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Image registration procedure used in intrasubject comparison of pelvic configuration

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Summary

The objective of the study was to prove magnetic resonance imaging as suitable instrument for exploring the nature and amplitude of displacements within the bony pelvis induced by asymmetrically altered pelvic floor muscle characteristics. Repeated MR imaging of 14 females was performed. Spatial coordinates of 23 pelvic landmarks were localized in each subject and registered by interactive and automatic procedures. Modalities of registration procedure were tested and compared by the precision of registration. The software tool was developed to perform registrations and data analyses including individual registration error evaluation. The automatic registration with vertebra L5 as reference has been found optimal. The study has demonstrated benefits associated with processing of MRI data in terms of high detection reliability of pelvic configuration. The precision of MRI data processing, tested in the study, may contribute to the enhanced accuracy of MRI data registration, easier data manipulation and analysis.

Introduction

Because of anatomical position of pelvic joints, kinematic analysis of the pelvis is difficult. Accurate and precise measurements typically require highly invasive techniques. There is a need for a practical, noninvasive and accurate measurement method that will allow researchers to evaluate pelvic alignment and/or motion accurately and reliably[1].

The present study aims to project universal image processing tool, which would enable to register effectively MRI data within individual subject. The relative configuration of pelvic bony segments affected by different conditions of attached pelvic floor muscles is detected.

Subject replaces various positions in the gantry tunnel and in its reference system, the image orientations of the same subject taken at different time intervals differ (irrespective to the applied intervention). Thus, to be able to compare the different images within one subject, it is essential to relocate or "fuse" the image sets onto each other by corresponding reference bodies = image registration[2].

The accuracy of registration process seems sensitive to factors, such as reference body disposition towards reference system orientation or towards other pelvic structures; behaviour of the reference body within the chain of pelvic structures; the number and localization quality of reference objects etc. Thus, five registration

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modalities were tested to find an optimal image registration procedure for intrasubject comparison of pelvic configuration.

Methods

Three sequential MRI-scannings of 14 female pelvises *in vivo* were performed with 1.5 T static body coil (Gyroscan ACS-NT, Philips Medizin System, Germany) in the coronal orientation and 3D TFE gradient sequence with supine subject. After the second MRI-scanning, reversible unilateral intervention was applied onto the area of pelvic floor muscles to alter their characteristics and to cause change in the relative configuration of pelvic segments via pelvic floor muscle attachments.

The localization process of 23 pelvic landmarks (Fig. 1a), performed by two examiners, was based on interactive visual identification of objects and so tested for acceptable intraobserver and interobserver reliability.

To facilitate effective processing of data registration and large data volume, we designed MRI-based processing tool MPT2006. The programme involves automatic process interfacing of image registration, individual error computation, data analysis and spatial data visualization (Fig. 1b).

We tested five registration modalities, as combinations of factors possibly influencing reliability of image registration:

- interactive algorithm, guided by user, employed standard instruments of CAD system for spatial modelling;
- automatic algorithm, point-based rigid-body registration[2], traced optimal transformation parameters by minimizing the sum of relative residual distance squares between the corresponding reference object pairs within the reference bodies;
- type of reference body: vertebra L5; sacrum; combination of vertebra L5 and sacrum;
- number of reference objects defining selected reference body: 3; 5; 8.

The registration testing used the entire sample data without applied intervention. Mean sum square of residual distances within the reference bodies was the criterion 1. The mean effect of matching inaccuracy on position of observed target objects was criterion 2. The lowest score was guarantee of the most optimal registration procedure and decided, which registration modality was used in data processing.

Even minimal proportion inaccuracies of the corresponding reference bodies, originating in erroneous localization, caused “virtual” displacement of target objects = registration error. Because expected changes in pelvic configuration were in millimeter rank, we were forced to allocate registration error for each subject, each object and each direction individually (Fig. 1c, d). We based registration error

