Respiratory Physiology & Neurobiology 232 (2016) 57–65

Contents lists available at ScienceDirect

Respiratory Physiology & Neurobiology

journal homepage: www.elsevier.com/locate/resphysiol

Relationship between costovertebral joint kinematics and lung volume in supine humans

Benoît Beyer[a,b,d,*], Serge Van Sint Jan[a], Laurence Chèze[d], Victor Sholukha[a,c], Véronique Feipel[b]

[a] Laboratory of Anatomy, Biomechanics and Organogenesis (L.A.B.O), Université Libre de Bruxelles, Brussels, Belgium
[b] Laboratory of Functional Anatomy, Université Libre de Bruxelles, Brussels, Belgium
[c] Department of Applied Mathematics, Peter the Great St. Petersburg Polytechnic University (SPbPU), Russia
[d] Univ Lyon, Université Claude Bernard Lyon 1, Ifsttar, UMR_T9406, LBMC, F69622 Lyon, France

ARTICLE INFO

Article history:
Received 9 April 2016
Received in revised form 11 July 2016
Accepted 12 July 2016
Available online 12 July 2016

ABSTRACT

This study investigates the relationship between the motion of the first ten costovertebral joints (CVJ) and lung volume over the inspiratory capacity (IC) using detailed kinematic analysis in a sample of 12 asymptomatic subjects.

Retrospective codified spiral-CT data obtained at total lung capacity (TLC), middle of inspiratory capacity (MIC) and at functional residual capacity (FRC) were analysed. CVJ 3D kinematics were processed using previously-published methods. We tested the influence of the side, CVJ level and lung volume on CVJ kinematics. In addition, the correlations between anthropologic/pulmonary variables and CVJ kinematics were analysed.

No linear correlation was found between lung volumes and CVJ kinematics. Major findings concerning 3D kinematics can be summarized as follows: 1) Ranges-of-motion decrease gradually with increasing CVJ level; 2) rib displacements are significantly reduced at lung volumes above the MIC and do not differ between CVJ levels; 3) the axes of rotation of the ribs are similarly oriented for all CVJ levels.

1. Introduction

Since the descriptions of von Hayek (1953) and Felix (1928), ribs have been demonstrated to be involved in both respiratory function (Cappello and De Troyer, 2002) and thoracic spine stability (Oda et al., 1996; Takeuchi et al., 1999). Literature concerning *in vivo* segmental costovertebral (CVJ) kinematics during breathing is scarce. Planar radiographic techniques were previously used to quantify 2D rib angle variations (*i.e.*, the "pump handle") at various lung volumes over the vital capacity (VC) (Sharp et al., 1986). Three-dimensional (3D) kinematics of the upper ribs were quantified at specific costal level according to vector displacement analysis from external measurements (Jordanoglou, 1970, 1969; Jordanoglou et al., 1972) and joint surface geometry (Saumarez, 1986). 3D rib displacements between total lung capacity (TLC) and functional residual capacity (FRC) were also obtained from medical images on small samples (Wilson et al., 2001, 1987). Recently, a method was developed using computed tomography (CT) data (obtained at three different lung volumes (Cassart et al., 1997; Pettiaux et al., 1997)) and virtual palpation of few anatomical landmarks (ALs) on the 3D bone models reconstructed from the available CT data (Beyer et al., 2014). Sensitivity analysis was used to quantify the influence of AL palpation errors on the determination of the axis of motion at each specific CVJ level (Beyer et al., 2015). These previous works focused on the CVJ ranges-of-motion (ROMs) of the seven first pairs of ribs only and did not attempt to quantify the relations between CVJ ROMs and lung volumes. A non-uniform coupling between the ribs and the lungs was also previously demonstrated in dogs; no conclusive explanation was however given to explain the underlying coupling mechanism (De Troyer and Leduc, 2004; De Troyer and Wilson, 2002). The influence of both rib level and lung volume above FRC was demonstrated to alter rib compliance in caudal-cephalic direction (De Troyer et al., 2005; Wilson and De Troyer, 2004). Further, force transmission during diaphragmatic contraction has been previously demonstrated

Abbreviations: BMI, body mass index; CVJi, costovertebral joint (i = joint level (from 1 to 10)); TLC, total lung capacity; MIC, middle of inspiratory capacity; FRC, functional residual capacity; IC, inspiratory capacity; VC, vital capacity; RV, residual volume; MHA, mean helical axis; FHA, finite helical axis; ALs, anatomical landmarks.

