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Short communication

A 3-dimensional rigid cluster thorax model for kinematic measurements during gait ☆

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ABSTRACT

The trunk has been shown to work as an active segment rather than a passenger unit during gait and it is felt that trunk kinematics should be given more consideration during gait assessment. While 3-dimensional assessment of the thorax with respect to the pelvis and laboratory can provide a comprehensive description of trunk movement, the majority of existing 3-D thorax models demonstrate shortcomings such as the need for multiple skin marker configurations, difficult landmark identification and practical issues for assessment on female subjects. A small number of studies have used rigid cluster models to quantify thorax movement, however the models and points of attachment are not well described and validation rarely considered. The aim of this study was to propose an alternative rigid cluster 3-D thorax model to quantify movement during gait and provide validation of this model. A rigid mount utilising active markers was developed and applied over the 3rd thoracic vertebra, previously reported as an area of least skin movement artefact on the trunk. The model was compared to two reference thorax models through simultaneous recording during gait on 15 healthy subjects. Excellent waveform similarity was demonstrated between the proposed model and the two reference models (CMC range 0.962–0.997). Agreement of discrete parameters was very-good to excellent. In addition, ensemble average graphs demonstrated almost identical curve displacement between models. The results suggest that the proposed model can be confidently used as an alternative to other thorax models in the clinical setting.

1. Introduction

The trunk acts as an active segment rather than a passive unit during gait (Armand et al., 2014; Leardini et al., 2009). Plantarflexor weakness, hip adductor weakness and hip extensor weakness can all result in compensatory trunk patterns and consequently it has been suggested that trunk kinematics should be considered an important part of the pathological gait assessment (Gutierrez et al., 2003; Lamoth et al., 2002). Methods for modelling the trunk range in complexity, depending on the movement of interest, with trunk kinematics often described by tracking a combination of skin surface markers placed directly on the thorax segment (Gutierrez et al., 2003; Nguyen and Baker, 2004; Romkes et al., 2007; Su et al., 1998). A number of drawbacks exist when using this approach. Skin surface markers require experienced clinicians for palpation and localisation of anatomical landmarks, although there is still room for error regardless of the experience of the clinician (Armand et al., 2014). For pathological groups such as Cerebral Palsy this can be made all the more difficult as cooperation may be an issue when applying multiple marker sets. Many thorax models require a marker on the Xypoid Process (XP). Issues regarding the practicality and invasiveness of accurately applying this marker in females have been previously highlighted (Armand et al., 2014). Skin surface markers are also susceptible to skin movement artefact (SMA), where soft tissue moves over the underlying bone. As an alternative to the skin surface marker approach, we propose a rigid marker cluster model that attaches to a single point on the thorax. Few studies have used rigid marker clusters for measuring thorax movement during gait and where they have been used the specific point of attachment is often not reported (Houck et al., 2006; Krebs et al., 1992; Wu et al., 2004). When placed at the appropriate point, a rigid cluster has the potential to address many of the limitations of the skin surface marker approach and provides a better fit for the clinical assessment. Consequently, there is a clinical need for such a model.

☆ All authors were fully involved in the study and preparation of the manuscript and the material within has not been and will not be submitted for publication elsewhere except as an abstract.

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Following from this, the aim of this study is to describe and provide validation of a rigid cluster model to quantify thorax movement during gait.

2. Materials and methods

2.1. Subjects

Fifteen healthy subjects participated in the study: 9 male and 6 female, aged 6–18 years. Informed written consent was obtained from all participants and from their parents when legally minor. The study was approved by the Central Remedial Clinic's Ethical Committee.

2.2. Thorax model

The thorax model of this research, the Central Remedial Clinic Thorax Model (CRCTM), was developed using custom scripts in Matlab 8.1.0.604 (The MathWorks, Natick, Massachusetts, USA). The CRCTM is further development of a model used previously in our laboratory for measuring functional movements at the low back (Rice et al., 2004). Markers were placed on a rigid mount attached to the thorax at the level of T3 (3rd Thoracic Vertebra). T3 has been previously highlighted to lie within the area of least skin movement artefact during active movement of the trunk (Rice et al., 2002). The mount was made of lightweight plastic with a small rectangular base that is attached to the skin using double sided sticky tape (Fig. 1). The mount is positioned proud of the back so markers are not obscured by shoulder or arm movement. Three active markers were attached to the mount. The centre lines of mount's longitudinal and transverse axes were marked and aligned with the vertical axis of the spine and the centre of T3. The *Z*-axis of the model was defined using two markers along the base of the mount. Positive *Z*-axis was defined as m2 to m1 (Fig. 2). The *X*-axis was defined using a Gram–Schmidt procedure incorporating m3 and the *Z*-axis with positive X-direction forward through the body (Fig. 2). The *Y*-axis was defined as the vector product of the *X*-axis and *Z*-axis.

