European Journal of Radiology 82 (2013) 2359–2364

Contents lists available at ScienceDirect

European Journal of Radiology

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

Three-dimensional reconstructions for asymptomatic and cerebral palsy children's lower limbs using a biplanar X-ray system: A feasibility study

Ayman Assi[a,b,c,*], Yasmina Chaibi[a,1], Ana Presedo[a,d,2], Jean Dubousset[a,1], Ismat Ghanem[b,c,e,3], Wafa Skalli[a,1]

[a] Laboratoire de Biomécanique, Arts et Métiers ParisTech, Paris, France
[b] Laboratory of Biomechanics, Faculty of Medicine, University of Saint-Joseph, Beirut, Lebanon
[c] Gait and Motion Analysis Lab, SESOBEL, Beirut, Lebanon
[d] Hôpital Robert Debré, Paris, France
[e] Hôpital Hôtel Dieu de France, Beirut, Lebanon

ARTICLE INFO

Article history:
Received 18 December 2012
Received in revised form 4 July 2013
Accepted 8 July 2013

Keywords:
Biomechanics
Cerebral palsy
Children
Biplanar X-rays
Clinical 3D measurements
Lower limbs
EOS

ABSTRACT

The aim of this study is to explore the feasibility of 3D subject-specific skeletal reconstructions of lower limb in children using stereoradiography, and to assess uncertainty of clinical and anatomical parameters for children with cerebral palsy and for healthy children. The stereoradiography technique, using the EOS® system (Eos-imaging®), is based on the acquisition of two simultaneous digital anteroposterior and lateral X-rays, from head to feet in standing position and at low radiation dose. This technique allows subject-specific skeletal 3D reconstructions. Five children with cerebral palsy (CP) and 5 typically developing children (TD) were included in the study. Two operators performed the lower limb reconstructions twice. Tridimensional reconstructions were feasible for children over the age of 5 years. The study of reproducibility of anatomical parameters defining skeletal alignment showed uncertainties under 3° for the neck shaft angle, the femoral mechanical angle, and for the femoral and tibial torsions. The maximum degree of uncertainty was obtained for the femoral tibial rotation (4° for healthy children and 3.5° for children with CP).

1. Introduction

Cerebral Palsy (CP) results from a non progressive lesion in the immature brain affecting 4/1000 of newborns. This lesion can cause abnormalities of posture, balance, muscle strength and tone (spasticity), leading to the development of muscular contractures and bone deformities. The decision-making for treatment is based on several data: patient's medical history, physical examination, imaging techniques, gait analysis, and physical examination under general anesthesia [1]. The reliability of the decision-making process will depend on consistency of the information generated from these data.

The skeletal alignment evolves with growth and may result in progressive torsional and angular deformities. The most common anatomical deviation within one bone segment appears in the transverse plane leading to lever arm and architectural deformities in the femur (femoral torsion and femoral anteversion) and the tibia (external or internal torsion) [2–5]. The impact of skeletal deformities on gait has been described [1]; however, quantitative assessment of 3D skeletal deviations is not performed on a regular basis because it may involve high doses of radiation.

Conventional 2D X-ray imaging is commonly used for lower limb frontal and sagittal plane deviations diagnosis and follow-up. Full-length anteroposterior radiograph of the lower limbs (teleoroentgenogram and orthoradiograph) or the combination of three separate radiographs centered on the hip, knee and ankle (scanogram) [6,7] are used to evaluate leg length discrepancies. However, the measurements based on bidimensional images are subject to errors when frontal plan deviations are combined to

* Corresponding author at: Laboratory of Biomechanics, Faculty of Medicine-PTS, Campus of Innovation and Sports CIS, University of Saint-Joseph, Damascus Street, Beirut, Lebanon. Tel.: +961 1421676, +961 3564557.
E-mail addresses: ayman.assi@gmail.com, ayman.assi@usj.edu.lb (A. Assi), yasmina.chaibi@gmail.com (Y. Chaibi), a.presedo@gmail.com (A. Presedo), jean.dubousset@wanadoo.fr (J. Dubousset), ghanem.i@dm.net.lb (I. Ghanem), wafa.skalli@ensam.eu (W. Skalli).
[1] Laboratoire de Biomécanique, Arts et Métiers ParisTech, 151 Boulevard de l'Hôpital, 75013 Paris, France. Tel.: +33 144246364.
[2] Robert Debré Hospital, 48 Boulevard Serrurier, 75019 Paris, France. Tel.: +33 671189430.
[3] Hôtel Dieu de France Hospital, Alfred Naccache Avenue, Achrafieh, Beirut, Lebanon. Tel.: +961 3394442.

0720-048X/$ – see front matter
http://dx.doi.org/10.1016/j.ejrad.2013.07.006

transverse or sagittal plan deformities. CT-Scan is used to analyze transverse plan deviations [8,9]. However, due to the amount of radiation this technique emits, it is mostly used for surgical planning in adults. Other techniques (ultrasound, MRI) have been used in order to overcome the effect of radiation. Technical aspects related to image acquisition and measuring methods make these techniques unsuitable for clinical use. Also, none of the previously described methods obtain the measurements in an upright position.

