Rigid overlay of volume sonography and MR image data of the female pelvic floor using a fiducial based alignment—feasibility due to a case series

Janko F. Verhey\textsuperscript{a,\*}, Josef Wisser\textsuperscript{b}, Thomas Keller\textsuperscript{b}, Carl-Fredrik Westin\textsuperscript{c}, Ron Kikinis\textsuperscript{c}

\textsuperscript{a}Department of Medical Informatics, University of Goettingen, Robert-Koch-Str. 40, D-37075 Goettingen, Germany
\textsuperscript{b}Department of Obstetrics, University Hospital Zuerich, Zurich, Switzerland
\textsuperscript{c}Surgical Planning Laboratory, Department of Radiology, Brigham and Women’s Hospital Boston, Boston, MA, USA

Received 27 February 2004; accepted 26 October 2004

Abstract

The visual combination of different medical image acquisition techniques (modalities) can lead to new modalities with enhanced informative content. In this paper, we present an overlay technique of magnetic resonance (MR) and 3D US image data sets of the female anal canal (internal and external sphincter) as a base for a new diagnostic modality. It is a new field of the application of the overlay technique.

Three corresponding MR and US volume data sets from the female pelvic floor region were filtered using adaptive filtering techniques and overlayed (Z-registered rigidly) with a landmark based alignment method.

© 2005 Elsevier Ltd. All rights reserved.

Keywords: Overlay; Rigid registration; Magnetic resonance; 3D ultrasound; Female pelvic floor; Anal canal

1. Introduction and literature

As described in recent studies by one of the authors [1], advances in 3D sonographical imaging as well as in data acquisition techniques allow a sophisticated study of anal sphincter and levator ani muscle anatomy. Today’s common US examination techniques using a 7.5 MHz transducer allow a spatial resolution of up to 0.3 mm in each direction [2,3], whereas it is hard to find standard MR devices with resolutions below 0.5 mm in even a single direction. Nevertheless, MR is a well established 3D data acquisition technique, which leads to rigid non-deformed data sets in contrast to most sonographical data acquisition techniques. In spite of the higher quality and resolution especially, for soft tissue, the 3D ultrasound technique is limited by the penetration depth. So far 3D MR data sets have been used as gold standard to show the anatomy. Due to the better structural contrast of the displayed region spatial orientation is easier than in sonography. By using registration techniques this problem might be overcome, and it might lead to a change in the gold standard.

It is a clinical necessity to enhance the information contained in imaging for diagnostic and also therapeutic purposes. In the past, this lead to new imaging techniques which use the information of at least two modalities in order to maximize the benefit for the clinician [4]. Registered modalities support the clinician in diagnosis and treatment. In this context, the registration of MR and US is of special interest because sonography is a diagnostic technique which is easy to handle and it is more economic than the use of expensive MR devices [5]. To combine the best of the two worlds, we will show that it is possible to match 3D MR and ultrasound for the assessment of female pelvic floor morphology.

Registration techniques generally are divided in two classes: framed or frameless registration. Framed registration uses external frames like bony landmarks or manually placed external fiducial landmarks to match complementary data sets. In contrast, frameless fusion of soft tissue may use organ surfaces and vascular structures to superimpose image data sets [6]. As a method, registration
techniques are divided in two categories: rigid and non-rigid. Rigid registration techniques only use affine transformation for all points together like rotation, translation and scaling of the image data sets, whereas for non-rigid registration techniques relationships between correspondent points need to be found for each data set point separately.

Sonographic landmarks are highly hypoechogenic or hyperechogenic structures that can be used as a frameless overlay or registration method [7]. For the female pelvic floor the bladder, urethra, symphysis, anal sphincter and anal mucosa are sonographic landmarks which have their correspondence in MR morphology [8,9]. In deduction from the transverse (axial), frontal (coronar) and sagittal plane of the human body, e.g. [10,11] introduced a systematic sonographical documentation method for examination of the pelvic floor in analogon to the usually used MR nomenclature which we applied, too.

