COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 121 (2015) 36–48

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

A new method for the automatic identification of the dimensional features of vertebrae

*L. Di Angelo, P. Di Stefano**

Department of Industrial and Information Engineering, and of Economics, L'Aquila, Italy

ARTICLE INFO

Article history:
Received 30 December 2014
Received in revised form
24 March 2015
Accepted 9 April 2015

Keywords:
Vertebral dimensions
3D medical-image analysis
Computer methods for vertebra analysis
Shape segmentation
Measurement protocols in biomedicine
Measurement accuracy

ABSTRACT

In this paper a new automatic approach to determine the accurate measure of human vertebrae is proposed. The aim is to speed up the measurement process and to reduce the uncertainties that typically affect the measurement carried out by traditional approaches. The proposed method uses a 3D model of the vertebra obtained from CT-scans or 3D scanning, from which some characteristic dimensions are detected. For this purpose, specific rules to identify morphological features, from which to detect dimensional features unambiguously and accurately, are put forward and implemented in original software. The automatic method which is here proposed is verified by analysing real vertebrae and is then compared with the state-of-the-art methods for vertebra measurement.

1. Introduction and related works

The human vertebrae are solid morphologically-complex objects whose raison d'être is to house and protect the spinal cord and its nerve and muscle roots, as well as to support the body. These geometric and dimensional parameters of the vertebrae are usually analysed to gather some evidence which may be useful in medicine and in anthropological and forensic investigations.

In Section 2, the most significant dimensional features used in the related literature are presented. Some of the lines of investigation described in the literature concerning anthropology, wherein human vertebrae measurement is dealt with are: body mass estimation [14]; identification of the height, posture and locomotion mode of a subject [14]; gender, age and ethnicity of the subject ([8] and [15]). In medicine, vertebral measurement is performed so as to identify in vivo subjects the correlation existing between the vertebral dimensions and women's menopausal phase [4]. In all the previously described applications, measures are required to be accurate enough to discriminate the factor being investigated.

The measurements on real vertebrae are commonly performed with a sliding caliper and a goniometer. However, in the last few years, the Coordinate Measure Machines (CMM) are being widely used too. When the vertebra is available in the form of a 3D geometric model (as it is the case of CT-scans) its measurement can be performed by a specific software application.

* *Corresponding author*. Tel.: +39 0862434314; fax: +39 08624333613.
E-mail address: paolo.distefano@univaq.it (P. Di Stefano).

http://dx.doi.org/10.1016/j.cmpb.2015.04.003
0169-2607/

The concept of dimensional measure requires that some geometric features should be associated with the real object, and used as a reference, whose position is compared with a known size (the distance between the arms of the caliper). The identification of the geometric feature which is useful to perform the measurement of human vertebrae, and in general of any biological object, is made by the operator, but not without uncertainties and some arbitrariness. In order to make up for the lack of reliable measuring references, a protocol, as rigorous as possible, is required to conduct any measurements; the operator interprets the protocol and measures the dimensional parameters by identifying the morphological features associated with the measuring parameters. This measurement process is tedious and time-consuming, though, and the quality of its results depends on the training and experience of the operator. Moreover, it is important to highlight that, even in the case of highly qualified operators, the wide measuring variability inevitably implies a lack of objectivity in measurement estimation.

In Section 3, the typical measuring processes (CMM and sliding caliper) are experimentally characterized and their uncertainties identified.

In order to evaluate the measures of human vertebrae in a repeatable and reproducible way, the present study proposes a new method, which requires a 3D geometric model of the object (coming from CT-images or 3D scanning). The method is based on an algorithmic protocol implemented in original software devoted to the measurement of vertebrae. The method is verified and the results are compared with those obtained by traditional approaches.

2. Dimensional features of lumbar and thoracic vertebrae

The human vertebrae can be classified into three main categories: lumbar, dorsal and cervical. The lumbar and thoracic vertebrae have a similar morphology and the same dimensional features. Conversely, the cervical vertebrae have a different morphology and specific dimensional features. In this work, the lumbar and thoracic vertebrae are going to be considered. The most used dimensional features of the lumbar and thoracic vertebrae in anthropological and medical investigations are listed and described in Tables 1–3. They refer to the spinous process, the vertebral body and the vertebral canal [4,7,8,12,15], respectively.

3. Performance evaluation and experimental characterization of contact methods for measuring vertebrae

In order to characterize the methods which are mainly used to measure vertebrae, a set of eight vertebrae (five thoracic and three lumbar) have been used (Fig. 1). This set of vertebrae has been submitted to 20 medical students, in the fifth year of their medical course and onwards, trained appropriately, who have carried out the measurements listed in Tables 1–3. The testers have also been presented with the measuring protocols, which have been rigorously defined. Let us consider, then, that the

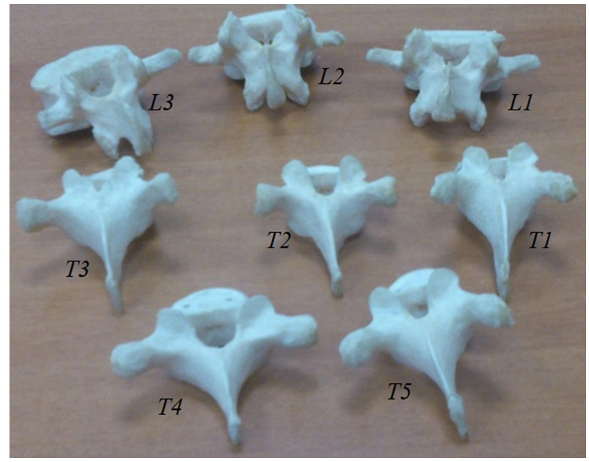

Fig. 1 – The eight real vertebrae measured with their corresponding labels.

intra-tester repeatability and the *inter-tester reproducibility* of two measurement procedures have been examined and that the measurements with sliding caliper (Fig. 2a) and those with CMM (Fig. 2b) have been made according to the rules reported in Tables 1–3. The measurements with CMM are carried out by the 7-axis Faro Edge contact measurement system with 3-mm zirconia ball i-probe (Faro Company, USA, accuracy of 0.029 mm).

As regards the task been assigned, each tester has repeated the same measurement six times under repeatability experimental conditions. Nonetheless, all the testers have been blinded to the results of the measurements.

Each set of measures has been subjected to the Kolmogorov–Smirnov test so as to check whether the data is normally distributed. In this case, the P values recorded are higher than 0.05, which indicates a normal distribution of all variables.

Intra-tester repeatability, on the one hand, is examined on 12 ($j = 1$–12) dimensional features measured on eight different vertebrae (lumbar and thoracic) ($k = 1$–8). *Intra-tester repeatability* is evaluated as the mean value ($\bar{\sigma}^A_{j,k}$) of the standard deviation of the 20 measured values for the same dimensional feature D_j of a vertebra V_k. Those measurements have been taken within short intervals of time by the same tester, and, in this case, by means of both the sliding caliper and the CMM. The results are reported in Tables 4 and 5, respectively.

It can be observed that intra-tester repeatability seems to be insensitive to the specific vertebra being measured. In fact, $\bar{\sigma}^A_{j,k}$ changes little between the same dimensional features D_i measured on different vertebrae, with few exceptional cases. However, high values of repeatability can be detected in the measure features of the spinous process with respect to the other dimensional features. This is mainly due to the objective difficulties found when it comes to performing the measurement of the spinous process length and the *spa* angle, which is measured by sighting from the spinous process to the superior border by means of a goniometer. This, in turn, entails subjectivity in the application of the measuring protocol, which is also evidenced by high values of intra-tester reproducibility.