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A method to calculate the centre of the ankle joint: A comparison with the Vicon® Plug-in-Gait model

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Background: In gait analysis, calculation of the ankle joint centre is a difficult task. The conventional way to calculate the ankle joint centre is using the Vicon® Plug-in-Gait model. The present study proposes a new model, which calculates the joint centre from two markers positioned over the medial and lateral malleoli (i.e. Two-marker-model).

Methods: In order to compare the proposed model with Plug-in-Gait model, gait data from healthy and patient subjects were captured using a motion capture system. The ankle joint centres were calculated by the two models. A test–retest experiment was carried out to check reliability and repeatability for Two-marker-model.

Findings: Two ankle joint centres produced by two models were significantly different. The distances between two ankle joint centres were approximately 16.8 (mm), and the differences in the posterior–anterior, medial–lateral and inferior–superior directions were approximately 6.3, 7.7 and 8.2 (mm). Further error analysis highlighted that the probability of producing errors in Two-marker-model is lower than that in Plug-in-Gait model due to the Two-marker-model's simple and reliable marker positioning. The reliability and repeatability coefficients for the new model were greater than 0.9.

Interpretation: In principle, the Plug-in-Gait model is more likely to produce errors than the Two-marker-model, because the former employs multiple markers from the pelvis to calf to define the ankle joint centre with marker positions being very user-dependent. The results suggest that the Two-marker-model can be considered an alternative to Plug-in-Gait model for calculating ankle joint centre.

1. Introduction

Defining the joint centres accurately is an important prerequisite to ensure the accuracy of the calculation of kinematic and kinetic parameters during gait analysis (Gill et al., 1997). This is particularly important at the ankle where the moment arm of muscles acting across the joint may be as low as 15 mm (Challis, 2001). Despite advances in technology, the problem of inherent errors which are caused by the methods or models used rather than by motion capture systems or marker data remains unresolved. Various mathematical models are used for processing data. Gill et al. (1997) stressed the importance of errors resulting from selecting a wrong model (i.e. being deficient in design principle) for processing data collected by motion capture systems. The diversity of models used for calculating joint centres indicates that none is ideal or universally acceptable. Predictive methods for calculating joint centres are known to be associated with errors due to marker mislocation (Croce et al., 2005), movement of skin markers (Cerveri et al., 2005; Leardini et al., 2005) and inaccurate subject measurements (e.g. bone lengths). Previous studies (Besier et al., 2003; Hicks and Richards, 2005; Leardini et al., 1999; Kirkwood et al., 1999) have been carried out to validate several models for calculating the hip and the knee and most methods were on function and radiography, but few studies are available regarding the ankle.

The Vicon® Plug-in-Gait model (PGM), currently used in the majority of clinical gait analysis laboratories, applies a specific 'chord function' in the calculation of the ankle joint centre (Vicon®, 2002). To determine the ankle joint centre (AJC), the PGM estimates the hip joint centre (HJC) using three markers on the pelvis; then uses the derived HJC and other two markers on the thigh to estimate the knee joint centre (KJC); finally uses the derived KJC and other two markers on the shank to estimate AJC. Since seven markers are logically involved in the calculation of the AJC, thus errors in the proximal joints are transferred/enlarged to the distal joints, especially in subjects where bony landmarks are difficult to identify around the pelvis, e.g. obese or overweight subjects. The PGM accuracy is affected by many factors, such as inaccurate limb measurements and observer-dependent variability in multi-marker placement.

Based on the cadaveric studies by Dempster in 1955, LeVeau (1992) stated that the AJC falls within the body of the talus in the axis

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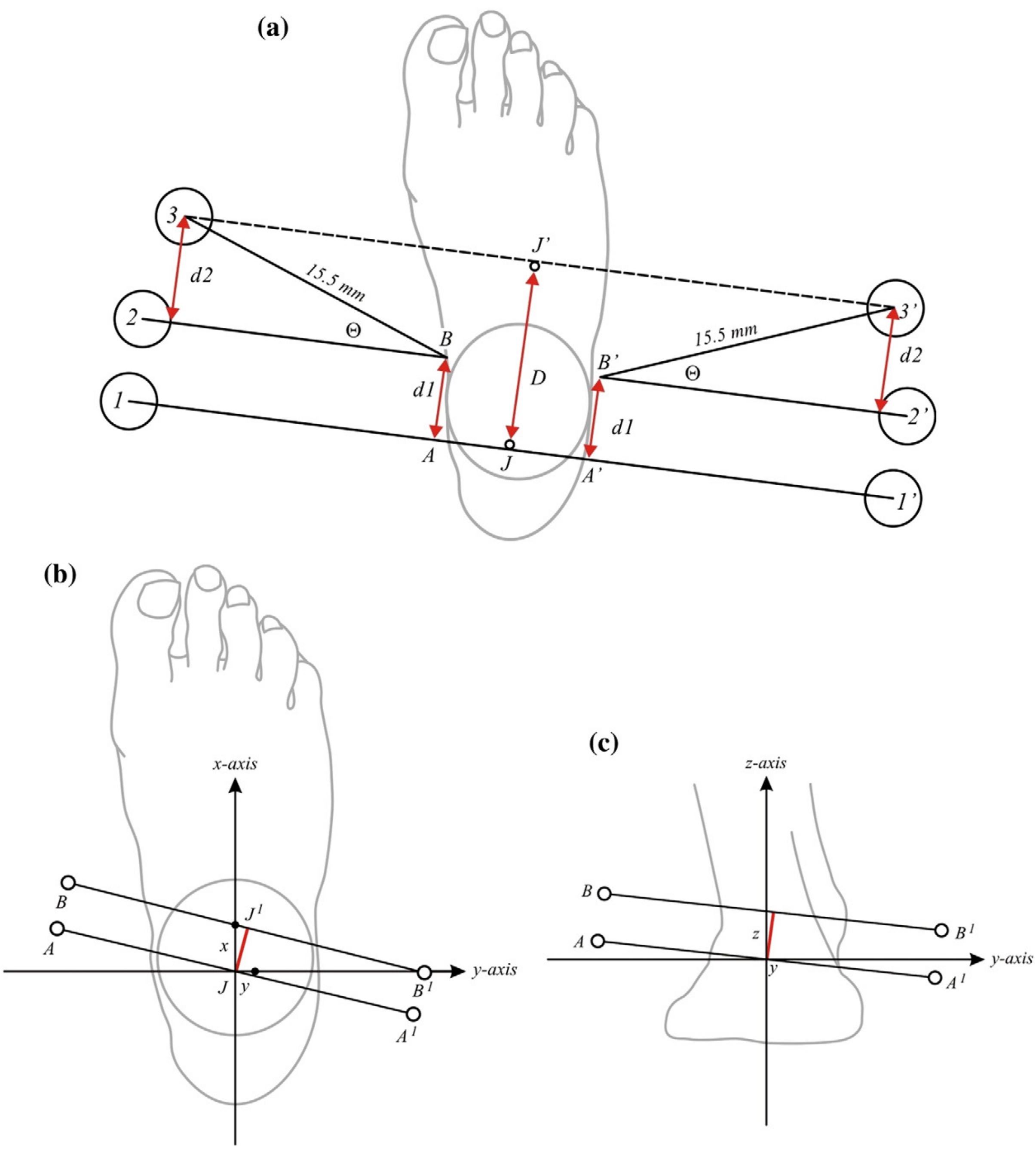

