm high, 2 m long, 1 m wide) with their lower limbs placed separately on to two solid wooded blocks (15 cm high, 50.7 cm long, 46.5 cm wide). The block the right limb was placed on was located on top of a force platform (AMTI OR6-7, Advanced Mechanical Technologies Inc., Boston USA). The block the left was placed on was on the laboratory floor. Participants completed trials in two blocks, with feet either supported on the wooden blocks (heels as point of contact, block 1) or hung over the end of the blocks (calves as point of contact, block 2, Figure 1a). Each participant's position was adjusted to ensure their feet (heels) were either supported by the wooden blocks or hanging over the end of the blocks, with the centre of their knees located in line with the edge of the wooden block (Figure 1). Within each block of trials, the height of the wooden blocks was varied so that it was either at the same height as the support surface (zero elevation) or elevated by 35 or 70 mm. We chose these elevation heights by reasoning that when lying on a sunken and/or soft mattress compression of the mattress will be greater under the upper body/trunk, because the upper body/trunk has greater mass than the lower body, and this would lower the hips relative to the feet. Pilot work involving asking three healthy adults to lie supine on a solid surface and then on a soft foam mattress and observing the height of the ankles relative to the hips, highlighted the feet of the volunteers became slightly elevated (25-40 mm) relative to the hips, when lying on the foam mattress. It is likely that obese individuals would induce greater mattress compression under their upper body/trunk and this would further lower the hips relative to their feet, which is why we included both a 35 and 70 mm height condition. Trial block (heel support, calf support) and height (level, 35 mm, 70 mm) order were randomised across participants.

An 8-camera motion capture system (Vicon MX3, Oxford Metrics Ltd, Oxford, UK) was used to record (30 Hz) the position of the lower right limb, and the force platform were used to record contact forces (30 Hz) for the right limb. Participants wore a t-shirt, tight-fitting lycra shorts and were bare foot. Retroreflective markers were placed on the right limb's lateral malleolus and lateral femoral condyle. Data were collected over a 1 minute period. Using Workstation software (Vicon, Oxford Metrics Ltd) markers were labelled and their 3-D coordinates, along with ground reaction forces (GRF) and centre of pressure (CoP) coordinates, were exported in ASII format for further analysis.

Data analysis

A free body diagram (Figure 1b) of the combined shank + foot segment (of right limb) was used to determine the knee moment for the different conditions. The shank + foot segment mass and centre of mass (CoM) location were determined using the anthropometric parameters from Continni and Drillis [7]. The knee moment (M_{Knee}) when lying supine was determined using the following formula (see Figure 1b):