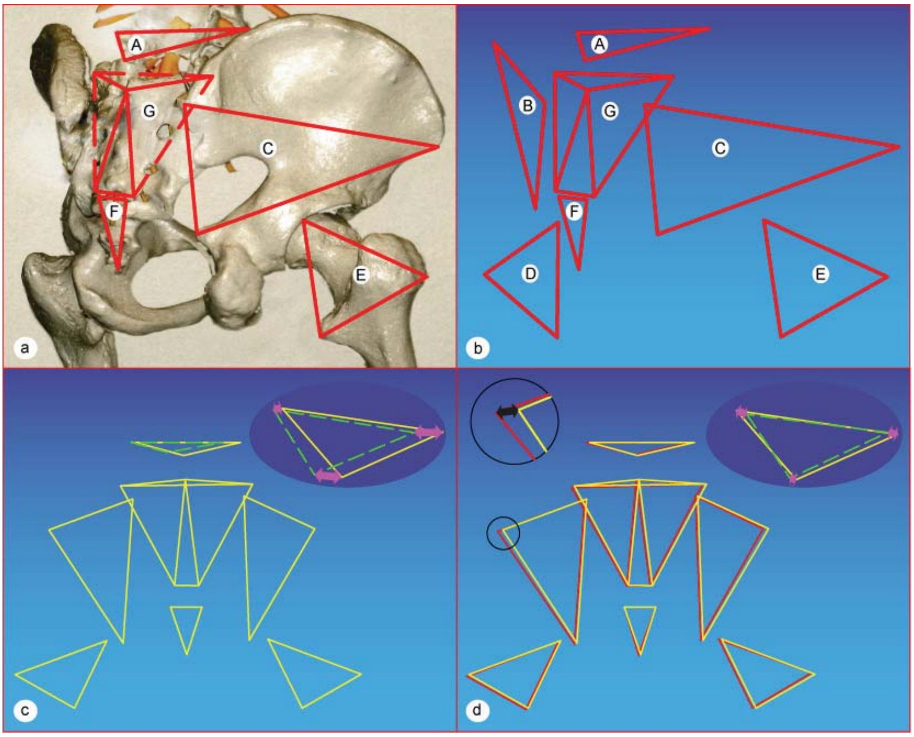

Figure 1: a) Localized anatomical landmarks (A vertebra L5; B, C pelvic bones; D, E femoral heads; F coccyx; E sacrum). b) Spatial data visualization. c) Existing matching inaccuracy of the corresponding reference bodies (detail). d) Registration error determination. The original target objects (yellow line); repositioned target objects (red line); residual distances (detail); individual registration error (in circle).

determination on existing matching inaccuracy of the corresponding reference bodies. The original target objects were then repositioned into a position indicated by the extent and the direction of residual distances after reference body matching. Individual registration error was resulting spatial distance between the original target object and the repositioned original target object. We utilized calculation formula into functions of MPT2006.

Results

The ability of the examiner to localize the same object in different subjects[1] or to localize different objects in the same subject[2] demonstrated high level of reproducibility ($IraCC^1 = 0.9968$; $IraCC^2 = 0.9999$; $P < 0.01$). Localization agreement between two examiners also appeared to be high ($IerCC = 0.9973$; $P < 0.01$). The average localization error was 1.23 mm (SD 0.14).

Results of registration modality testing are shown in table 1 and 2. The registration modality, characterized by vertebra L5 reference body and by rigid-body point-based registration algorithm, appeared to be most accurate. Surprisingly, interactive registration with L5 vertebra as reference body was the second most accurate although influenced subjectively.

Table 1: Registration modality testing, criterion 1 (L5 – vertebra L5; S – sacrum; (x) – number of reference objects).

Algorithm	Interactive		Computational		
Reference body	L5(3)	S(3)	L5(3)	S(5)	L5(3)+S(5)
Average residuum (n = 28; mm)	0.69	1.51	0.31	4.06	4.71

Table 2: Registration modality testing, criterion 2.

Algorithm	Interactive		Computational		
Reference body	L5(3) (n=560)	S(3) (n=560)	L5(3) (n=560)	S(5) (n=504)	L5(3)+S(5) (n=420)
Average distance (mm)	4.87	7.13	4.81	3.88	3.50

Conclusions and discussion

The study has demonstrated benefits associated with processing of MRI data in terms of highly accurate image registration, provided by designed MPT2006. The convenience of processing tool is direct data analysis, automatic spatial visualization, accurate error calculation and outcome comparison with predefined parameters. The ability to adjust MPT2006 settings makes it universal in processing of any image data and may favour its application in clinical practice.

Interactive and automatic algorithms are suitable for image registration. Main advantage of interactive algorithm is instantaneous visual control. On the contrary, there is limited access to CAD packages and user has to rely on build-in features. Straightforward automatic algorithm offers individual parameter set-up adjusted according the needs. However, it requires knowledge of computer programming to add or change outcome variables.

Testing procedure showed the importance of the registered object position towards weighted centroid and principle axes of the reference body. When vertically oriented sacrum was used as reference body, the largest registration deviations appeared in the ventro-dorsal direction. The sacrum did not prove to be an optimal reference body also due to high level of position dependency on both innominates. The horizontally oriented L5 vertebra, with low level of dependency on the other pelvic structures, proved as optimal reference body in image registration within pelvic region.

West et al.[3] proposed registration error lower than 1 mm as high registration accuracy. Fitzpatrick et al.[4] suggested a method of registration error estimation based on estimation of localization inaccuracy within reference bodies, which would represent an average of 0.52 mm (SD 0.24) in our conditions. We applied error calculation based on existing matching inaccuracy of reference bodies, producing registration error for each target object individually. On average, the registration error was 0.57 mm (SD 0.38).

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