Introduction
The pelvis is considered more and more as a part of the spine, the pelvic vertebra. The role of this bone is essential in the balance of the spine, either healthy or pathologic. Hence the importance of the 3D reconstruction of the pelvis in diagnosis when dealing with 3D pathologies. The existing 3D reconstruction techniques use either the CT scan, too irritating for the patient, or the stereo-radiography. The stereo-radiographic reconstruction techniques are based on the DLT (Direct Linear Transformation) and/or NSCP (Non Stereo Corresponding Points) [Mitton et al., 2000]. Kriging algorithms are used for a more detailed modeling of bony structures.
Existing studies on this topic only indicate the accuracy of 3D reconstructions of a limited set of anatomical landmarks, but do not deal with a global 3D geometrical modeling of the complete pelvis [Gauvin et al. 1998]. A previous paper by the authors presented a feasibility and validation study on the global 3D geometrical modeling of the pelvis using NSCP (Non Stereo Corresponding Points) and kriging algorithms, but the accuracy of these models could still be improved (mean error 3.9 mm) [Mitulescu et al., 2000].
The purpose of this study is to re-evaluate the accuracy of 3D personalized geometrical models of pelvises issued from the NSCP stereo-radiographic 3D reconstruction technique, after basic optimization of several factors involved in the reconstruction and modeling procedure.

Materials and methods
6 dry non pathologic pelvises were considered, in order to verify the accuracy of the 3D models obtained by NSCP & kriging: 3 male and 3 female pelvises, from 71 and 82 years old subjects, provided by Anatomy Laboratory of the Faculty of Tours, France.
For each pelvis, direct measurements of 193 anatomical landmarks were available, previously recorded by means of an electromagnetic device (Fastrak®: accuracy ±0.2 mm). A 3D geometrical model was built for each pelvis using the 3D location of the 193 anatomical landmarks to define basic surfaces (figure 1).
Front and lateral X rays were obtained for each pelvis in a calibrated environment. A set of about 20 to 40 anatomical landmarks per pelvis were digitized on the X ray films and reconstructed by NSCP, then a kriging technique allowed us to obtain 193 points per pelvis, corresponding to those previously measured by Fastrak®.
Similar meshes containing the set of 193 points were obtained from the NSCP & kriging reconstruction. The complete protocols have already been described by the authors elsewhere [Mitulescu et al., 2000].

After initial digitizing and reconstruction of the anatomical landmarks from stereo X rays, a retro-projection procedure was employed in order to verify the accuracy of the landmark identification on the X rays. The software used for this step has been developed by our team. It allowed to modify the location of the 2D projections of each point directly on the X ray images in order to make them better respect the bone contours.
The NSCP and kriging steps require the use of a generic object. For the present study, we employed the same generic object as previously described by Mitulescu [Mitulescu et al., 2000] that we adapted for each pelvis with
regard to the sex and global size. The size was adjusted by homothetic transformation in order to be as close as possible to the size of each pelvis. As for the sex, two generic objects were obtained by calculating the average geometry of the three female pelvises and the three male ones respectively.

For each pelvis of our sample, the 3D geometrical model obtained from stereo-radiography after the modifications mentioned above was compared to the corresponding reference model obtained from direct measurements. The comparison consisted in superimposing the two models and calculating the point to surface distance [Mitton et al., 2000, Mitulescu et al., 2001] between each point obtained from stereo-radiography and the surface of the reference model. We calculated the mean errors, the 2RMS and the maximum errors for the whole set of 193 points per pelvis.

We also compared 5 significant morphometric parameters per pelvis (pelvic thickness, Velpeau diameter, sacro-cotyloidian distance, pelvic ring circumference, pelvic height) calculated from the 3D models obtained by NSCP & kriging and from the direct measurements.

Results
The point to surface comparisons between the 3D geometrical models obtained by NSCP & kriging (after control of the retro-projection errors and modification of the generic object with regard to sex and size) and the reference models yielded respectively mean/RMS errors of 2.8/3.7 mm for all 658 points (6 pelvises). Local maxima for 95% of points are less than 2RMS (7.4 mm) while the 5% remaining maximum errors were found lower than 13.5 mm. For the 5 linear parameters, we obtained mean errors inferior to 5% (7.5 mm), with maximum errors less than 9% (10.5 mm).

We also proceeded to a qualitative evaluation of the models by visualization of the superimposed models (i.e. NSCP & kriging model vs. reference model) for each pelvis.

Discussion
This study presents a detailed 3D personalized geometrical models of the pelvis obtained from stereo X rays. The results obtained by Gauvin et al. showed 3D errors of 2.4±1.2 mm for 19 anatomical landmarks per pelvis.
reconstructed by modified DLT. The preliminary results of the geometrical modeling of the pelvis from stereo-radiography by NSCP & kriging, presented by Mitulescu et al. (2000), indicated mean point to surface errors of 3.9 mm, with local isolated maxima up to 26.1 mm, for the complete set of 193 points per pelvis.

The present study showed that basic optimization of certain factors influencing the reconstruction and modeling process could considerably improve the accuracy of the 3D geometrical models. Little modifications in our protocol resulted in an important increase of accuracy since both the mean and the maximum values of the point to surface distances diminished considerably (i.e. mean /max: 2.8 vs. 3.9 / 13.3 vs. 26.1). Because of the complexity of the pelvic shape, the accuracy obtained is promising and demonstrates the usefulness of the NSCP & kriging technique. Moreover, this study demonstrated the importance of sometimes neglected factors in the complex process of modeling.

Nevertheless, the accuracy of pelvic 3D geometrical models issued from stereo-radiography could still be improved by using contouring methods that would allow the operator to better identify the anatomical landmarks on the X ray images and also enable a semi-automatic extraction of main bone contours. Another possible improvement of the modeling procedure consists in modifying the reconstruction algorithms in order to reconstruct not only distinct anatomical landmarks but also complete contours. Indeed, given the curved shape of most pelvic contours, the identification of specific points situated on is hardly accurate and also time consuming. These further developments of this method are in progress, but the results of the present study already allow us to consider these geometric personalized models as useful tools for 3D clinical analyses of the pelvis as well as for the 3D finite element modeling of this structure.

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