ORIGINAL ARTICLE

Impact of load on the knee in relation to a treadmill angle

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ABSTRACT

Aim To determine the effect of the load on the meniscus in relation to a different angle, and to present the impact of force on eventual injury of menisci.

Methods Research included 200 males with average height of 178.5 cm, mass 83.5 kg, and average age of 22 years. The simulation of treadmill that was used in the evaluation of ischemic heart disease was made. Effects on the knee were evaluated by measuring at different inclinations (5°70’, 6°80’, 7°90’, 9°10’, 10°20’, 11°30’ and 12°40’).

Results With increasing ascent of treadmill the load on the meniscus also increased. Each increase in ascent after 22% (which corresponded to the angle of 12°40’ and seventh degree of load according to the Bruce protocol) at given anthropological values was an etiological factor for meniscus injury.

Conclusion The seventh degree of load according to the Bruce protocol can lead to the meniscus injury.

Key words: computer simulation, injuries, mechanics, meniscus

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INTRODUCTION

In the evaluation of ischemic heart disease, cardiac stress testing is the basis of the diagnostic modality (1). The most commonly used are treadmill and cycle ergometer (1,2). Treadmill testing according to the Bruce protocol is most common in practice (3,4). A load level lasts 3 minutes with an increasing inclination and speed of treadmill (initial treadmill inclination is in the first stage of exercise 10% at a speed of 1.7mph or 2.7km/h, and then the inclination and speed of movement gradually increase). Arterial pressure is measured every 2 minutes, with monitoring of the electrocardiogram (ECG) (4). According to the Bruce protocol, when the submaximal and/or maximum heart rate is achieved, the test is considered to be technically appropriate (4). Changes in heart rhythm, ST segment and T wave are monitored (4). During cardiac stress testing metabolic equivalents of task (METs) are noted and represent a sign of a condition of the body (4). A value of 1 MET is the consumption of 3.5 mL of per kilogram of body mass per minute (4).

Cardiac stress testing is often unreliable, and in a large percentage it is done without real indication (5,6). Although there are methods to objectify whether the patient is adequately loaded during the test, or whether the test is valid, the test in most cases cannot be completed due to fatigue of the patient, which is not associated with coronary circulation (6,7). Obesity, insufficient physical fitness, and especially the condition of the musculoskeletal system can lead to false results, which then lead to immoderate spending of medical resources (4,5). In the evaluation of ischemic heart disease, the sensitivity of cardiac stress testing is 68%, while the specificity is 77% (4).

The knee is the largest joint in the human body, and also the largest joint of the musculoskeletal system, which supports body weight and has the biggest role in body movement (8). Due to the high load it is prone to frequent various overexertion syndromes or chronic damage (9). In order for the knee to have normal function, the correct shape and position of the bones, strong and developed muscles and strong ligaments are important (9,10). The intra-articular bodies are the condyles of the femur and the tibia; additionally, the patella is also part of knee joint (8-10). The movements in the knee joint are enabled by passive and active knee stabilizers (8,9,10). Passive stabilizers are ligaments, while active knee stabilizers are muscles (8). In terms of mechanics, the knee joint is made up of an angular and a rotating joint (10,11). The knee joint contains the menisci, which are located between the femoral condyle and the tibial plateau (9). Menisci have a role in the distribution and transfer of load in the knee when walking and standing, absorb shocks, serve as a secondary stabilizer of the knee, provide joint lubrication, nourish and protect articular cartilage, ensure compliance of joint surfaces, increase contact area and prevent extreme flexion and extension (10,12).

Menisci injuries, especially those resulting from sports activities, are usually caused by rotational forces (12,13). A common mechanism of injury is the action of lateral forces on the knee in flexion (12). Predisposition to injury is the position in which the meniscus is most retracted into the joint (12). For the medial meniscus, this position is a knee flexion with the lower leg rotated outward and the knee turned inward (lower leg abduction) (13,14). For the lateral meniscus, it is the knee flexion, inward rotation, and lower leg abduction (13,14). They make up about 75% of intra-articular pathology of the knee (15). Ruptures of the meniscus can be different, from partial rupture to complete longitudinal or transverse rupture or rupture of a part of the meniscus or its grip (16,17). Chondral defects can also be in the form of micro sutures, but they can also give clinical symptoms (18,19).

