

## COMPARISON OF US ELASTOGRAMS AND MR IMAGES OF THERMAL LESIONS IN THE PROSTATE

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### Abstract

The objective of this study is to assess the reliability of thermal lesion elastography in the prostate using a comparison of lesion volume and dimensions with MRI.

Thermal lesions were created using high intensity focused ultrasound (HIFU) in the prostate *in vivo*. This technique was shown to provide an efficient alternative for the treatment of localized prostate cancer. Multi-compression elastograms were acquired using a transrectal imaging probe immediately after HIFU therapy on 109 patients. A balloon covered the probe and was inflated to compress the prostate. Displacements were calculated using a standard cross-correlation technique. The elastograms were obtained from the gradient of the cumulated displacements. Elastograms were acquired from slices that were separated by 4.0 mm. Gadolinium-enhanced T1-weighted TSE MRI of the HIFU lesions were acquired from 14 patients 2-5 days after therapy using the same spacing between slices. The contours of the lesions were manually delineated from the elastograms and from the MRI to determine their volume.

After exclusion of elastographic series considered as not interpretable by the radiologist, 7 patients were used for data analysis. HIFU lesions were visible as stiff areas in the corresponding elastograms. The average volume of the HIFU lesions was  $16.1 \pm 2.7$  cm<sup>3</sup> in MRI and  $19.5 \pm 8.5$  cm<sup>3</sup> in elastograms. The ratio of the volumes measured by elastography to the volumes measured by MRI for all 7 patient was  $1.20 \pm 0.46$ , and Pearson's correlation coefficient between volumes was 0.51. The volume was clearly over-estimated by a factor of 1.7 to 1.9 for two patients, whereas good correspondence (volume ratio  $0.95 \pm 0.22$ , correlation 0.83) was found for the five other patients. These preliminary results show that HIFU lesion volumes measured in elastography are of the same order as those observed in MRI. More patients are needed for the results to be statistically significant.

### Introduction

The principle of high intensity focused ultrasound (HIFU) therapy is to create thermal lesions in biological tissues using ultrasonic bursts of a few seconds duration [1]. This technique provides an efficient alternative for the treatment of localized

prostate cancer [2]. Elastography is an ultrasound-based imaging technique able to visualize strain contrast in soft tissues undergoing a small compression [3]. The feasibility of visualizing HIFU-induced lesions in liver *in vitro* [4,5] and in the prostate *in vivo* has been demonstrated [6]. The objective of this study is to assess the reliability of elastographic visualization of HIFU-induced lesions, using a comparison of the volume and of the dimensions of the lesions between elastography and MRI.

### Materials and Methods

A HIFU therapy probe was mechanically coupled to a transrectal imaging probe, and both were covered by a latex balloon filled with a coupling liquid. A computer-controlled motorized holder allowed stable positioning of the probes. The imaging system was based on a commercially available ultrasound scanner (Combison 311, Kretz, Austria), slightly modified to output the analogue ultrasonic radio-frequency (RF) echo signal, the frame trigger and the line trigger. The imaging probe was a rotating single-element transducer with a fixed focus. All acquisitions were performed with the scanner operating at 5.5 MHz. The scanner was able to provide 8 frames per second (fps) with a 0.4° pitch. Focal length was 52 mm, 6 dB focal depth was 35 mm, and fractional bandwidth was 40%. Compression of the prostate was applied by a continuous injection of a 60-ml syringe into the balloon. RF data were acquired using a 14-bit 100 MHz digitizer (CompuScope CS14100, Gage, Canada) synchronized with the ultrasound scanner. Consecutive RF frames were acquired in real-time during compression.

Displacements were estimated from the RF lines using the position of the maximum of the normalized cross-correlation function between corresponding segments of consecutive RF frames [3]. The cross-correlation coefficient and the time delays were calculated using  $W=1$  mm window length (1.3 μs) and  $\Delta W=0.5$  mm window shift (50% window overlap). A 5x5 (2 millimeters x 2°) median filter was applied to the displacements before the gradient was calculated. Displacements were cumulated over a 1.5-s duration (11 frames) to increase strain contrast. Strain was estimated from the gradient of the cumulative displacements.