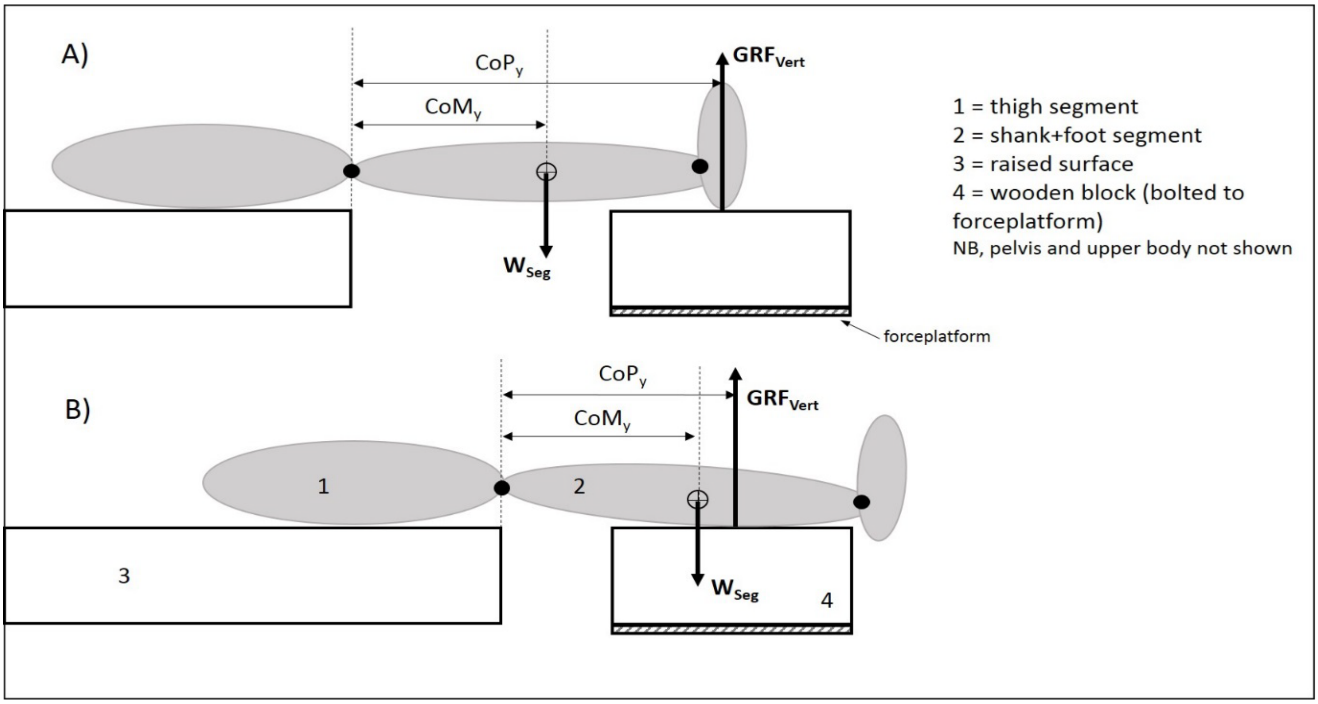

Figure 1: Schematic of experimental set-up and the free body diagram used to determine the knee moment induced from lying supine with either a) Feet/heels supported on wooden block, or b) Feet hanging over end of wooden block. See text for details and formula used to calculate the knee moment.

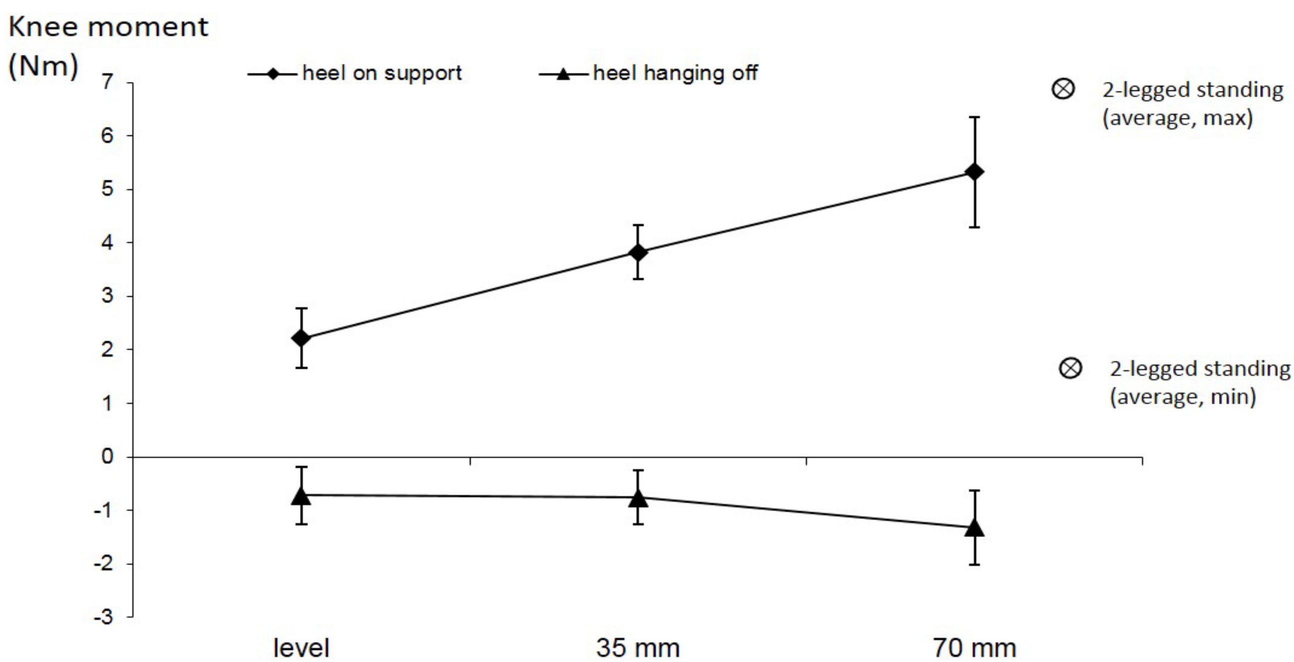

Figure 2: Group (n = 10) mean (SE) external knee moment when lying supine with the heels on support or hanging off it, and with heels level with, or 35 mm or 70 mm higher than the hips. The knee moment for 2-legged standing, previously reported in the literature [8] are plotted for comparison.

