Ultrasound-Based Elastography: A Novel Approach to Assess Radio Frequency Ablation of Liver Masses Performed With Expandable Ablation Probes

A Feasibility Study

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Objective. The purpose of this study was to evaluate the technical feasibility of ultrasound-based elastography as a tool for assessing the size and shape of the coagulation necrosis caused by radio frequency ablation (RFA) probes using expandable electrodes ex vivo as well as in a patient with a liver metastasis.

Methods. A commercially available expandable RFA probe was used to create a 3-cm ablation in a piece of bovine liver. The ablation probe was used in situ to induce tissue deformation for elastography before and after ablation. Ultrasonic radio frequency data were processed to generate elasticity strain images. The appearance of the ablation zone was compared with magnetic resonance imaging and a gross section specimen. One patient with malignant metastatic disease to the liver and a clinical indication for RFA was investigated for the feasibility of percutaneous elastography of RFA using the same technique. Sonographic strain images were compared with the appearance of the nonenhancing ablation zone on contrast-enhanced computed tomography.

Results. Ex vivo, the ablation zone on ultrasound-based elastography was represented by an area of increased stiffness and was well demarcated from the nonablated surrounding tissue. The size and shape of the ablated zone on the strain image correlated well with the gross specimen and the magnetic resonance imaging appearance. Strain images obtained from the patient showed results similar to those of the ex vivo experiment and correlated well with the nonenhancing area of ablation on contrast-enhanced computed tomography.

Conclusions. Ultrasound-based elastography may be a promising tool for displaying the ablation zone created by expandable RFA probes.

Key words: elasticity imaging; elastography; radio frequency ablation; strain imaging; ultrasound.

Among various methods of liver-directed therapy for primary and secondary hepatic malignancies, percutaneous radio frequency ablation (RFA) has been shown to be more effective than other percutaneous ablation methods such as ethanol.
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Ultrasound-based elastography (also referred to as ultrasound-based elasticity imaging) is a novel method with which to quantify and display the stiffness of organ tissue. It has been used as a novel diagnostic approach for benign and malignant diseases of the thyroid, breast, and cervix. Different elastographic techniques display different elasticity information, with several techniques choosing to display the relative strain information due to an external force; this article will refer to such information as “strain images.” It has been shown ex vivo and in animal models that on strain images, ablated organ tissue correlates with a higher degree of tissue stiffness than nonablated parenchyma.

An early method for compression-based elastography was based on creating mechanical pressure on the skin and underlying organs by compressing tissues with the transducer, but this force would only induce strain in tissue near the skin surface. The use of expandable RFA probes allows generation of strain forces where they are most needed for assessment of the thermal zone: directly at the depth level of the ablation within the organ of interest and not at the skin level. Varghese et al showed preliminary results from in vivo porcine RFA elasticity images using the ablation probe (in a stage controller) to induce an internal compression force.

In this article, we present ex vivo bovine liver results using freehand electrode needle movement to induce strain at the location of the ablation zone and the immediate surrounding tissue, and we provide a clinical example of elastographic assessment before and after RFA.

Materials and Methods

Ex Vivo Ultrasonic Data Collection

A large piece of degassed bovine liver was embedded in a gelatin mixture (7% porcine skin gelatin in water with 0.2% graphite) in a 64-oz rectangular plastic container. A 6-MHz linear transducer (L8-4, iU22 ultrasound system; Philips Medical Systems, Andover, MA) was placed directly on top of the specimen and fixed in place. An expandable 3-cm RFA electrode (Starburst-XLi, RITA 1500X ablation system; RITA Medical Systems, Inc, Mountain View, CA) was inserted under sonographic guidance, entering the specimen in the sonographic scan plane at approximately 45° with respect to the ultrasound beam direction. This is similar to most clinical RFA electrode insertion scenarios. The RFA needle tip was positioned in the center of the sonographic plane, and the RFA tines were
fully deployed to create the desired 3-cm lesion (deployment extent specified by the RITA system). The ultrasound scanner was equipped with a special ultrasonic radio frequency (RF) data capture board that enabled ultrasound frame data acquisition. One to 2 seconds of ultrasonic data were collected in real time at conventional frame rates (30 frames per second) as the needle was gently pulled and pushed within the specimen (electrode needle movement rate, 1 cm/s) to induce about 1% frame-to-frame strain.

The first data set was collected before ablation. Thereafter, the electrode and probe were held in the same position, and a 3-cm RFA was performed, heating the tissue to a target temperature of 125°C (200 W) for 5 minutes. Although this is less than the manufacturer’s recommended heating time (15 minutes), we found that the parameters chosen were adequate for lesion formation in this ex vivo nonperfused phantom case (no heat sink effect through vessels as can be observed in a perfused tissue environment). After RFA, we allowed a 5-minute period for dissipation of the gas bubbles that are an expected result of RFA heating. A second set of strain images was then acquired by the same method used before ablation, with the RFA electrode in its position being the only instrument for displacing tissue.

