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In vivo thorax 3D modelling from costovertebral joint complex kinematics

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A B S T R A C T

Background: The costovertebral joint complex is mechanically involved in both respiratory function and thoracic spine stability. The thorax has been studied for a long time to understand its involvement in the physiological mechanism leading to specific gas exchange. Few studies have focused on costovertebral joint complex kinematics, and most of them focused on experimental *in vitro* analysis related to loading tests or global thorax and/or lung volume change analysis. There is however a clinical need for new methods allowing to process *in vivo* clinical data. This paper presents results from *in vivo* analysis of the costovertebral joint complex kinematics from clinically-available retrospective data.
Methods: In this study, *in vivo* spiral computed tomography imaging data were obtained from 8 asymptomatic subjects at three different lung volumes (from total lung capacity to functional residual capacity) calibrated using a classical spirometer. Fusion methods including 3D modelling and kinematic analysis were used to provide 3D costovertebral joint complex visualization for the true ribs (i.e., first seven pairs of ribs).
Findings: The 3D models of the first seven pairs of costovertebral joint complexes were obtained. A continuous kinematics simulation was interpolated from the three discrete computerized tomography positions. Helical axis representation was also achieved.
Interpretation: Preliminary results show that the method leads to meaningful and relevant results for clinical and pedagogical applications. Research in progress compares data from a sample of healthy volunteers with data collected from patients with cystic fibrosis to obtain new insights about the costovertebral joint complex range of motion and helical axis assessment in different pathological conditions.

1. Introduction

The rib cage is regarded as an anatomical structure organized for both protection of vital organs, and mechanical support for respiratory function and spinal stiffness. Rib cage mobility function was previously demonstrated to support breathing (Cappello and De Troyer, 2002). The relationships between the costovertebral joints (CVJs) and the thoracic spine were also described (Oda et al., 1996, 2002; Takeuchi et al., 1999). Functional impairments of the respiratory function and the thoracic spine have been related to show important kinematic and compliance consequences (De Troyer et al., 1986; Estenne et al., 1985; Gilmartin and Gibson, 1986). Quantification of rib cage mobility from computerized tomography (CT) images is a reproducible method (Mueller et al.,

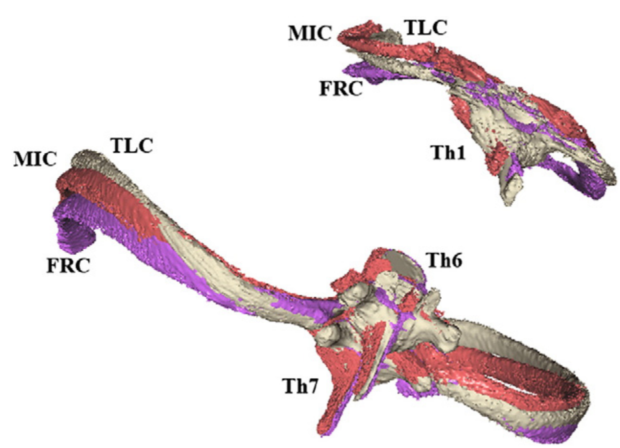

Fig. 1. First and seventh CVJ complex (involving respectively 1st thoracic vertebra (Th1); the 7th rib and the 6th and 7th vertebrae (Th6 and Th7)) in the three available discrete positions (TLC in white, MIC in red and FRC in purple). Posterior view.

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2012). Clinical perspectives of this method are promising in order to describe normal and pathological patterns of both respiratory and postural thorax mechanics (e.g., neuromuscular or musculo-skeletal diseases, etc…). Also, as no evidence is currently available on manual therapy techniques for improving rib mobility or alveolar gas exchange, methods should be developed to evaluate validity and kinematics impact of such therapeutic approaches. According to the literature (Dugailly et al., 2010; Salvia et al., 2000), the 3D orientation of motion axis was reported to provide qualitative description of motion.

The aim of the present study was to develop a methodological protocol allowing *in vivo* quantification and representation of CVJ 3D kinematic behaviour with an emphasis on using motion representation that would respect the physiological CVJ behaviour (Beyer et al., 2011, 2013). Another aim of the study was to develop the protocol from data that are ethically acceptable in clinical practise; therefore use of invasive methods was avoided.

2. Method

2.1. Subjects

This study is based on a previously-described method used for CVJ motion representation (Beyer et al., 2011, 2013). This study relied on the latter method to collect data related to *in vivo* CVJ behaviour during breathing. Retrospective codified medical imaging datasets were obtained from the Department of Radiology of the Erasme Academic Hospital for 8 asymptomatic volunteers (mean age 30.4 (5.5) years old; mean body mass index 21.1 (2.2) kg/cm^2). The protocol was approved by the local ethical committee (P2005/021).