Previous attempts to register MR and US data sets consequently used structures which are easy to identify in both modalities such as major vessels or ventricle structures. The first attempt to use the benefits of the overlay technique was carried out on the brain using the skull [12] or the ventricles as landmarks [13]. In therapeutical used applications, this method for example measures the brain shift during an operation [14–16]. Huge vessels are used widely as landmarks in angiology [17,18]. Actually very few progresses in MR and US image overlay or registration in the pelvic floor area are reported because the organs in pelvic floor area are highly moveable in position and size. Therefore, mostly non-rigid registration techniques need to be used in this region. Some progresses using non-rigid registration techniques in the pelvic floor area were reported for both male and female cases: especially, in the treatment of prostate cancer, the development of new non-rigid registration algorithms has been reported recently, e.g. by [19]. But in general rigid registration techniques have been used so far. In female pelvis treatment of fibroids using rigid registration of preoperative MR and intraoperative US is described by [20]. Rigid registration techniques are described in detail in for example in [13,21,22].

Introitus sonography as data acquisition method focuses on rectum and anal sphincter muscle morphology [23,24]. A recent publication by [25] shows a good correlation of endosonographic anatomy with endocoil MR. In contrast to the cases presented with the present article [25] show the anatomy in a non-native physiologic state stretching the tissue with a transrectal probe. No results have been published so far about the combination of introitus sonography and standard bodyflex coil MR used for clinical purposes showing the anatomy in native status using a transvaginal probe. Knowledge of this type of registration of image data sets of the anal canal could lead towards new diagnostic or therapeutic methods in the treatment of female pelvic floor dysfunctions.

2. Materials and methods

To perform the ultrasound examination, a 3D-ultrasound equipment Voluson 530D, Kretztechnik, Zipf, Austria, was used. Therewith, 3D volume data sets were acquired as it has been described in [1]. The examination is performed in lithotomy position with an empty bladder and the patient at rest [26] with no other specific precautions made. Volume data sets of the undistended anal sphincter and levator ani muscle were taken with a 7.5 MHz transvaginal probe placed at the posterior frenulum of labia minora. Data acquisition was carried out carefully in order not to compress the anatomy in the considered anatomical region using an opening angle of 105° in transversal and of 100° in longitudinal direction. For our feasibility study, a data set of each of the three women attending the outpatient clinics for diagnosis and treatment of urinary incontinence were taken arbitrarily and with no specific clinical preference other than an ongoing study. The data sets have an isotropic resolution of 0.3 mm in each spatial direction.

The MR examination was carried out with an 0.5 T open configuration MR system, Signa SP GEMS, using a bodyflex surface coil for data acquisition in sitting position. After a locator sequence, one axial and two sagittal T2-weighted fast-spin-echo sequences (TR 4000, TE 100, Matrix 256×256, slice thickness 7.2 mm, intersection gap 1.2 mm) were acquired and stored in DICOM format. The resolution in the matrix is 1.09 mm, whereby the MR data sets result to be non-isotropic in the three directions in space in contrast to the isotropic sonographical data sets.

Leading structures in both of our data sets are the rectum and the anal canal with the mucosa, the circular as well as the conjoined longitudinal muscle layer of the anorectal junction and the levator ani muscle, specially the puborectalis muscle. These morphological leading structures and organs can be identified clearly in US as well as in MR images—in the latter case with much less contrast than in the US data sets. In addition to this in MR, the pelvis and skin’s surface are visible which is essential for spatial orientation.

As a base system for both alignment and visualization we used the 3D-Slicer 2 software [27–29] on both Standard MS Windows platforms and Sun Solaris 5.8 Workstations. MR data sets can be processed without further preprocessing. The ultrasound data sets needed to be reformatted into parallel slices in RAW format, being stored originally in a proprietarian cartesian volume data format. Processing followed the strategy as described in Fig. 1. For a trained operator, it will approximatively take 15 min to process one pair of data sets.