$M_{Knee} = (GRF_{Vert} \times CoP_y) - (W_{Seg} \times CoM_y)$

Where GRF_{Vert} is the vertical ground reaction force, CoP_y is the horizontal distance between the centre of pressure and the knee centre, W_{Seg} is weight of combined shank + foot segment, and CoM_y is the horizontal distance between the centre of mass location of shank + foot segment and the knee centre. The value recorded for each condition was the mean value determined over the 1 minute period. Values were normalised to participant's body mass.

Statistical analysis

Data were analysed using repeated measures ANOVA with foot positioning (heel support, calf support) and relative foot height (level, 35 mm, 70 mm) as repeated factors. All statistical analyses were undertaken using Statistica (Version 5.5: StatSoft, Inc., Tulsa, OK, USA).

The alpha level of significance was set at $p < 0.05$, and post-hoc analyses were undertaken using Tukey HSD.

Results

Knee moments (M_{Knee}) across the different foot positioning and foot height conditions are shown in Figure 2. M_{Knee} was significantly affected by foot positioning ($P < 0.001$) and by relative foot height ($p < 0.008$) and there was a significant interaction between terms ($P = 0.004$). M_{Knee} was greater when the feet/heels where supported on the wooden blocks compared to hung over the end of them, and increased as foot height (relative to the hips) increased but only when the feet/heels where supported on the blocks (level versus elevated by 70 mm, $P = 0.0026$: no significant difference between the intermediate levels, $P > 0.21$): i.e. M_{Knee} did not change as foot height increased when the feet where hanging over the end of the blocks ($P > 0.99$).

Discussion

Results indicate that when lying supine on a solid surface the resulting knee-extension moment experienced is comparable to the magnitude of the knee moment reported in the literature for standing [8]. Given that having an occupation that involves routine standing has been shown to be a risk factor for knee-OA [6], and given that many individuals can spend several hours an night sleeping in a supine position, these preliminary findings suggest that the knee moment experienced when lying supine may be large enough (particularly if experienced for long periods of time) to have detrimental effects on knee cartilage. It is noteworthy that when lying supine the feet naturally turn outwards (encouraged by the weight of the blankets or quilt) which will mean compression within the knee will be higher on the medial aspect, which is where knee-OA commonly occurs in human knees.

Importantly, when the feet were hung over the end of the support (which eliminated any contact forces acting through the heels), the knee moment was all but eliminated, and this was the case even if the feet were elevated 35 or 70 mm higher than the hips. This suggests that for those who sleep supine, a change in sleeping position so that the heels hang over the end of the mattress, rather than being supported on it, will eliminate knee compression loading (even if lying on a soft or sunken mattress). This simple intervention might provide pain relief and/or symptom improvement in individuals suffering with knee-OA, and also may prevent or delay the onset of osteoarthritis in high risk individuals, e.g. sports men/women, and certain professions; although future work would be required to confirm this. The 'proof of concept' findings of the present study suggest that such an intervention warrants full/proper evaluation via randomised clinical trial. We have just gained ethical approval from the Health Research Authority (UK) to undertake such a trial in patients with knee-OA and/or chronic knee pain. We realise that lying with feet hanging over the end of a mattress can be problematic, for example, in terms of how to keep the feet warm or how to share common bed-covers with a partner/spouse who isn't lying in such a position. However, the present study is about 'proof of concept'. If this simple intervention can be shown to be beneficial (via randomised clinical trial), then this would highlight that manufacturers should consider designing a

