Optimal Instantiation of 3D Dynamic Structure of the Levator Ani

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Introduction

Pelvic floor dysfunction is a significant problem affecting many women after childbirth. The injury to the levator ani, which is the main pelvic floor muscle group, can lead to pain, incontinence and/or constipation. In the worst cases, surgery is required and 20% of patients need a second surgery. A better understanding of the pelvic floor during 3D dynamic manoeuvres is required for surgical planning as well as for assessing the efficacy of the interventional procedures. In practice, 3D dynamic imaging of the pelvic floor has been hampered by the length of time any subject can hold a maximal contraction or a maximal strain position. Usually, this ranges from 20-30 seconds and is not enough time to obtain the full 3D coverage. By incorporating a-priori information about the levator ani by statistical shape modelling, it is possible to reduce the number of scan planes required to instantiate the full 3D dynamic structure of the levator ani. The purpose of this study is to propose an optimal scan planning method based on statistical shape modelling that can be used in routine clinical environment for reducing the amount of time required for a dynamic scan of the entire levator ani.

Method

For statistical shape modelling, a training set was built from 3D volumetric MR images obtained from a 0.5T interventional MR scanner (GE SIGNA SPIO) of subjects sitting between the imaging coils. A FSPGR sequence was used to obtain the coronal images with a slice thickness of 5mm and three positions were imaged: at rest, at maximal squeeze upwards and at maximal strain downwards. Total scan time amounted to approximately 30 seconds. 10 asymptomatic subjects were scanned and the surface of their levator anis were manually segmented from the images and then triangulated. A shape model was built with these shapes using a technique developed by Horkaew and Yang [1], where correspondence between surfaces is optimised using the Minimum Description Length criterion. The scan planning technique extends the previous work by Lee *et al* [2]. The scan planes were fitted to points extracted from the training set by examining the control points with the most variance in each mode of the analysis. The proposed technique called Subspace Reprojection starts with the first mode of variation in PCA, sets the used points to the mean thus nullifying their influence:

$$\forall i \,\middle|\, x_i = \bar{x}_i, if \;\; \delta_i \le \delta,$$

where δ is the threshold distance to the mean, and then uses factor rotation to find the set of points for the second plane. Direct Oblimin was the factor rotation used with the criterion:

$$D = \sum_{j=k=1}^{r}\left[\sum_{i=1}^{n} b_{ij}^2 b_{ik}^2 - \frac{d}{n}\left(\sum_{i=1}^{n} b_{ij}^2 \sum_{i=1}^{n} b_{ik}^2\right)\right].$$

5 subjects (a subset of the original 10 in the training set) were scanned using the optimal planes in three positions (rest, maximal squeeze up and maximal strain down) and a leave-one-out model was fitted to the resulting segmented points. Each scan plane was obtained in under 8 seconds. The average closest point error was calculated between the original and model instantiated shapes. The results were compared with mid-sagittal and mid-coronal planes, the conventional methods used for dynamic pelvic floor studies.

Results

Figure 1 shows a mid-sagittal slice with the optimal scan planes marked in white. The results from the improved scan planes compare favourably to the mid slices, as can be seen in Figure 3. The surfaces instantiated from the Subspace Reprojection scan planes result in a mean error of 3.74mm (stdev 0.78mm) compared to errors of 4.59mm (stdev 1.24mm).

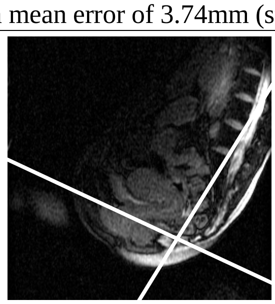

Figure 1 – FSPGR MR image with optimal scan planes

Figure 2 – Example 3D levator ani surface

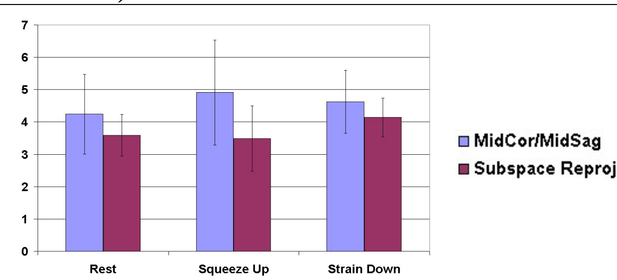

Figure 3 – Mean closest point error values and standard deviations for each position

Conclusion

The proposed scan plane technique performs consistently better than the usual mid-coronal and mid-sagittal scans. The use of statistical shape modelling is a promising technique for the instantiation of the levator ani while significantly reducing the scanning time. The proposed method is a new way forward for studying dynamic 3D structures where complete volumetric imaging is prohibited by the inherent temporal resolution of the scanning technique.

References

[1] Horkaew P and Yang GZ. Information Processing in Medical Imaging, 2003; 13-24.

[2] Lee SL, Horkaew P, Darzi A and Yang GZ. presented at MICCAI, Montreal, Canada, 2003; 714-721.