Fig. 3. Calculation of the error occurring in the TMM due to inaccurate placement of the marker and its movement (a). Note that the foot is not drawn in proportion. The J–J′ line indicates the distance between the true joint centre (J) and the calculated joint centre (J′). Possible errors occur in the horizontal plane (b) and frontal plane (c) due to incorrect marker placement in the TMM. The difference in the *y* axis is small even when there are remarkable differences in the *x* and *z* axes.

palpable bony landmarks such as the malleoli, is more reliable for calculating the AJC than PGM.

4.6. Feasibility

When TMM was were used for healthy adults and disabled children, the new model worked very well in most of the cases. One problem observed from the TMM was the difficulty in retaining the larger diameter medial ankle marker (e.g. 25 mm) in some children, as they have smaller gaps between the medial malleoli which make the markers more susceptible to being dislodged during walking. However, this can be easily resolved by using smaller markers (e.g. 14 mm) for the collection of gait data in children. Much smaller markers (e.g. 3 mm) should work perfectly well with the new higher resolution motion capture systems. With smaller markers, the errors produced by TMM also can be largely reduced, according to previous error analysis. The experiments done confirmed that the TMM is feasible in clinical practice.

4.7. Shortcoming in TMM

A possible drawback in the TMM is that the markers on the medial malleoli are more prone to low frequency skin movement artefacts, because the skin slides over the bone during movement and the more prominent the landmark the greater such movement. However, similar shortcomings also exist in the PGM where seven markers are involved in the determination of the AJC and introduce high or low frequency skin movement artefacts. Only two markers in the TMM are

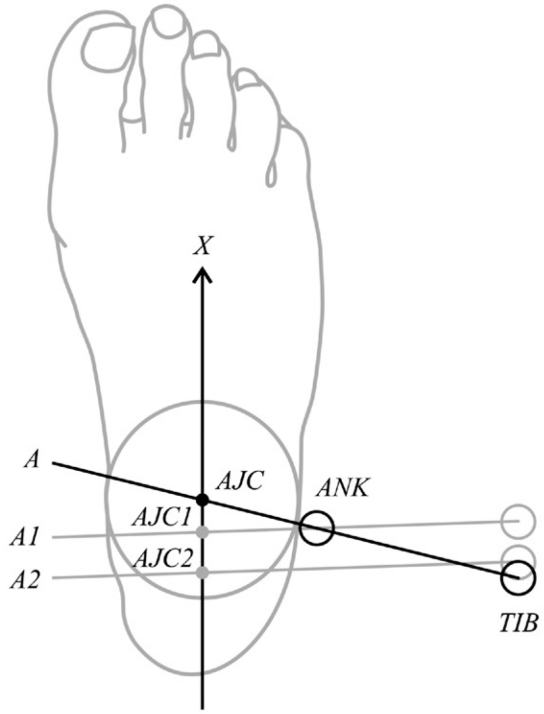

Fig. 4. Calculation of the error occurring in the PGM due to inaccurate placement of the marker and its movement. The line A indicates the right position, and the lines A1 and A2 represent wrong positions due to wrong marker placement while AJC, AJC1 and AJC2 are different ankle joint centres caused by the lines A, A1 and A2, respectively.

affected by skin movements. From this viewpoint, the TMM should be more reliable than the PGM.

In practice, the new model is compatible with the conventional model and allows marker data to be collected simultaneously while collecting gait data using the conventional PGM. The reliability and repeatability analysis also showed that the TMM is easy to operate. The error analysis indicated that TMM had less chance to bring in error than PGM. Future research should consider a comparison of TMM and PGM in terms of joint angle, moment and power. Further studies are required to compare the TMM with the methods such as Roentgen Stereophotogrammetric Analysis (RSA) (Leardini et al., 1999) or other methods based upon Computerised Tomography (CT) or Magnetic Resonance Imaging (MRI) (Sutherland, 2002), which provide different ways to measure joint centres.

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