After carrying out an edge enhancement in the 3D US data set using adaptive filter techniques [30,31] both data sets were aligned. Placing three landmarks as fiducials in two different axial slices of both axial MR and ultrasound data set, the alignment was carried out by using 3D-Slicer’s fiducial alignment method [29]. As anatomical landmarks,
points in the mucosa and in the internal or external spincter muscle shape were taken. The MR images were assumed to be the gold standard for the muscle components [25]. After this initial alignment fine tuning of the alignment was carried out manually. The resulting transformation matrix could be used to replace the resampled and filtered data sets and to align the original ultrasound data sets instead. Using the same fiducial alignment method for the sagittal MR data set and the axial MR data set the US data set was aligned to the sagittal MR data set, too. Both the MR and the ultrasound data sets then were overlayed for all three patients. Using the 3D-Slicer software the registered images were processed in transparent mode. In addition to this, using a commercial graphics software package (Adobe Photoshop 5.0) spliced images were processed so that the appearances of identical muscle structures could be compared.

According to [32,33], the worst registration errors of the correlation ratio are due to MRI resolution. Following [34] we carried out a visual assessment of the accuracy. As it is clear that the localization of the fiducial points is never perfect and a gold standard not available the fiducial localization error (FLE) as well as the fiducial registration error (FRE) and the target registration error (TRE) for each modality could only be estimated assuming it in our case to be in the region of half a voxel size. Practically this means the registration accuracy for each single patient has to be estimated by visually inspecting the images. This approach has carefully been studied for rigid body registration of MR and CT images. Preliminary work in serial MR registration has suggested that observers have high sensitivity to errors greater than 0.2 mm when viewing different images [34].

3. Results

In order to enhance the anatomical details, the US data sets are filtered using the adaptive filter techniques. The noise could significantly be lowered as it is shown in Fig. 2. As a consequence, edges could be detected much better and they appear enhanced in the filtered images. Anatomical details are visible much clearer: Both external and internal anal sphincter muscle as well as the anal mucosa can be identified with much higher accuracy in the filtered images of Fig. 2. The internal anal sphincter muscle appears as a hypoechogenic region. The levator ani muscle has a V-form surrounding the external anal sphincter muscle best visible in the axial plane (Fig. 2(a)). It can be distinguished clearly from the hyperechogenic tissue of the external anal sphincter. Furthermore, the anal mucosa is clearly visible. For general spatial orientation in Fig. 3, the corresponding MR data sets of the pelvic floor of the same patient as in Fig. 2 are shown in its different planes. Bone structures as well as muscles and skin tissue are clearly distinguishable in Fig. 3(a) and (c). Fig. 3(b) shows the size of the overlayed US data set and the spatial orientation in the axial MR data set. In Fig. 3(c), the poor resolution and contrast of the vaginal and anal region is visible. No structures are clearly visible in this region. Even filter techniques could not increase the contrast significantly in this region in sagittal scan and are therefore, not shown. Fig. 3(d) shows the coronal plane and is shown for illustration purposes only.

The overlay of MR and US data sets enhances the anatomical findings significantly as shown in Fig. 4. Due to the higher resolution of the US data set, about three times more data points are visible in the overlay region in comparison to the MR image. The overlay therefore, magnifies this region.

Best enhancement could be achieved with the axial data sets of all three patients shown in Fig. 5. Especially,
the sliced image display illustrates the correspondencies of the anatomical findings in both modalities. Best results were observed in patient P1’s data sets. Whereas the image content in axial planes could be enhanced significantly in sagittal and coronal planes only few anatomical landmarks could clearly be identified. The contrast and the resolution of both data sets in sagittal and coronal planes were not comparable as it is shown in Fig. 4(b) and (c). The overlays in axial planes qualify very well for the visual assessment. Unlike this finding an estimation of accuracy in both sagittal and coronal plane could be quantified no better than half a voxel size.

