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Introduction

Spine and posture problems are topics of great interest in both biomechanical research and clinical fields. The development of eidoogy, i.e. of image-processing based diagnostic technologies like digital X-Ray, CAT Scan, MRI, has determined a real improvement in obtaining an ever increasing anatomical delineation of the involved structures in the evaluation of spine related pathologies. Unluckily, except for dynamic X-Ray, no one of these techniques is able to provide information about the functional state of the rachis and the related patient posture. In this case, optoelectronic measurement approach can be very useful to complete the necessary functional information, but its use in clinical environment requires the following three specific necessities to be satisfied: 1) To develop a detailed skeleton model with particular focus on 3D spine morphology, but at the same time keeping as low as possible the number of body landmarks to be used; 2) To extract as many as possible parameters of clinical significance strictly related to anatomical and anthropometrical subject’s characteristics; 3) To represent them in an intuitive and clinical compliant fashion maintaining a biomechanical strictness but hiding the burden of complex mathematical approach. With these three goals in mind, our group started a project to transfer into a complete fully 3D reliable and detailed representation different segmental biomechanical models presented in literature. As result, a complete 3D parametric biomechanical human skeleton model has been developed. It has been conceived in a parametric form in order to be scaled according to each subject characteristics by fitting the 3D anthropometric sizes to opto-electronic measurements. Particular care and studies have been devoted to arrange the 3D human skeleton model parameterisation. The accuracy and precision of this model relies both on anatomical findings (cadaver dissections, in vivo and X-ray measurements, parametric regression equations [4,5,6]) reported in literature and on the approach and signal processing procedures we largely described [1,2]. Given the extraordinary growth of both hardware and software tools, this highly sophisticated computing demanding task can be approached even on relatively low cost powerful PC workstations. This model is currently used as clinical tool for diagnostic and therapeutic purposes in different clinical centres. Several hundreds of patients have been already analysed and followed up with this methodology that proved to be useful for various posture and spine related pathologies (in particular scoliosis, low-back pain etc.).

Methods

A non-ionising approach based on 3D opto-electronic measurements of body landmarks labelled by passive markers has been chosen to build the 3D parametric biomechanical skeleton model. The developed model can work at different stages of complexity. That is, depending on different analysis purposes and necessities, the parametric scaling can be detailed with several accurate anthropometric measurements and the dimensions of each skeleton component are estimated and fitted to match the subject’s skeleton. To this aim various protocols involving different body labelling have been established for different analyses. To analyse human posture and spinal related pathologies, a 27 markers protocol has been set and tested extensively in clinical environment [1,2,3]. The following anatomical repere points are identified: zygomatic bones, mentum, acromions, sterno-clavicular joints, xyphoid, ASIS, PSIS, knee joints, heels and spinous processes from C7 down to S3 every second vertebra. A special focus has been devoted to identify and model the spine, given the 11 spinous
processes and 2 PSIS markers 3D measurements, with a correct degree of accuracy and reliability. Indirect measurements such as joint centres positions are derived from external markers (for instance, hip joints centres are derived from ASIS and PSIS positions and related pelvis dimension, model and regression function [5,6]). Our experimental recordings are based on the AUSCAN opto-electronic system); anyway this methodology is a very general one and it can be indifferently applied to any stereo-photogrammetric recording system.

Figs.: 1a) Instrumentation and Acquisition set-up; 1b) Passive markers positioning.

In such a way 3D posture taking into account head, trunk, pelvis and legs postural disposition (upper limbs and ribs are not considered), as well as 3D spine shape at each metameric level can be represented. Also pelvis orientation and scaling and eventual helicoidal deformation can be evaluated from ASIS and PSIS positions. The standard trial session is aimed to completely define subject posture both in orthostatic and in simple dynamic conditions. Each static postural attitude is considered correctly recorded when at least 5, one second lasting, acquisitions are performed. Given the 100Hz opto-electronic device data acquisition rate, this means that a minimum of 500 measurements are averaged per each static postural attitude [1,2,3]. Before averaging, an amount of pre-processing is needed on the acquired 3D raw data in order to comply clinical analysis requirements. Namely, the frontal plane of the subject is chosen, in each frame, as the plane containing the PSIS and parallel to the vertical axis, while his sagittal plane is the one orthogonal to this latter and parallel to the vertical axis. For all the following computations (averaging, clinical parameters extraction both in static and dynamic conditions, etc.) the measurements are re-aligned in the so defined subject's local co-ordinate system. Our studies as well as our clinical experience led us to identify a set of static attitudes (such as indifferent orthostasis with and/or without an under-foot wedge, self-corrected manoeuvres, ante-retroversion static postural exercises, sitting posture), that can provide a complete documentation of subject postural, balancing and morphological characteristics.

**Results and Discussion**

From the 3D reconstruction all the 2D clinical parameters claimed for the correct description and biomechanical characterisation of spinal pathology, related to those usually calculated on the radiographic image, are derived (i.e. Cobb and Kypho-Lordotic angles). Moreover, a set of significant biomechanical variables describing the three-dimensional nature of body posture are obtained, such as frontal and sagittal spinal offsets of each marked metamere with respect to the vertical axis passing by S3, frontal and sagittal global offsets of each labelled landmark with respect to the vertical axis passing through the middle point between heels, pelvis frontal and sagittal inclinations, horizontal rotations among shoulders, pelvis and heels, and several more. This step is completely automatic and goes through the determination of the limit vertebrae limiting the various curves present, allowing in this way angles computing for both the frontal and sagittal planes (as defined before). In Scoliosis analysis, an automatic classification according to Moe is provided. Comparisons taking into account spine morphology have been performed between X-Ray films and opto-electronic processed outcomes to assess the clinical significance of the developed algorithms [7]. For the graphical representation as well as clinical parameter visualisation and enlightening, an MS-Windows software package based on 3D graphic modelling has been
developed. Figures 2 and 3 represent an example of clinical outcome also compared to X-Ray film evaluation. The easy clinical approach of this procedure suggests its use in routinely clinical evaluation for the study of Posture. Several hundreds of patients have been already analysed and followed up in different centres with this methodology that proved to be useful for various posture and spine related pathologies. The developed 3D human skeleton model and software package can be used as stable, accurate, reliable and fast tools for the quantitative identification of human body biomechanical characteristics, for the understanding of spine and posture related pathologies as well as a guideline to formulate a diagnosis and a therapy plan.

Fig. 2) 3D skeleton representation (frontal and sagittal view) compared to x-ray film.

Fig. 3) 3D skeleton representation (gait, lateral bendings, top view).

References