A large number of stress tests cannot be performed adequately due to knee pain, and as such are not adequate for the evaluation of ischemic heart disease. It was necessary to make a model that can determine exact loading of the patient without consequent knee injury. No investigations were found relating to this topic.

The aim of this research was to determine the effect of the load on the meniscus in relation to different angle, and to present the impact of force on eventual injury of menisci. The results will be important in everyday clinical cardiac practice.

EXAMINEES AND METHODS

Examinees and study design

This prospective research was conducted at the Faculty of Mechanical Engineering, University of Sarajevo, in June 2020 and included 200 male students. The inclusion criteria were the absence of osteomuscular deformity and negative anamnestic data on the existence of heart disease.

The participants were volunteers. A written informed consent was obtained from all the participants. The average anthropometric measurements (average model) of the examinees were obtained (height 178.5 cm, mass 83.5 kg, average age 22 years). An ethical approval was obtained from the Ethical Committee, Faculty of Mechanical Engineering, University of Sarajevo.

Methods

The simulation of examinees on a treadmill that was used in the evaluation of ischemic heart disease was made. Average values of anthropometric measures were obtained: height of 178.5 cm, mass of 83.5 kg, weight was equal to the product of the force of the earth's gravity and the mass of the examinees, and it was equal to 819.135 Newton (N). According to the average model, the model of the knee joint was analysed (Figure 1, Figure 2). Measurements were observed at different inclinations (5°70', 6°80', 7°90', 9°10', 10°20', 11°30' and 12°40') and effects on knee were evaluated (Figure 1). The mass of the foot was obtained from the Donskoi-Zaciorski pattern, as well as the mass of the lower leg (20).

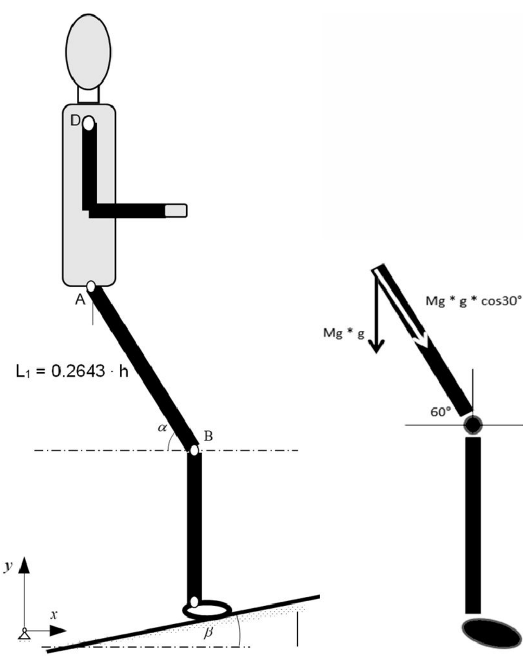

Figure 1. Biomechanical model of a male examinee - position during testing on treadmill; the mass of the foot was obtained from the Donskoi-Zaciorski pattern, as well as the mass of the lower leg

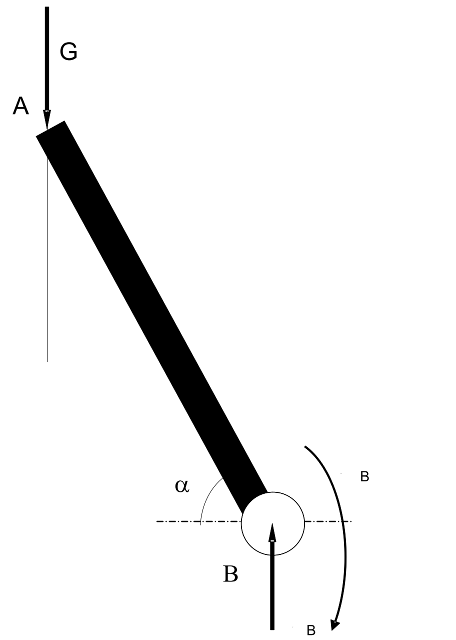

Figure 2. Equilibrium of the thigh in a given position; Y_B, force in the knee; M_B, moment in the knee

