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DYNAMIC CHANGES IN MOMENTS OF INERTIA OF THE SHANK DURING DROP LANDINGS

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SUMMARY

During impacts soft tissue motion is greater than during active muscular contractions but usually only lasts for tenths of a second, at most, and is difficult to measure. The aim of this study was to use an array of markers on the shank to track soft tissue deformation during landing and rapidly approximate changes in inertial parameters. Six subjects performed a series of drop landings, where landing was heavily favoured onto one leg only from four different heights. A 10 camera Vicon motion analysis system operating at 700 Hz tracked 48 spherical markers (7.9 mm) placed on the shank and for each recorded frame an arbitrary ellipsoid was fitted to the markers. Although not the goal the ellipsoid fits gave inertial parameters that were similar to human subjects. Changes in inertial properties of the shank of between 10% and 100% were found during the impacts. These segment changes are considerable and should be considered during inverse dynamics analysis involving impacts.

INTRODUCTION

For the mechanical analysis of human movement body segments are frequently assumed to be rigid bodies, with the inertial parameters of these bodies required for detailed analyses fixed to a constant value. During impacts the shape of a body segment can change due to a mechanical wave propagating through soft tissue and had been represented by wobbling masses. Soft tissue deformation has been reported to account for up to 70% of the energy lost in some of these segments [1] during certain types of impact and occurs in conjunction with large changes in segment shape. We have previously reported that the inertial properties of the shank can change markedly solely due to active muscular contractions [2]. In [2] the volume of each segment varied on the same order as the repeatability but changes in maximum dimensions were around 10%. The moments of inertia increased by 5% about the longitudinal axis and decreased by 8% about the two transverse axes.

During impacts soft tissue motion is greater than during active muscular contractions (Figure 1) but usually only lasts for tenths of a second, at most, and is difficult to measure. Previously we have shown [3] that by using arrays of small reflective markers and Vicon motion analysis system reasonable estimates of static segment volumes can be made at frame rates up to 1000 Hz (cylinder <3% error, forearm +2 to -8%). The worst case results were at the highest sample frequencies due to marker loss. For the forearm measures the worst values were obtained when the markers were placed on a thin nylon material rather than directly to the skin.

Figure 1: Stills from high speed video (1000 Hz) of a drop landing onto the heel showing changes in soft tissue distribution. Left is pre-impact, middle is post impact at minimum shank width, and right is post-impact at maximum shank width (note the right image has the shank rotated forward compare to the other two).

Some typical problems with measuring impacts with arrays of small markers are marker loss, marker confusion, and coverage of the complete area of interest, all of which previous methods [2] are sensitive to. The aim of this study was to use an array of markers on the shank to track soft tissue deformation during landing and rapidly approximate changes in inertial parameters with a more robust method. This makes use of the redundancy of multiple markers but at the expense of absolute accuracy in the inertial parameters by fitting an ellipsoid to the marker set. Thus the goal is to examine changes in inertial properties that can be related back to the static inertial parameters obtained by any preferred method.

METHODS

Six male subjects (age 23 ± 3 years, height 1.81 ± 0.08 m, weight 81 ± 5 kg) who were free from lower extremity injury gave informed consent in accordance with the Loughborough University Ethical Advisory Committee procedures. Subjects performed a series of drop landings where landing was heavily favoured onto one leg only from four different heights (0.3, 0.5. 0.7 and 0.9 m). Two conditions were utilized active markered leg landing on the force plate and passive markered leg landing on the force plate. Active landings landed on the forefoot and controlled the impact. Passive landings landed as much onto the heel as comfortable and minimal effort was used in this leg to brake the landing. Each subject performed multiple landings and the landing with the most complete data set was taken forward for further analysis.

A 10 camera Vicon motion analysis system (612 series, 1.3 megapixel cameras, Oxford, UK) operating at 700 Hz tracked 48 spherical markers (7.9 mm) placed on the shank in a 6x8 array. Incomplete marker trajectories were reconstructed using Vicon Nexus 1.4.116 and the pattern filling function. Marker data were low pass filtered at 50 Hz with a 2nd order zero lag Butterworth filter. Reconstructed marker locations were transformed in Matlab (Figure 2) and for each frame an arbitrary ellipsoid was fitted (ellipsoid_fit, Y. Petrov, North Eastern, Boston USA). Inertial properties of the ellipsoids at each frame were calculated for each drop across subjects.

