A STUDY OF MOMENTS ACTING ON THE TIBIA DURING GAIT IN THE ACTIVE ELDERLY POPULATION

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The purpose of this study was to estimate the moment acting on three points of the tibia, in order to better understand the loads acting on the shank during gait for the active elderly population. Ten subjects were investigated and walking was chosen as the movement to be studied, since it is a highly common activity in terms of exercising and it is available as a universal solution to improve the quality of life. The data was collected in a motion study laboratory, and inverse dynamics was used to estimate the forces and moments in the joints. An advanced human model was used in this purpose. The results show that in this population, the highest bending moment in the sagittal plane is during late stance phase. It is possible to correlate this data with people with gait disabilities or with implants for bone fixation and help their recovery.

KEY WORDS: active, elderly, tibia, moment.

INTRODUCTION: The most commonly injured bone, by stress fracture, is the tibia (Milner et al., 2006); Milner et al. (2005) stated that tibial injury occurrences may be related to the higher loading of the lower limb. Furthermore there is evidence that some tibial stress fractures are spiral fractures, suggesting that, in addition to vertical and shear forces, moments may be involved in the development of these fractures (Milner et al., 2006). Furthermore, the tibia is exposed to a combination of bending, shearing and torsion simultaneously during activities (Ekenman et al., 1998). The loss of minerals in bones is a serious problem for the elderly people, where the bones become fragile and fractures are more likely; World Health Organisation has estimated that 30% of all women aged over 50 (postmenopausal) have osteoporosis according to a definition of bone mineral density being more than 2.5 standard deviations below the mean for young healthy adult women at any site. Therefore, the understanding of the behaviour of the moments in the tibia of the elderly during common activities is of importance.
To understand the forces in the human body the inverse dynamic has been widely used. Generally, inverse dynamics is performed using simplified models that view each anatomical part of the body as a geometrical shape with a certain mass, the joints of the body being also the joints of the model used in inverse dynamics. While a classical solution offers good results (Vaughan, 1999), the improvement of these models by inputs such as mechanical work of the muscles attached to bones in anatomically correct positions can provide additional and important information about forces acting on the human body, the internal moments on the bones is one example. The internal forces are dependant on the musculoskeletal loads generated by the muscles and tendons attached on the bones while performing various activities. The advanced AnYBody® modelling system is one example of these improved models, being able to capture more accurately the complexity of the musculoskeletal system, which can be very useful in sports science analysis. Therefore, the purpose of this paper is to analyze the moments acting on the tibia during elder people´s gait, by using the advanced AnYBody® modelling system.

METHODS: Subjects: Ten healthy adults, 6 female and 4 male were selected as subjects for this study, aged 67 ± 8 years with an average height of 1.64 ± 0.09m and mass of 66.4 ± 14kg.
Protocol: The individuals walked on an 8 m walkway, at a self selected speed. After a short adaptation, each subject walked three successful times wearing their own shoes stepping the right leg over the forceplate.
Instruments: A Bertec force plate (model 4060-15, Bertec Corporation, Columbus, USA) operating in a sample frequency of 1000Hz and a video system with four cameras operating in a sample frequency of 50Hz were used. The cameras were placed on the walls with the image taken at the four corners of the force plate, in an angle of 45º with the ground; and a 3D calibrated volume that contemplates the whole area of analysis was filmed before the tests.
Data collection: The software Acknowledge (Bertec Corporation, Columbus, USA) was used for the GRF data acquisition and the software Dvideo® (UNICAMP, São Paulo, Brazil) was used for the video manipulation and for obtaining marker positions;
Data analysis: The video data was processed and the reflective markers placed in anatomical points of the lower right limb, based on the Helen Hayes marker configuration (Vaughan, 1999), were converted into 3D coordinates. The forceplate data was exported as 3 major force and moment directions. The data were synchronized and inverse dynamics was calculated using AnYBody Software®. This paper uses the GaitUniMiamiTDRightLeg model, developed and provided under public domain by the AnYBody® Research Group (anybodytech.com). The TLEM lower extremity model (Horsman, 2007) was chosen. In order to estimate the moments acting on different points of the tibia, several changes were done in the initial model, 3 points of interest from the tibia were chosen, namely at 22% of the length, measured from the knee and towards the ankle, and at 40%, and 60% respectively in the same direction. The rationale for choosing these points was to have a point close to the anatomical middle of the tibia and a point on each side of the initial point, close to the middle of the remaining length. In each point, the tibia was split in two rigid parts, the cut being perpendicular to the axis of the bone, as defined in the leg model (Fig.1). The length of the cut was computed based on the location of the ankle joint and then subtracting the length of the tibia multiplied by the cut coefficient. The two rigid parts were then joined with an additional joint added in the system which was afterwards rigidized. The origins of the two new parts were placed in the middle of the two resulting parts. The masses, inertia matrix, and muscle attachment points were adjusted to suit the length of the rigid tibia parts. The method used is largely based on the work of Wehner et al. (2009).

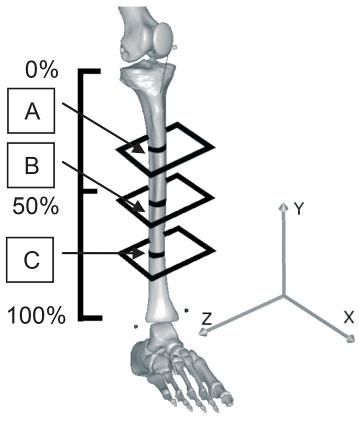

Figure 1: Coordinate system and location of cuts.

