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Spartacus: an open dataset of normal shoulder girdle kinematics

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1. Introduction

Motion capture with sensors put on the skin is prone to soft tissue artefacts, *i.e.* the motion of the skin, fat, and muscles gliding on the underlying bone, limiting the accuracy of the collected data. On the other hand, intracortical pins, x-ray radiography, CT-scan, and MRI are recognised as gold standard methods for joint kinematics measurement. As latter methods often raise ethical and experimental challenges, extensive data collection is limited, and few studies have been reported in the literature. Nonetheless, there have been some noteworthy studies over the years that provided highly valuable data by reporting gold standard shoulder girdle joint kinematics. But to date, their inventory remains unavailable.

The information provided by these studies is often partial, stemming from their limitations in the joints and degrees-of-freedom (DoF) examined or reported, the variety of motor tasks, and the sample size. Their synthesis can thus fill these gaps and provide a comprehensive dataset of reference shoulder girdle

kinematics. When seeking to synthesise existing data, a uniform convention must be shared across measurements to allow their comparison and merging. By defining a comprehensive framework for all shoulder girdle joints with the description of bone coordinate systems (BCS) and appropriate sequences of Euler angles for joint kinematics analysis, the recommendations of the International Society of Biomechanics (ISB) (Wu et al. 2005) have been a reference for two decades. Nevertheless, protocol specificities may lead to deviations from such a standard or even the use of another approach. This is particularly true when using medical imaging methods, often restrained to a limited volume of interest.

To fill these gaps, the objectives of this study were 1) to perform a systematic literature search of datasets reporting reference joint kinematics of the scapula girdle obtained using gold standard methods and 2) to gather them in a common dataset through a rigorous methodology. Combining datasets opens new avenues for more complete overviews of the shoulder girdle kinematics. First, this allows us to further document the 24 DoFs of the shoulder girdle (4 joints x 6 DoFs per joint) during various standardised arm motions. Second, this should minimise experimental bias as original datasets are sourced from *ex vivo* or *in vivo* experiments with different measuring techniques and kinematic processing. Third, this may facilitate study comparisons by providing a unified convention for kinematics re-processing.

2. Methods

2.1 Collecting original data

Original sources were identified in the current literature (until December 2023) through an extensive search in the Embase, Medline, Scopus, PubMed, and Web of Science databases. Inclusion criteria were 1) to report kinematic data related to at least one rotational or translational DoF, 2) obtained *in vivo* from an asymptomatic population or *ex vivo* from deceased donors with no known history of trauma, fractures, or dislocations, and no abnormalities of the shoulder joint, 3) using a gold standard measurement method (protocols using bone pins or imaging), 4) during at least one standardised arm motion, and 5) expressed as continuous variables using time-series that were 6) expressed as a function of the motion-related thoracohumeral angle. Time-series expressed as a function of a glenohumeral angle were excluded.

2.2 Transformation into ISB standards

Seven types of deviation from ISB standards were defined. The first four are related to the BCS construction (*i.e.* origin, axis label, sense, and direction). The last three are related to the computation of joint kinematic time-series (*i.e.* Euler sequence, coordinate system used to express translations,

thoracohumeral angle measurement). Both proximal and distal BCS were, when possible, corrected.

2.3 Evaluation of datasets

Original dataset compliance with ISB standards was assessed. For each deviation, a score was given for both rotations and translations. These values were arbitrarily set to differentiate data states: no difference (1, when ISB standards are applied), high compliance (0.95) and low compliance (0.80) levels. For each joint, a compliance level was then computed as the product of each related deviation, ranging from 0 (very low compliance) to 1 (full compliance).

3. Results and discussion

3.1 Original data

The search strategy allowed us to identify 20 datasets related to 30 original sources. Overall, datasets have been published regularly, in a linear fashion, over the last two decades. The experiments were conducted primarily in *in vivo* (75%) and secondarily in *ex vivo* (25%) conditions on 12 ± 7 shoulders (min: 1, max: 35). Bone kinematics was primarily obtained using intracortical pins (55%), followed by single-plane x-ray fluoroscopy (25%), biplane x-ray fluoroscopy (10%), MRI (5%), and 4DCT (5%) during active dynamic movements (65%), passive dynamic movements (30%), or active quasi-static (5%) movements. Related standardised arm motions were elevation in the scapular plane (70%), frontal plane (50%), or sagittal plane (50%), internal-external rotation at 0° (20%) or 90° (20%) of frontal elevation, and horizontal flexion (15%).

3.2 Compliance with ISB standards

While 85% of the included datasets are related to original sources published after the ISB recommendations for upper limb segment and joint coordinate systems (i.e. after 2005), several deviations from ISB standards were observed.

Concerning BCS construction, ISB standards were fully respected in only 40% of cases for the thorax, 22% for the clavicle, 35% for the scapula, and 44% for the humerus. In some cases, the deviations were cumulative, leading to a greater gap from ISB standards. Hence, up to 4 deviations were observed for the thorax (in 40% of cases), clavicle (22%), and scapula (35%), against 2 deviations for the humerus (11%). Concerning the computation of joint angle and translation time-series, ISB standards were fully respected in only 40% of cases of the sternoclavicular joint, 38% for the acromioclavicular joint, 47% for the scapulothoracic joint, and 24% for the glenohumeral joint. Median dataset compliance appeared to be high ($c > 0.80$) in 30% of datasets, moderate ($0.40 < c \leq 0.80$) in 45% of datasets, and low ($c \leq 0.40$) in 25% of datasets. Highest compliances (median)

were obtained for the sternoclavicular translations and the lowest compliances were obtained for the glenohumeral rotations.

3.3 Spartacus open dataset

Original datasets were gathered in a dataset called Spartacus. To allow comparison, all joint angles and translations were computed following ISB standards and expressed as a function of the motion-related thoracohumeral angle. ISB sign conventions were applied. The Spartacus dataset is open sourced on GitHub and: (1) time-series are dynamically visualisable through HTML files, (2) a code will be provided to add any new time series, (3) and the repository will be so that it can be expanded over time.

4. Conclusions

The Spartacus dataset stands as a milestone in advancing our understanding of normal shoulder girdle kinematics. We meticulously compiled a collection of original articles, employing gold standard measurement techniques. The resulting dataset offers an unprecedented update and expansion of the field's knowledge base. It is also proposed as foundational tool for future studies, enabling the comparison of new and existing data, while serving as a continually evolving open-source resource. The authors assert that the Spartacus dataset will be instrumental in substantially enhancing both the quality and the consistency of future research in shoulder girdle kinematics.

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