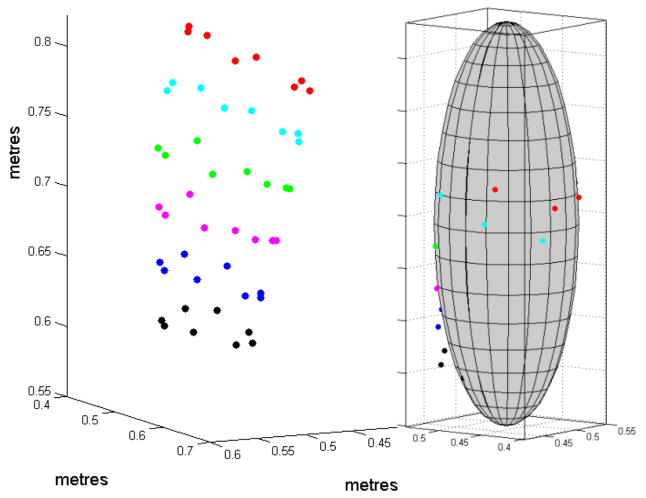

Figure 2: Left is array of 48 markers for the shank reconstructed in Matlab for a frame pre impact and right is an ellipsoid fit to the same markers.

RESULTS AND DISCUSSION

Although the goal was not to reproduce accurate inertial parameters of the subjects the ellipsoid fits gave inertial parameters that were within the ranges seen in human subjects. For example Subject 1 had shank mass = 3.81 Kg, length 0.38 m, max width 0.14 m, and moments of inertia of 0.031, 0.032 and 0.007 N.m^2 indicating that the ellipsoid is providing a decent simulacrum of the whole shank. This should be advantageous when looking at changes with time and relating them to real changes in the human shank as there is a simpler level of mapping required.

An estimation of the change in width from the stills of the shank in Figure 1 gave a total change in width of 15%. For a similar sized subject the ellipsoid fits had a change in width of ~10%. Changes in mass of the ellipsoid were 8% to 40% depending on the subject, condition and drop height. The larger values seemed to be mainly due to distinct short duration spikes and may be artifacts that need further consideration. This change in volume does not represent a change in the actual shank volume, which will remain constant, but is an indicator of the mass associated with that portion of the shank associated with the markers at any time which can change.

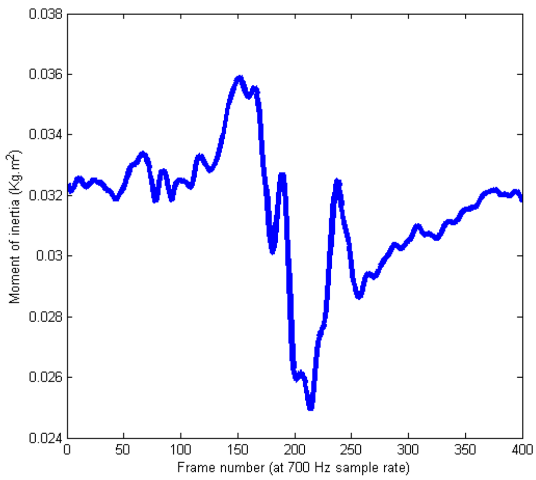

Figure 3: change in moment of inertia the ellipsoid about the medial-lateral axis.

Changes in moment of inertia about the vertical axis were highly subject dependent, with changes of around 10% for some subjects and up to 30% for others, again condition and height dependent as well. Changes in the moments of inertia about the other two axes varied from 20% to 100% again depending on the subject, condition and drop height (Figure 3). Again the larger values seemed to be mainly due to distinct short duration spikes and may be artifacts that need further consideration. Further examining the results by subject and looking for systematic effects of drop height and condition on changes in inertial properties will aid in the understanding of the extent of soft tissue motion and when it will have a significant effect directly on joint moment calculations.

CONCLUSIONS

Using arrays of markers on the shank it is possible to track the deformation of the soft tissue under different impact conditions and produce a relatively realistic ellipsoid fit that can give some strong indication of the dynamic changes in segment inertia properties. It appears that the segment changes are considerable and should be considered during inverse dynamics analysis involving impacts.

REFERENCES

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