The CRCTM angles were calculated according to International Society of Biomechanics (ISB) recommendations as the rotation between (1) the thorax axes system and the pelvic axes system and (2) the thorax axes system and the

Fig. 1. Position of the CRCTM on a normal subject. The rigid cluster is made of lightweight plastic with a small rectangular base that is attached to the skin using double sided sticky tape. The mount is positioned proud of the back so markers are not obscured by shoulder or arm movement.

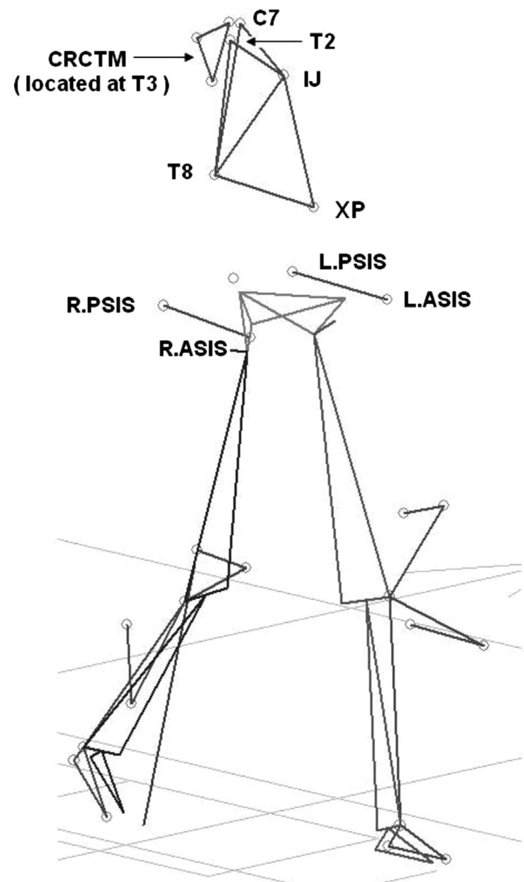

Fig. 3. A stick figure diagram of all three thorax models in situ. Model 1 (ISB) defined using ISB recommendations, with markers placed directly at C7, T8, IJ and XP. Model 2 (Armand) defined using an "optical and minimal" skin marker set (Armand et al., 2014), with markers placed directly at IJ, T2 and T8. Model 3 (CRCTM) placed directly at T3 and aligned with the vertical axis of the spine.

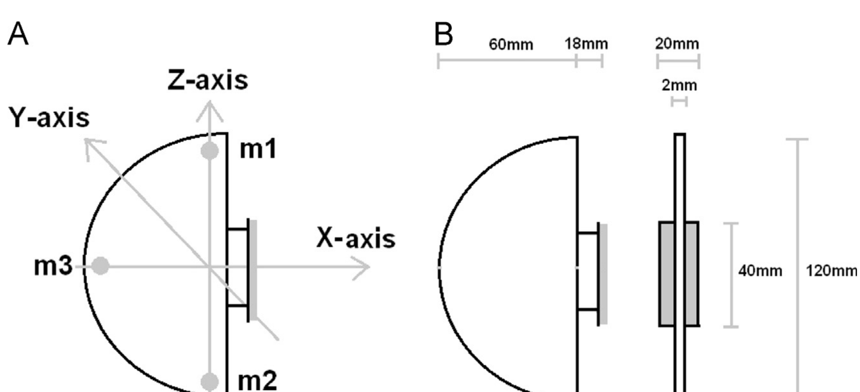

Fig. 2. Schematic and dimensions of the thorax mount and the corresponding axes of the mathematical model. The *Z*-axis is defined by the vector between Marker 2 (M2) and Marker 1 (M1). The *X*-axis is defined using a Gram-Schmidt procedure incorporating Marker 3 (M3) and the *Z*-axis. The *Y*-axis is defined as the vector product of the *X*-axis and *Z*-axis.