HIFU lesions were induced using the Ablatherm machine (Edap-Technomed, France) with a 40 mm fixed focus probe operating at 3 MHz, 1.7 mm step between shots, 28-30 W acoustic power, 5 s duration and 5 s between shots. Individual lesions generated using this device were ellipsoids measuring 19-24 mm in length and 1.7 mm in diameter. Adjacent individual lesions were repeated to treat the whole prostate, leaving a 3 mm untreated safety margin near the rectal wall. Elastograms were acquired in transverse views every 4 mm, 1-5 min after HIFU therapy on 109 patients. On 14 patients, gadolinium-enhanced T1-weighted TSE MRI of the HIFU lesions were acquired using the same inter-slice spacing, 2-5 days after HIFU treatment [7].

Elastograms were scored according to the criteria listed in Table 1. Patients with more than 33% elastograms scoring 1 were excluded. The contours of the HIFU lesions were manually delineated by a radiologist from the elastograms and from MRI, and the total volumes of the lesions were calculated. If the lesion was not visible in a particular elastogram, the surface was linearly interpolated from the two adjacent elastograms.

Score	Criteria
1	Not interpretable
2	Lesion visible, noisy margins
3	Lesion visible, clear margins

Table 1. Scoring criteria

**Results**

131 elastograms were acquired in the patients who had post-therapy MRI. Typical elastograms are illustrated in Figs. 1-3. Black corresponds to zero strain and white to twice the average strain. A linear scale is used for strains below the average strain, while a gamma correction (square root of the normalized strain) is used for strains above the average to minimize saturation. This combined scaling results in more gray levels being allocated to low strain areas, therefore enhancing contrast in low strain areas. A medium gray mask hides areas of decorrelation noise. The HIFU lesions as delineated by the radiologist are outlined.

In "score 1" elastograms the HIFU lesion was generally not visible (Fig. 1). In elastograms scoring 2 or 3 (Figs. 2 & 3), the HIFU lesion was visible as a large stiff area in the prostate. The shape of the lesion showed good visual correspondence both with the dimensions of the target area (~40 mm wide and 20 mm deep) and with the lesion shown in MRI.

Seven patients had 63-100% (mean 88%) "score 1" elastograms and were excluded. The scores for the remaining patients are shown in Fig. 4. The occurrence of "score 1" elastograms was only 0-33% (mean 14%) in the selected patients.

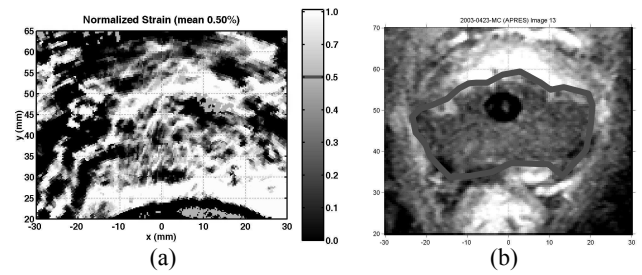


Fig. 1: (a) Typical "Score 1" elastogram and (b) corresponding MRI. The HIFU lesion (outlined in the MR image) has no visible edges in the elastogram and may extend over the full surface of the prostate. Areas of low correlation ( $\rho < 0.75$ ) are hidden by a medium gray mask.

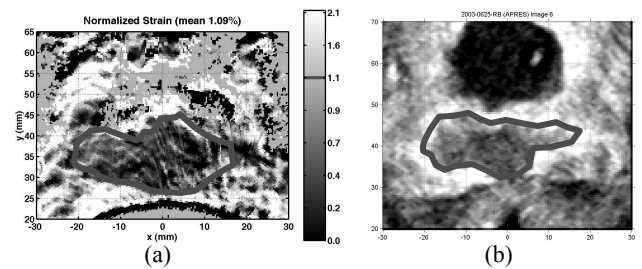


Fig. 2: (a) Typical "Score 2" elastogram and (b) corresponding MRI. The HIFU lesion is visible in the elastogram; it is adjacent to an anterior decorrelation noise area (top of elastogram).