2.2. Medical imaging and 3D bone model reconstruction

Spiral computed tomography (Siemens SOMATOM, helical mode, slice thickness = 0.5 mm, inter-slice spacing = 1 mm, image data format:

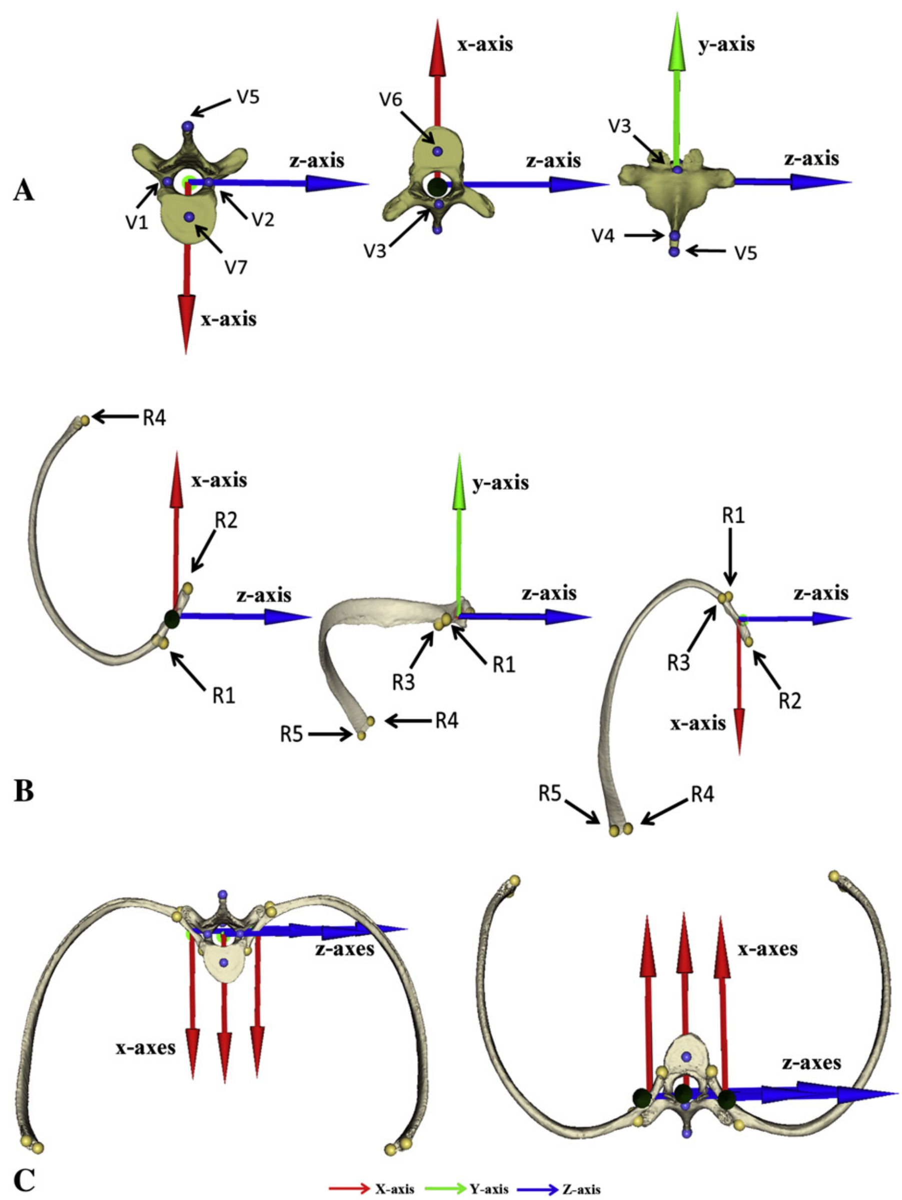

Fig. 2. A: Anatomical landmarks (ALs) and anatomical coordinate systems used for vertebra (from left to right: inferior, superior and posterior view); B: ALs and coordinate frames used for ribs (from left to right: superior, posterior and inferior view); C: AF alignment at TLC position as referential position (left: inferior view, right: superior view). Vertebra landmarks: (Fig. 2A). **V1** Centre of inferior border of left pedicle. **V2** Centre of inferior border of right pedicle. **V3** Superior junction of lamina. **V4** Posterior and superior apex of spinous process. **V5** Posterior and inferior apex of spinous process. **V6** Centre of upper endplate. **V7** Centre of lower endplate. Rib landmarks: (Fig. 2B). **R1** Posterior apex of tuberosity. **R2** Anterior apex of inter-articular crest of costo-corporeal joint. **R3** Inferior point of tuberosity. **R4** Superior apex of costo-chondral surface. **R5** Inferior apex of costo-chondral surface.