Several authors reported the uncertainties of anatomical skeletal parameters assessment depending on the calculation technique. For example, femoral anteversion calculated by clinical examination has an uncertainty level of 4–9° when compared to the peroperative method and the radiological method (Magilligan's technique) [10]. CT-Scan uncertainty on femoral anteversion could reach 3.6° [8,10]. For tibial torsion, uncertainty ranged from 5 to 10°, when two frontal X-rays one for the tibial plateaus and one for the malleoli, are overlaid [11–13]. These uncertainties are mostly related to the bias induced by the 3D orientation of the bone when horizontal slices are considered to calculate torsional deformities, even if image summation techniques are used [14].

More recently, methods for accurate 3D subject-specific reconstructions of the lower limbs in standing position have been developed, using one frontal and one lateral X-ray in a calibrated environment [15]. Specific algorithms, based on parametrical models and statistical inferences for the spine [16], the pelvis [17] and lower limbs [18] are used and aim to avoid tedious digitalism processes which are required to get a morpho-realistic 3D reconstruction. Accuracy of these reconstructions was evaluated regarding the scanner [18,19].

These methods of reconstructions were implemented in a novel imager, the EOS® system (Eos-imaging®) which allows to simultaneously take two perpendicular X-rays from head to feet with a low radiation dose [20]. Such method of 3D subject-specific reconstructions opens new perspectives for investigation of children with CP when torsions and malalignments are present. A previous paper studied the reliability of clinical parameters in children and adolescents using the EOS® system [19]. The minimum age of children included in this previous study was 11 years and the reliability of clinical parameters did not include any torsional or rotational parameter.

The aims of this study were 1/to explore the feasibility of 3D subject-specific skeletal reconstructions of the lower limbs for children older than 5 years using the stereoradiography technique, and 2/to assess reproducibility of clinical parameters, including parameters in the transverse plane, for children with cerebral palsy and typically developing children.

2. Materials and methods

2.1. Population

Two groups of children were considered. The first group consisted of 5 typically developing (TD) children (aged 5–15 years; average 9.4) referred as the control group. These children had the stereoradiography exam done as a control X-ray for atypical pain in the back and the lower limbs. An EOS® exam was prescribed for these children because of its advantages in taking a head to feet radiograph with low dose radiation (8–10 times less than the conventional X-rays). The advantage of scanning the patient from head to toe is to eliminate spinal problems correlated to the lower back pain and to have a better view of the frontal and sagittal balance of the patient. Children with no abnormal findings on their radiographs were included in the control group.

The second group consisted of 5 children with spastic diplegia (aged 4–13, average 12.8) will be referred as the CP (Cerebral Palsy) group. All children in this group were scheduled to receive surgical treatment on their lower limbs and the stereoradiography exam was performed as part of their pre operative work-up. The institutional review board of Pitié-Salpêtrière approved the study design. Parents had signed a written consent.

2.2. Acquisition protocol

Digital X-rays from head to feet in frontal and sagittal views were performed using the EOS® system. Acquisition time was 10 s. Two acquisitions were performed. For the first one, the child was asked to be in a neutral standing position. For the second acquisition, subjects were asked to shift forward one limb to avoid knee overlapping on the sagittal plane [18]. Children from the control group were in a free standing position, with hands on cheeks and flexed elbows, without interfering with the sagittal contour of the spine. Children with CP were allowed to hold on their hands on the EOS cabin wall to avoid balance disorders during X-ray acquisition.

2.3. Reconstruction method

A specific software (SterEOS®) was used, based on the method described by Chaibi et al. [18]. The user is instructed to digitalize a few geometrical primitives (3 circles for the femoral head and the 2 condyles) and 3 axes (2 for the femur and 1 for the tibia). A simplified personalized parametrical model (SPPM) is obtained. Then a 3D morpho-realistic parametric model based on CT-Scan reconstructions is deformed by either changing the value of descriptive parameters or the control points according to the SPPM [18] (Fig. 1). This deformation is based on statistical inferences and the moving least squares method [21]. The initial model was projected on both X-rays and manual adjustments were performed to improve coherence between projections and X-rays of bone outlines. The reconstruction time of both lower limbs for one subject was about 15 min.

2.4. Clinical parameters

The measured parameters were chosen on the basis of their clinical importance in the diagnosis and decision making for children with CP. These architectural parameters were calculated directly on the 3D reconstructions: mechanical, anatomical and geometrical axes were computed on 3D bones (Fig. 1). Angles and distances were calculated in 3D and have not been projected on any plane. These parameters are automatically computed in SterEOS® (Table 1).

2.5. Statistics

Three operators performed the reconstructions twice for the two groups of subjects at one week interval in order to study the degree of agreement of the clinical parameters. All operators were trained on the 3D reconstructions software.

The Shapiro–Wilk test was applied to evaluate the normality of distributions. The reproducibility was evaluated for each parameter. Six values (3 operators, 2 reconstructions each) were calculated for each parameter for 20 limbs (left and right sides for 10 subjects). The Confidence Interval at 95% was calculated for each parameter using the method of Gluer et al., [22]. The Intraclass Correlation