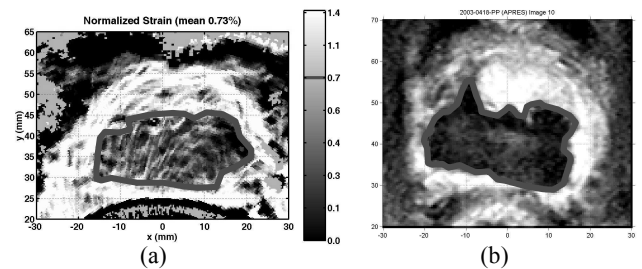


Fig. 3: (a) Typical "Score 3" elastogram and (b) corresponding MRI. The HIFU lesion is visible and has clear margins.

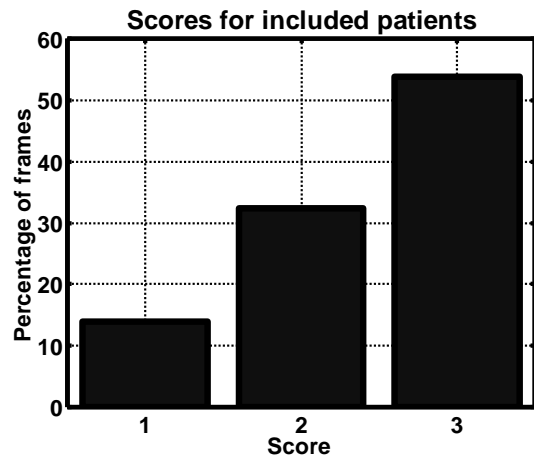


Fig. 4: Percentage of each score for 65 elastograms acquired in 7 selected patients.

The average strain was approximately twice lower in "score 1" elastograms than for higher scores, as shown in Fig. 5.

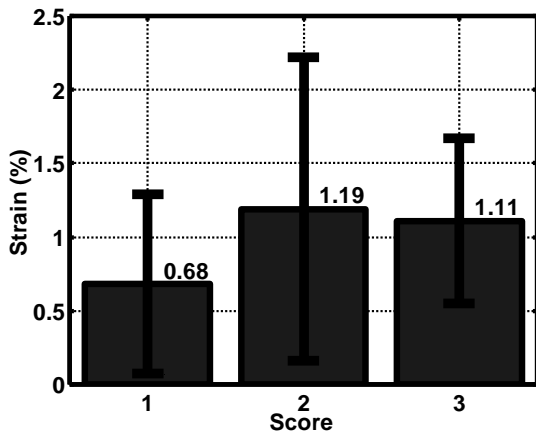


Fig. 5: Average strain vs. elastographic score.

The volume of HIFU lesions was  $16.1 \pm 2.7 \text{ cm}^3$  from MRI, and  $19.5 \pm 8.5 \text{ cm}^3$  from elastograms. The ratio of the volumes was  $1.20 \pm 0.46$ . Pearson's correlation coefficient between both series was 0.51. Fig. 6 shows the volume measured from elastograms on the vertical axis vs. measurements from MRI on the horizontal axis for each patient.

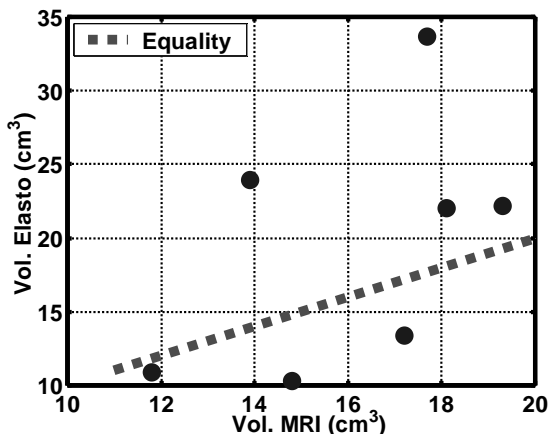


Fig. 6: HIFU lesion volume measured from elastogram (vertical axis) vs. volume measured from MRI (horizontal axis). The dotted line corresponds to perfect equality.

### Discussion

The volumes measured for five patients were consistent with MRI measurements. For these patients, Pearson's correlation coefficient was  $0.83$  and the volume in elastography was  $0.95 \pm 0.22$  the volume in MRI. However the volume was over-estimated in elastography by a factor of 1.7 to 1.9 for two patients. Part of the discrepancy between the measurements may be related to the increase of the prostate volume due to post-therapy edema [7]. The volume of the lesion may be normalized by the volume of the prostate to account for this global

variation. This was not possible in this study because T1-weighted MRI does not allow an accurate definition of the prostate contours. T2-weighted MRI would be required for this purpose. Furthermore, HIFU lesions shown by MRI include any eventual extra-prostatic extension of the lesion, but it has not been established yet if such extensions can be observed in elastography.