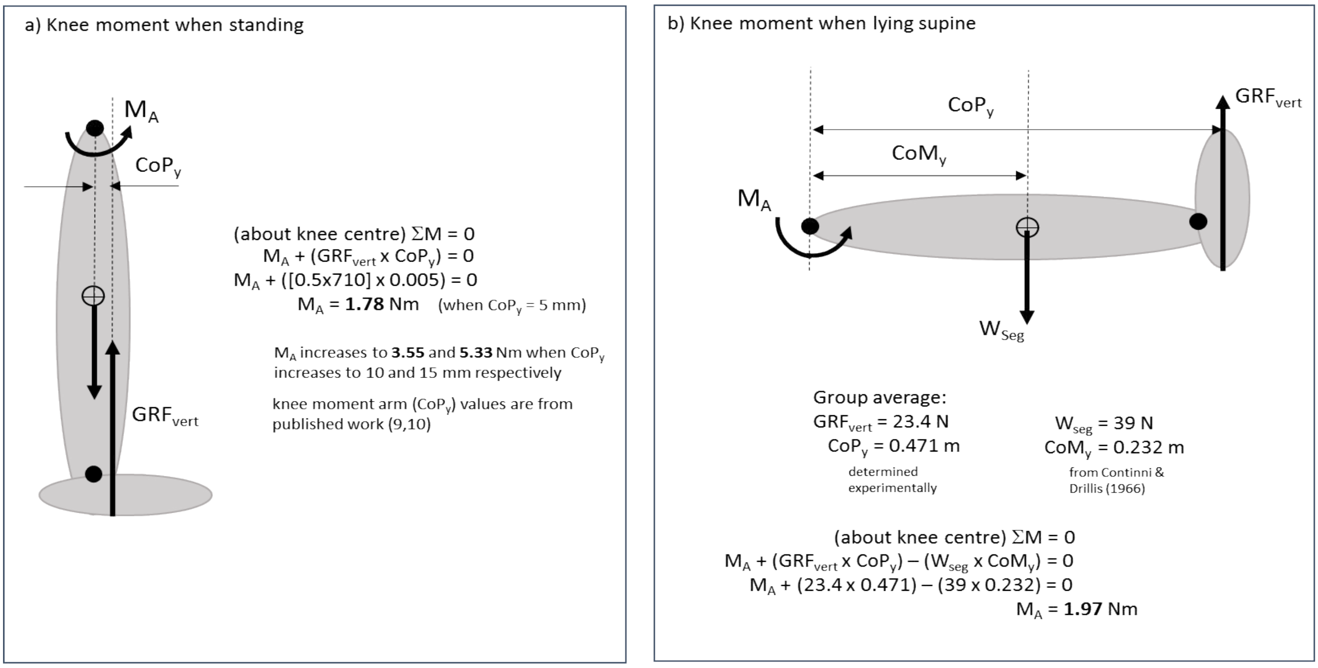

Figure 3: Comparison of the knee-extension moment for a) Standing, and b) Lying supine. Each free body diagram is scaled according to the average height and weight of participants from the present study. For standing, the knee moment was determined assuming each limb supports half the body weight and the GRF vector is anterior to the knee by 5, 10 and 15 mm [9,10]. For lying supine, the knee moment was determined using the group average GRF and CoP values recorded in the present study for when the feet were supported on the block and level with the height of the hips.

mattress with step-down or downward slope at the foot end in which the feet can be placed when lying supine. Such a mattress would avoid the problems highlighted above.

We were somewhat surprised of our finding that the knee-extension moment when lying supine is comparable to that reported in the literature for standing [8]. To highlight why/how the knee moment when lying supine would be comparable to that in standing we created a free body diagram (FBD) of the lower leg (shank and foot) for standing (Figure 3a). We then calculated the knee moment for when the GRF vector is anterior to the knee by 5, 10 and 15 mm, which is what occurs during standing [9,10]. In addition, we calculated the knee moment for lying supine with feet on the support using the group average GRF and CoP values recorded in the present study (Figure 3b). This analysis highlighted the knee-extension moment for standing was 1.78, 3.55 and 5.33 Nm, for when the GRF vector was anterior to the knee by 5, 10 and 15 mm respectively. These values are comparable to that found in the present study for lying supine (1.97 Nm).

A limitation of the present study was that participants laid on a solid surface not a mattress. This ensured that when lying supine with feet supported on the surface the contact forces would act through the heel. Although this may be analogous to lying on a solid surface with perhaps thin foam matting, it is unlikely to be representative of lying on commonly used mattresses. Most mattresses have some degree of cushioning ('give') which would allow more of the body surface to be in contact with the mattress, which would reduce the contact forces acting through the heel (when lying supine) and thus reduce the knee-moment experienced. This means the knee-moment data presented in the present study are likely to be an over estimation of what might be experienced when lying supine on most types of mattress, and as such they should be considered as a 'worst case scenario'. However, it is important to note that previous research has shown that when lying supine forces (pressure) at the heel are consistently higher than that at other body locations on all types of mattress [11,12], which suggests the knee extension-moment experienced is always likely to be non-zero. Still, future work is required to determine the actual knee extension-moment experienced when lying on commonly used mattresses.

In conclusion. Findings indicate that when lying supine when most of the lower limb contact forces act through the heel, the induced knee-extension moment (causing knee compression loading) is comparable to the magnitude of the knee moment reported in the literature for standing. Importantly, when the feet were hung over the end of the support, the knee moment was all but eliminated. This suggests that for those who sleep supine, a change in sleeping position so that the heels hang over the end of the mattress, rather than being supported on it, will eliminate knee compression loading, and this simple intervention should be evaluated in those suffering night time knee pain and more generally in those with knee OA.

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the Biomedical, Natural, Physical and Health Sciences Research Ethics Panel at the University of Bradford (ref: E119).

Competing of interests

The authors declare that they have no competing interests.

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Not applicable.

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