4. Discussion

Preprocessing is not very much appreciated by clinicians. For initial alignment purposes, nevertheless, we needed preprocessing because generally it is a necessary feature of performing overlay techniques and it helps to localize the anatomical landmarks. This is demonstrated in Fig. 2. Using most registration methods as well as filter techniques it is required to have a similar resolution of both images, similar regions with the same image size and only local deformations on a short range scale. Therefore, preprocessing steps were needed. Corresponding clinical data sets of two different modalities usually fail fulfilling those preconditions completely—so do ours.

The difference of resolution in MR’s axial direction in comparison to the resolution of ultrasound is huge being almost in the region of factor 12. Due to this, a misplacement of ultrasound’s axial slices in relationship with MR axial slices was of no initial relevance.

The resulting overlays clearly show that the method can be used with slightly deformed ultrasound data. In the overlay region the anatomical findings are enhanced using 3D US in addition to the MR data set. The overlay technique leads to a new modality with enhanced informational content in this anatomical region.

Carefully investigating the overlays in Fig. 5 shows minor shape differences for all the anatomical structures. The reason for this misplacement results from the two completely different data acquisition techniques. The misplacement occurred even if the techniques were carried out very carefully. The coupling of the transducer to the tissue induces a tissue deformation in every case. The patients’ position varies not placing any external markers in
addition to this, especially, if the data acquisition takes place at different places and different times. As a consequence, the new modality described here needs to be approved with a higher number of patients.

Nevertheless, the feasibility study with only three corresponding data sets yet shows the efficiency of the method for normal clinical data. It is not limited to high quality image data with a highly optimized data acquisition. The information is maximized using different overlay transparencies for illustration purposes. As previously emphasized the MR images were assumed to be the gold standard for the muscle components. Using the registration technique described in this paper, and developing a more sophisticated data acquisition and registering technique this might be changed in the future.

---

**Fig. 4.** Different overlay transparencies of the axial MR data set of the pelvic floor of the same patient as in Fig. 2: (a) axial, (b) sagittal and (c) coronal plane. From left to right: 0%, 10% and 90% intensity of the overlayed US image. The capital letters indicate anatomical structures: A: anal region; B: bladder; P: pelvis; V: vaginal region.

**Fig. 5.** Overlay of axial MR and US images for all three patients (P1, P2, P3). From left to right different types of overlay are shown: only MR, 20% intensity of the overlayed US image (transparent), spliced display and 100% intensity of the overlayed US image. The arrows mark anatomical landmarks: anterior (a) and posterior (b) edge of the external anal sphincter muscle; right (c) and left (d) edge of the levator ani muscle. Corresponding arrows placed in all three patients for orientation purpose.
5. Summary

For many medical applications in the field of Computer-Assisted medical Diagnosis (CAD) it is essential to combine visualization of different modalities to maximize the clinical informations. Combination of modalities can lead to new modalities with enhanced informative content. Especially, 3D ultrasound (US) has a high potential in the innovative development of future low-cost applications. In this paper, we present an overlay technique of magnetic resonance (MR) and 3D US image data sets of the female anal canal (internal and external sphincter) as a base for a new diagnostic modality. It is a new field of the application of the overlay technique.

Three corresponding MR and US volume data sets from the female pelvic floor region were filtered using adaptive filtering techniques and overlayed (= registered rigidly) with a landmark based alignment method. It is shown in all three cases of the pelvic floor region that the internal and external sphincter region could be registered and the information of the displayed data significantly enhanced using the rigid registration technique.