* Corresponding author at: L.A.B.O, Lennik Street 808, CP 619, 1070 Brussel, Belgium.
E-mail address: bbeyer@ulb.ac.be (B. Beyer).

http://dx.doi.org/10.1016/j.resp.2016.07.003
1569-9048/

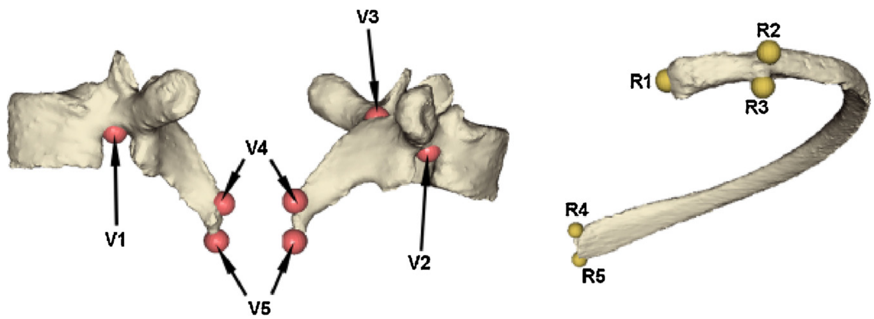

Fig. 1. Definition of anatomical landmarks (ALs) which spatial coordinates were used to compute transformation matrices between breathing poses. Vertebra ALs: V1, Centre of inferior border of left pedicle; V2, Centre of inferior border of right pedicle; V3, Superior junction of lamina; V4, Posterior and superior apex of spinous process; V5, Posterior and inferior apex of spinous process. Rib ALs: 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.

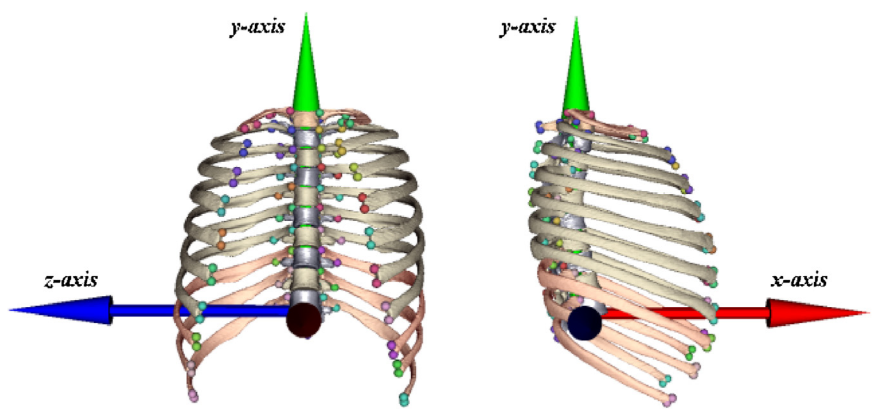

Fig. 2. Global thorax coordinate system used to express kinematic parameters at each costovertebral joint level.

to create a mechanical linkage between the ribs in the lower rib cage and those in the upper rib cage (De Troyer, 2012). From these studies, one may expect that the behaviours described will be reflected in the kinematics of the CVJ, but detailed quantified relationships between rib 3D kinematics at a specific CVJ level and lung volumes are yet to be described in humans.

In this paper, a previously-published method (Beyer et al., 2015, 2014) was used to analyse the 3D angular displacements and axes of rotation of the ten first rib pairs relative to the vertebrae in 12 humans in supine position. The main objectives of this study were: 1) to quantify CVJ 3D kinematics at CVJ 1 to 10 as function of lung volume; 2) to test the correlation with functional respiratory measurements and anthropometrical characteristics; 3) to test the influence of laterality, CVJ level and lung volume on CVJ 3D kinematics parameters.

2. Methods

2.1. Computed tomography data

Retrospective codified CT datasets were obtained from the Department of Radiology of the Erasme Academic Hospital. Spiral computed tomography (Siemens SOMATOM, helical mode, slice thickness = 0.5 mm, inter-slice spacing = 1 mm, image data format: DICOM 3.0) was performed in asymptomatic volunteers at three different lung volumes. Lung volumes were previously obtained during pulmonary functional tests and available for this study. CT images were sequentially performed at total lung capacity (i.e, TLC pose), middle inspiratory capacity (MIC pose) corresponding to FRC + 50% of inspiratory capacity (IC) and functional residual capacity (FRC pose), (Cassart et al., 1997; Gauthier et al., 1994; Pettiaux et al., 1997). In order to control the lung capacity adopted during the CT sequences, patients were connected to a spirometer and instructed to hold their breath against a closed airway at each expected lung volume. The protocol was approved by the Erasme Hospital Ethics Committee (P2005/021). Just prior to CT data collection, subjects were allowed to perform a few rehearsal trials to get acquainted with the breathing procedure (Cassart et al., 1997; Pettiaux et al., 1997). A sample of 12 datasets from asymptomatic adults (mean age 31 ± 6 years old) was obtained. Details of anthropometric and pulmonary characteristics of the subjects are given in Table 1.

Table 1
Anthropometric and functional characteristics of the subjects. Values are means ± SD. All lung volumes were measured seated during functional pulmonary tests.

Age, yr	30 ± 6
Sex, M/F	6/6
Height, cm	171 ± 8
Weight, kg	63 ± 13
TLC, l	6,25 ± 1,1
MIC, l	4,86 ± 0,7
FRC, l	3,44 ± 0,43
RV, l	1,67 ± 0,37
IC, l	2,82 ± 0,87

2.2. 3D-data extraction and kinematics computation

The entire procedure allowing to obtain 3D models and to compute costovertebral joint (CVJ) kinematics for the true ribs (n°1 to 7) has been previously described (Beyer et al., 2015, 2014). In the present study, this procedure was used and extended to lower CVJ levels (n°8 to 10) to describe the individual behaviour of all ribs