The mass of the part of an examinee above the knee, when standing on one leg (total mass-mass of the lower leg-mass of the foot) was calculated as the difference of total mass, lower leg mass and foot mass, and the result for the average examinee was 79.176 kg. The pressure on the meniscus (the force acting on the meniscus relative to the surface of the meniscus) was analysed, as well as the allowable stress on the meniscus relative to the angle of the moving strips. Equilibrium of the thigh was calculated according to Equation 1:

$= 0.2643 \times h = 0.2643 \times 178.5 = 47.177$ cm; $\alpha + \beta \approx 60°$

The weight of the portion of the examinee's mass above the knee was calculated from Equation 2:

$G' = m' \times g = 79.176 \times 9.81 = 776.716$ N

The length of the upper leg was calculated from Equation 3:

$AB = 0.2643 \times h = 0.2643 \times 1.785 = 0.471$

Statistical analysis

The obtained anthropometric values of the model were obtained from the mean value of the analysed parameters. Donskoi-Zaciorski pattern was used to analyse the mass of segments of the lower extremity. The moment of force in the knee and the load force on the knee was calculated in relation to the angle of inclination, as well as the tension in the meniscus.

RESULTS

As the angle of the treadmill increased, the slope also increased; the moment of force acts on the knee joint, and thus on the meniscus (Table 1).

At the slope of 10%, the moment of force on the knee was 213.53 Nm, and at 22% it was 246.71 Nm (Table 1).

Table 1. Moment in the knee (M_B) related to the angle of inclination

Slope (%)	10	12	14	16	18	20	22
Angle β°	5.71	6.84	7.96	9.09	10.20	11.30	12.40
Angle α°	54.29	53.15	52.03	50.91	49.79	48.69	47.59
MB (Nm)	213.53	219.35	225.07	230.67	236.14	241.49	246.71

M_B (Nm), moment in the knee (Newton meter);

With an increase of ascent, the load force on the meniscus also increased (Table 2). At the slope of 10%, the force on the meniscus was 837.37 N, the load on the meniscus was 0.23 N/mm^2, and it gradually increased with increasing of the slope; at the slope of 22%, the force on the meniscus was 967.51 N, while the load was 0.26 N/mm^2 (Table 2).

Table 2. Load force on the knee related to the angle of inclination

Slope (%)	10	12	14	16	18	20	22
Angle β0	5.71	6.84	7.96	9.09	10.20	11.30	12.40
Angle α0	54.29	53.15	52.03	50.91	49.79	48.69	47.59
F_{men} (N)	837.37	860.02	882.64	904.59	926.05	947.03	967.51
σ_{men} (N/mm^2)	0.231	0.237	0.244	0.25	0.256	0.261	0.267

F_{men} (N), force on the meniscus (Newton); σ_{men} (N/mm^2), load on the meniscus (Newton per square meter);

We could expect that for each increase in ascent after 22% at given anthropological values (which corresponded to the angle of 12° 40'), the meniscus can be damaged (in the comparison to permissible stress on the meniscus, which was 0.29 MPa (18) (Figure 3).