The results were not statistically significant yet because too few patients have been included to date. However the good correspondence found for 5/7 patients was encouraging, and further work is being conducted to include more patients. Parameters that would allow for identification of patients with over-estimated volumes were sought. For two patients observed so far, neither the scores nor the average strain were significantly different from the average values. Other parameters may be tested once a larger database becomes available.

Detailed analysis of scoring showed that for a given patient most elastograms ( $\sim 88\%$ ) were either uninterpretable, or most elastograms ( $\sim 86\%$ ) had scores 2-3. Moreover, the average strain in "score 1" elastograms was lower than in other elastograms (Fig. 5). These observations suggested that for "score 1" elastograms (1) either the whole prostate was coagulated, resulting in a stiff gland with no significant strain contrast and no clear margin, or (2) that there existed patient-specific conditions, probably related to anatomy, that prevented the balloon from applying a uniform compression. Uneven distribution of the displacements between the right and the left lobes was occasionally observed.

HIFU lesions with incomplete margins (score 2) were mostly associated with deep hypo-echoic areas in the corresponding sonograms, where sonographic signal-to-noise ratio was too low for accurate displacement tracking. The surface of the HIFU lesion is likely to be under-estimated in such elastograms.

Minimizing the occurrence of uninterpretable elastograms is desirable and is likely to be achieved using (1) a specific balloon designed to expand toward the prostate, resulting in a more directive compression and in a more efficient use of the injected liquid, (2) a higher acquisition frame rate to minimize decorrelation noise due to residual uncontrolled displacements [8], and (3) a higher transmit gain to increase signal-to-noise ratio in hypo-echoic areas.

### Conclusion

The volume of HIFU-induced lesions measured from elastography immediately after therapy was compared to the volume measured from MRI 2-5 days after treatment in 14 patients. After scoring and exclusion of clinically uninterpretable elastograms, comparison was possible for 7 patients. Good correspondence of lesion size and volume between

elastography and MRI was observed in five patients, while the volume was over-estimated in two patients. These preliminary results were encouraging and more patients are needed to provide a statistically significant comparison. Further work is also needed to determine if specific criteria can be found to identify patients with eventual over-estimated volumes. Finally, higher acquisition frame rates and better control of the applied compression are likely to improve the elastograms.

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### References

- [1] J-Y. Chapelon et al., "In vivo effects of high-intensity ultrasound on prostatic adenocarcinoma Dunning R3327", *Cancer Res.*, vol. 52(22), pp. 6353-6357, 1992.
- [2] A. Gelet et al., "Transrectal high intensity focused ultrasound for the treatment of localized prostate cancer: Factors influencing the outcome", *Eur. Urol.*, vol. 40(2), pp. 124-129, 2001.
- [3] J. Ophir et al., "Elastography: A quantitative method for imaging the elasticity of biological tissues", *Ultrason. Imaging*, vol. 13, pp. 111-134, 1991.
- [4] F. Kallel et al., "Elastographic imaging of the normal canine prostate in vitro", *Ultrason. Imaging*, vol. 21, pp. 201-215, 1999.
- [5] R. Righetti et al., "Elastographic characterization of HIFU-induced lesions in canine livers", *Ultrasound Med. & Biol.*, vol. 25(7), pp. 1099-1113, 1999.
- [6] R. Souchon et al. "Visualisation of HIFU lesions using elastography of the human prostate in vivo: Preliminary results", *Ultrasound Med. & Biol.*, vol. 29(7), pp. 1007-1015, 2003.
- [7] O. Rouvière et al., "MRI appearance of prostate following transrectal HIFU ablation of localized cancer", *Eur. Urol.*, vol. 40, pp. 265-274, 2001.
- [8] R. Souchon et al. "Visualisation of high-intensity focused ultrasound (HIFU)-induced lesions in the human prostate in vivo using elastography", *Proc. 3<sup>rd</sup> Int. Symp. Therapeutic Ultrasound (ISTU3)*, 2003.