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An alternative thorax coordinate system for motion analysis in sitting postures, applicable to both sexes

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1. Introduction

For marker-based motion analysis, a coordinate system (CS), built-up from at least 3 reflective markers located on the skin, is associated with each body segment. Standardized marker positioning has been established by the International Society of Biomechanics (ISB) to facilitate clinical interpretation and enable result comparisons across different studies. For the thorax, the ISB's CS is constructed from 4 markers, located in front of the jugular notch (IJ), xiphoid process (PX), and spinous processes of the 7th cervical (C7) and 8th thoracic (T8) vertebrae (Wu et al. 2005) (Figure 1).

However, in women, the PX marker is located in the intermammary zone. Should the marker be stuck to the bra, as is often the case, the marker might be positioned at some distance from the skin. Additionally, the PX marker may be masked from the cameras by the breasts, particularly when the experiments are carried out in a sitting posture and/or in cases of thoracic kyphosis, which is common, for example, during prolonged sitting or in the elderly. Issues arising from the PX marker masking in such situations remain largely unexplored.

As the sternum is practically rigid and located directly under the skin (Guntz & Albaret, 1975), we hypothesized that a thorax CS identical to that of the ISB can be constructed by substituting PX with a pre-sternal marker located above the breast level. The aim of this work was to construct such a CS, using a regression that can be easily implemented in motion analysis toolboxes, then to assess its consistency with the ISB's thorax CS, in two static postures.

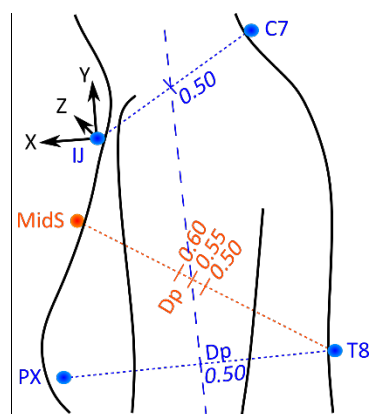


Figure 1. Construction of the ISB's and alternative thorax coordinate systems (CSs). IJ: jugular notch. PX: xiphoid process. MidS: pre-sternal marker substituting PX. C7, T8: spinous processes' markers. Dp: ISB's thoracic distal anteroposterior midpoint. In red: alternative construction of Dp. In blue: construction of the ISB's thorax CS. Black arrows: resulting thorax CSs.

2. Methods

2.1 Data acquisition

Twenty-two healthy participants (14 females (F), 8 males (M), 23.6 ± 4.4 years, BMI 21.8 ± 1.6 kg/m²) were involved in the study after ethical endorsement (CPP, N°2020-A00573-36). They were pre-equipped with cutaneous markers including the IJ, PX, C7, T8 markers and, for 20 participants (12F, 8M), a pre-sternal marker (MidS) placed 2 finger-widths below IJ, i.e. 58 ± 6 mm or $31 \pm 3\%$ of the distance from IJ to PX. When the PX marker had to be positioned on the bra, the bra was firmly held against the skin. Participants were placed in 2 sitting postures, erect and slouched, as defined in Tomezzoli et al. (2024), in random order. The markers' positions were recorded using a VICON optoelectronic system. One frame was automatically selected from the static pose preceding various upper limb tasks that will be analyzed in a later study, totaling 11 marker coordinate datasets per participant and spinal posture.

2.2 Construction of the CSs

The ISB's thorax CS origin is located at IJ. The Y axis direction is defined by the line connecting the thoracic distal anteroposterior midpoint (Dp) between PX and T8, and its proximal anteroposterior midpoint between IJ and C7; Y points upwards (Figure 1). Z is perpendicular to the plane formed by IJ, C7, and Dp; it points to the right. The X axis is defined by the line perpendicular to both Z and Y axes, pointing forward (Wu et al. 2005). Three alternative thorax CSs were constructed by substituting PX with MidS in datasets where both markers were visible (Table 1), and by successively locating Dp at 50, 55 and 60% of the

distance from T8 to MidS (Figure 1), to assess them as possible regressions for CSs construction.

Table 1. Number (percentage) of datasets analysed.

	Erect posture	Slouched posture	TOTAL
Female	101 (76.5)	28 (21.2)	129 (48.9)
Male	88 (100.0)	78 (88.6)	166 (94.3)
TOTAL	189 (85.9)	106 (48.2)	295 (67.0)

2.3 Assessment of deviation between CS' orientation

The difference in 3D orientation between each alternative and the ISB's CSs was quantified using a single value, the helical axis angle (θ), computed as:

$$\theta = \cos^{-1} \left(\frac{\text{trace}(R_{Thoz}^T R_{Tho1}) - 1}{2} \right), \theta \in [0, \pi]$$

where R_{Thoz}^T and R_{Tho1} are respectively the rotation matrices of the alternative and ISB's CS in the global frame of the laboratory (Michaud et al. 2017).

As the origin of every CS is identical, i.e. IJ, and as all markers used are theoretically located in the sagittal plane of participants, θ was expected to approximate the angle α between the various CSs' Y axes in the sagittal plane of the ISB's CS. For this reason, θ has been assigned a sign, a positive sign meaning Y backward rotation in the sagittal plane relative to the ISB's CS. For the best alternative CS, θ was computed for female and male.

3. Results and discussion

The frequency of missing data in our study, >50% in the case of slouched posture and for women (Table 1), illustrates the issues encountered when using the ISB's thorax CS for motion analysis in seated postures. For the 1st, 2nd, and 3rd alternative versus ISB's CSs, the θ angle was $-5.7^\circ \pm 2.0^\circ$, $-1.3^\circ \pm 2.5^\circ$, and $3.8^\circ \pm 2.2^\circ$, respectively. The 2nd alternative CS, i.e. with Dp located at 55% of the T8-MidS distance, can be used as a simplified approximation of the ISB's CS. For more accurate construction of ISB's CS, MidS can be used as a technical marker recorded from a position where PX is visible. θ approximated α ($\alpha = -1.2^\circ \pm 2.1^\circ$) and was lower for men (F $-3.3^\circ \pm 1.8^\circ$, M $-0.9^\circ \pm 1.0^\circ$).

To ascertain the generalizability of the results, they should be confirmed on a wider population, more diversified in terms of BMI and thoracic kyphosis. Similarly, the various CSs should be compared during different tasks, in both sitting and standing postures.

Finally, the repeatability of MidS's positioning might be improved by palpating a bony landmark rather than estimating its distance from IJ. The position of MidS as defined in our study is close to the medio-sternal joint, also known as the Louis angle (Guntz & Albaret, 1975), which could therefore be chosen for this purpose.

4. Conclusions

The cutaneous marker positioned in front of PX for motion analysis is often masked from cameras in seated postures, in case of thoracic kyphosis and for women. For motion analysis in sitting postures, the ISB's thorax CS should therefore be replaced by an alternative CS, constructed by substituting PX with a marker located higher on the sternum.

5. Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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