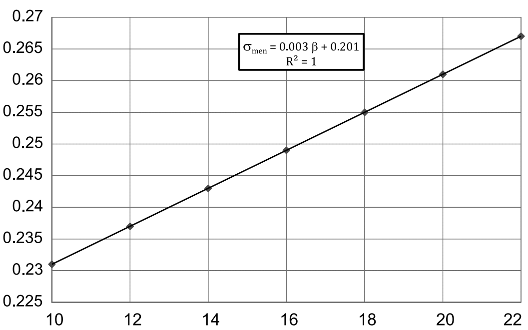

Figure 3. Tension in the meniscus as a function of the angle of inclination; σ_{men}, tension in the meniscus (N/mm^2); β, angle of inclination (%);

DISCUSSION

This research and biomechanical model indicated that in the angle of 22% on treadmill, the knee comes to a position where injuries are possible, and that is risk zone for the injury of musculoskeletal system. Similar studies that have addressed this problem have not been found in the literature. In research, male examinees were selected because of less bias due to anthropometric gender differences.

The main problem in the assessment of a patient who is on the treadmill is non-specific pain in the legs or back and abdomen, which is most often associated with osteomuscular deformities; because of that, cardiologists have a problem with a clear evaluation of the patient (5). All this leads to a waste of resources and a burden on the medical system, and often the doctors do not base their decision on objective facts, but on patient's subjective difficulties and the existence of comorbidities (5). The question is often asked whether this pain in the legs and especially in the knee is still a condition associated with the condition of the knee joint, or the existence of degenerative osteoarthritis, which is very present in the modern population (7). Load on the treadmill can even lead to acute meniscus injury, which is something that should be avoided (7).

The meniscus is a very important part of the knee joint because it has a function in transmitting of the load, thus preventing joint injury (17,21). Majewski et al. stated that the incidence of the meniscus injury is 12-14%, and the prevalence is 61 cases per 100,000 persons (22). The functional state of the joints is one of the most important factors contributing to the meniscus injury (23). Reid et al. stated that squatting, kneeling, crawling, sitting while driving, stair climbing, lifting items are etiological factors that can lead to the meniscus injury (24). McMillan and Nichols list osteoarthritis as one of the most important factors that can contribute to the meniscus injury, and chronic repetitive knee loading, and primarily squatting and kneeling can contribute to osteoarthritis (25). Snoeker et al. stated that the age (over 60), male gender, work-related kneeling and squatting, and climbing stairs are risk factors for the meniscus injury (26). The same authors stated, however, that running is not a risk factor for the injury itself, and that sitting greater than 2 hours per day may reduce the risk of degenerative meniscal tears (26). It is important to emphasize that the elderly population has a physiological degenerative knee changes, and that older people are expected to be more prone to sudden injuries (25,27,28).

In the daily work in cardiology, cardiac stress testing is an unavoidable method for the evaluation of ischemic disease. Due to inadequate testing it is increasingly sidelined and losing its importance, because multislice scanner coronary angiography and myocardial perfusion scintigraphy are more preferred methods (29-31). However, considering low availability, especially in less developed countries, cardiac stress testing still represents an important issue in clinical practice (2). The fact is that, according to the Bruce protocol (4,5), if there is no chest pain during six stages of exercise, there is probably no point in forcing the patient. However, this is questionable for professional athletes, and the decision about terminating stress testing should be made individually (5). Preventive programs before stress testing must be implemented, and risk factors that can lead to possible injury should be clearly isolated. Prevention of injury has to be the aim of clinicians' work, and modifiable factors especially noted. Ma et al. marked obesity as one of the most important factors leading to the meniscus injury (32). The same authors state that warming-up before exercise is very important for the prevention of the meniscus injury (32). It should be noted that the knee should always be a neutral mechanical axis, and inappropriate loading and sudden unnatural movement lead the knee to axis dysregulation, what is a predisposing factor for the injury (33,34). Before cardiac stress testing, attention should be paid to the condition of the musculoskeletal system, although this is probably very difficult to know without prior diagnostics. However, overloading of the patient, and especially an unnecessary load, can lead to the injury.

In conclusion, the seventh degree of load according to the Bruce protocol during cardiac stress testing and the slope of 22% of treadmill is a zone in which the meniscus injury can occur due to overload of the meniscus. These results can help cardiologists in daily work during the evaluation of ischemic heart disease.

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TRANSPARENCY DECLARATION

Competing interests: None to declare.

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