Acknowledgements

This work was supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation), Grant VE 239/3-1

References


Janko F. Verhey is the research fellow in the Department of Medical Informatics, University of Göttingen, Germany. His research interests are focussed on image processing and treatment simulations. He is currently working on two research areas: On the one hand, he is working on the registration of imaging modalities with special focus on magnetic resonance (MR) and 3D ultrasound. And on the other hand, he develops a new laser thermal therapy (LITT) based on finite element method (FEM). He received his diploma in Nuclear Physics in 1991 from the University of Göttingen. He continued his scientific education in the University of Hannover graduating there as PhD in natural sciences at the Faculty of Geosciences and Geography in 1995. From 1995 till 1998 he was the head of the Central EDP and Electronics in the Max-Planck-Institute of Experimental Medicine in Goettingen. Since 1998 he is in a post-doctoral position in the Department of Medical Informatics, University of Göttingen. Half a year he spent during two grant based research periods in 2001 and 2003 in the Surgical Planning Laboratory, Brigham and Women’s Hospital, Harvard Medical School, in Boston, USA.

Carl-Fredrik Westin is the Director of Laboratory of Mathematics in Imaging, Department of Radiology, Brigham and Women’s Hospital, Harvard Medical School. His research interests are focused on medical applications of image analysis. He is currently working on analysis of Diffusion Tensor MRI data, and automated segmentation and registration of data from MRI, CT, and Ultrasound, using multidimensional signal processing techniques. He received the MSc degree in Applied Physics and Electrical Engineering in 1988 from Linköping University. He joined the Computer Vision Laboratory the same year where he did research on colour, information representation, image flow, frequency estimation, filtering of uncertain and irregularly sampled data and tensor operators in image analysis. In 1991, Dr Westin was awarded the SAAB-SCANIA prize for his work in field of Computer Vision. He received the Lic.Techn. degree on the topic feature extraction from a tensor image descriptions in 1991. In 1994 Westin graduated as PhD in computer vision, also from Linköping University. His thesis “A tensor framework for multidimensional signal processing” presents a novel method for filtering uncertain and irregularly sampled data termed normalized convolution. He joined Brigham and Women’s Hospital and Harvard Medical School in 1996.

Thomas Keller is the research fellow in the Department of Medical Informatics, University of Göttingen, Germany. His research interests are focused on image processing and treatment simulations. He is currently working on two research areas: On the one hand, he is working on the registration of imaging modalities with special focus on magnetic resonance (MR) and 3D ultrasound. And on the other hand, he develops a new laser thermal therapy (LITT) based on finite element method (FEM). He received his diploma in Nuclear Physics in 1991 from the University of Göttingen. He continued his scientific education in the University of Hannover graduating there as PhD in natural sciences at the Faculty of Geosciences and Geography in 1995. From 1995 till 1998 he was the head of the Central EDP and Electronics in the Max-Planck-Institute of Experimental Medicine in Goettingen. Since 1998 he is in a post-doctoral position in the Department of Medical Informatics, University of Göttingen. Half a year he spent during two grant based research periods in 2001 and 2003 in the Surgical Planning Laboratory, Brigham and Women’s Hospital, Harvard Medical School, in Boston, USA.

Dr Wisser is a Professor for Obstetrics and Gynaecology at Department of Obstetrics, University of Zürich, Switzerland. His basic research interests include studies on fetal development and fetal pathologies as well as sonographical studies on the morphology of the female pelvic floor. Before joining the University Hospital Zürich in 1994 he worked as a physician and as a researcher at several institutions in Europe and the USA. He received his MD from the Ludwig-Maximilian University in München, Germany, in 1980. From 1986 to 1994 he was the head of the Diagnostical Ultrasound at the Women’s Hospital of the Ludwig-Maximilian University in München.

Dr Kikinis is the Director of the Surgical Planning Laboratory of the Department of Radiology, Brigham and Women’s Hospital and Harvard Medical School, Boston, MA, and a Professor of Radiology at Harvard Medical School. His interests include the development of clinical applications for image processing, computer vision and interactive rendering methods. He is currently concentrating on developing fully automated segmentation methods and introducing computer graphics into the operating room. He is the author of 174 peer-reviewed articles. Before joining Brigham & Women’s Hospital in 1988, he worked as a researcher at the ETH in Zurich and as a resident at the University Hospital in Zurich, Switzerland. He received his MD from the University of Zurich, Switzerland, in 1982.