For each subject, scaling was considered based on their weight and length of the leg, and an average of 60 time steps/subject were simulated. The study was done on the right leg only.
The resultant contact forces in the ankle, knee, and hip were extracted, along with the internal forces in the three cut points. Moments in the three points were also studied.

RESULTS: The average of the extracted resultant forces in the joints showed loading peaks at the beginning and at the end of the stance phase, for all participants. Time was also normalised to total stance time (in percentage) to facilitate the comparison. The average resultant forces maximum value was 3.6 times body weight (BW) for the ankle, 3.8 BW at the knee, and 3.7 BW for the hip (fig.2).

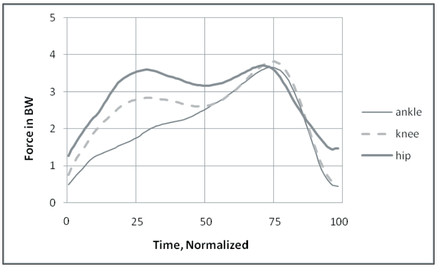

Figure 2: Resultant forces in the ankle, knee and hip joints.

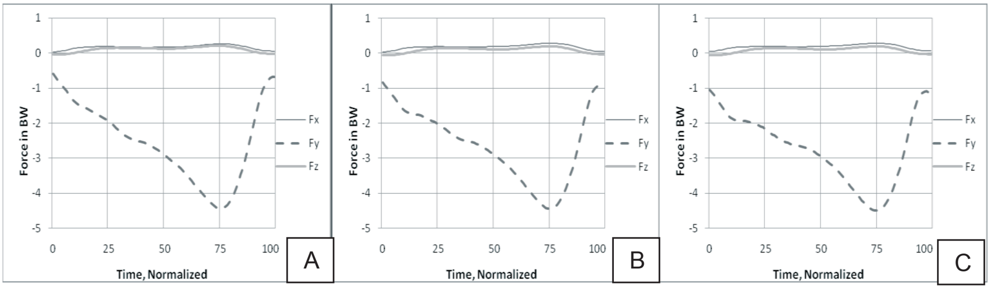

Figure 3: Internal force components at 0,22%(A), 0,40%(B), 0,60%(C) of the tibia from the knee down.

For the rigid joint between the two tibia segments, the maximum average resultant force in each of the 3 points of interest was 4.42 BW, 4.43 BW and 4.49 BW, indicating an increase of the resultant force in the axial direction from the knee to the ankle (Fig.3).
The moments in each section area showed peak values of up to 0.056 BW*m, in the point closest to the knee, but decreased their values towards the ankle, where the maximum value was 0.023 BW*m (Fig.4).

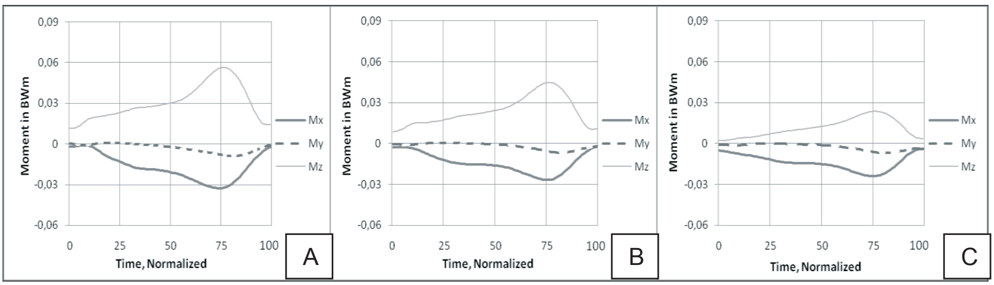

Figure 4: Internal moments at 0,22%(A), 0,40%(B), 0,60%(C) of the tibia from the knee down.

DISCUSSION: This work describes a method to assess stress factors that act on the tibia during gait, and attempts to better understand the internal loads on the tibia during gait. The loads are dependent on the phase of the motion, and also on the location investigated. As expected, the loads increased towards toe off, when the moment in the ankle also increases, in order to facilitate pushing the body forward.
The internal forces in the tibia on the axial direction had a peak of 4.5 BW for this study, with 3 cut points, as opposed to a previous work, where 9 points were used and the peak value was 4.7 BW (Wehner et. al., 2009).
The tendency of the internal moments was to increase towards the knee joint, which can indicate a tendency of fracture in the upper part of the bone if stressed over a long period of time. Also, it must be considered that the people investigated are elderly, even though they live active lifestyles.
The limitations of this study are related to errors in the kinematics which influence the results, and errors induced by force platform signal noise. Also, this study was conducted with only 3 points of interest and, while they are far apart from each other, adding more points into the system could give a better image of the overall load on the tibia.
However, the peak loading values are similar to what has been previously presented, which indicates that while limited, the study does provide useful results.

CONCLUSION: In this study, a method of evaluating moments acting on the tibia has been used on a group of 10 subjects. The data can be used to study loads in the skeleton and simulate the behaviour of the tibia in a finite element environment. With this protocol, it is possible to evaluate different skills and analyse the stress acting on the skeleton in a variety of situations, therefore the model used in the present study can be useful in sports analyses, mainly considering sports that require high loads on the lower limbs. Since the data shown is a mean value of the actual moments and is also normalized by body weight, estimation for similar individuals is possible, and this can be correlated with the loss of minerals and the reduction in bone strength, giving an estimate of the possibility of fracture.
Additionally, it is also possible to use this protocol to compare the pattern of stress obtained in normal individuals with that of people with disabilities and implants for bone fixation. This kind of comparison may help the improvement of this population’s recovery.

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