Compression-Based Strain Imaging Algorithm

The offline algorithm used to generate the strain image is based on a phase-sensitive 2-dimensional (2D) cross-correlation speckle-tracking algorithm using ultrasonic RF signals.\(^\text{14}\) Frame-to-frame displacements were estimated with a 0.6-mm lateral × 0.5-mm axial 2D cross-correlation kernel. Axial displacements were estimated, taking into account lateral (in-plane) correction detected by the 2D speckle tracking. The displacement estimates were then accumulated over about 20 frames (with geometric compensation), and the axial strain image was generated by taking the spatial derivative of the accumulated axial displacement. In these strain images, positive values indicate tissue elongation, and negative values indicate tissue compression. There are several methods to display the strain information, including using only the absolute strain values in a gray map or other color maps or overlaying the strain information on the B-mode image to capture more of the tissue structure. For better visualization in this article, we represent the accumulated strain image in an absolute scale using a hot color map (white to red). In addition, we also show the combination of the first B-mode frame (the first B-mode frame used to generate the elasticity image) overlaid with the strain image within the region of interest; this is denoted “strain + B-mode” on the images.

A Panorama 1-T MRI system (Philips Medical Systems, Best, the Netherlands) was used to image the phantom before and after the ultrasound-based RFA experiments. Different magnetic resonance (MR) sequences were tested for optimum ex vivo lesion contrast, and we selected a T1-weighted spoiled gradient echo sequence with these imaging parameters: repetition time, 14.8 milliseconds; echo time, 7 milliseconds; total scan time, 54.5 minutes; flip angle, 45°; slice thickness, 0.8 mm; and voxel reconstructed resolution, 0.4 × 0.4 × 0.4 mm\(^3\). The post-RFA MR images were collected 2.5 hours after the ablation. Magnetic resonance imaging markers (vitamin E capsules) and anatomic markers were used to identify the sonographic scan plane to select the corresponding MRI scan plane. After MRI, the phantom was dissected along the sonographic plane, and optical (caliper) measurements were obtained to measure lesion diameters.

In Vivo Data Collection

A 37-year-old obese female patient with a solitary metastasis to the liver from an adenocarcinoma of the colon agreed to participate in this study. The study was approved by the Internal Review Board, and written consent was obtained from the patient. Contrast-enhanced CT before RFA showed a solitary 2 × 1.5 × 1.4-cm subcapsular hypovascular mass in liver segment 7 (Figure 1, a and b), which was fluorodeoxyglucose avid on positron emission tomography (PET; Figure 1c). Conventional B-mode sonography performed 1 month later showed a subtle correlating hypoechoic mass at the corresponding location, now enlarged to 2.6 × 2.4 × 1.9 cm (Figure 1d).
The ablation was performed under general anesthesia with endotracheal intubation, which is the usual setting in our institution for liver tumor ablations. Two overlapping $5 \times 3$-cm ablations of the mass were performed to achieve full coverage of the liver tumor geometry as well as an additional safety margin; an impedance-based ablation system with an expandable monopolar electrode (LeVeen RF3000 probe; Boston Scientific Corporation, Marlborough, MA) was used. Under B-mode sonographic real-time guidance using a 3-MHz center frequency curvilinear transducer (C5-1; Philips Medical Systems) the 5-cm RF electrode was percutaneously introduced using an intercostal approach with a lateromedial and slightly cranially oriented trajectory and the tines fully extended; this was carried out initially at the superomedial portion of the mass. At no point did the curved tines extend beyond the liver margin. After completion of the first ablation using the manufacturer’s ablation protocol for a 5-cm ablation zone, the probe was repositioned by withdrawing it for a second ablation located more laterally and inferiorly. The desired ablation size was $5 \times 5 \times 5$ cm. Because the subcapsular

Figure 1. Clinical case: 37-year-old obese patient with metastatic colon cancer. a and b, Axial and coronal views, respectively, of preinterventional contrast-enhanced CT showing a $2 \times 1.5 \times 1.4$-cm subcapsular hypodense metastasis in segment 7 of the liver, indicated by the arrows. c, Fluorodeoxyglucose PET image (maximum intensity projection) with strong focal fluorodeoxyglucose uptake at the corresponding location within the liver, typical of a metastasis (arrow). d, Conventional B-mode image 1 month after PET and before RFA showing a subtle hypoechoic mass close to the diaphragm 17 cm deep from the skin level (arrows) but with an interim increase in size, measuring $2.6 \times 2.4 \times 1.9$ cm. Only a semicoronal plane obtained intercostally is displayed.
metastasis was located close to the diaphragm, a sympathetic reaction of and minor thermal damage to the diaphragm with resulting pleural effusion were expected.

Before and after the ablation, a gentle pull-and-release maneuver was carried out along the axis of the RFA electrode to induce tissue strain over a distance of 3 to 4 mm for 1 to 2 seconds each, similar to the procedure described above in the ex vivo experiment. A single similar maneuver is routinely carried out before an ablation to ensure stable anchoring of the probe within the liver parenchyma and is not considered a risk for promoting electrode dislocation given the special anchorlike design of this electrode.

For sonographic guidance, an ultrasound system similar to the one described in the ex vivo experiment was used. Ultrasonic RF data collection for further offline processing was performed before and after completion of each ablation while imaging at a frame rate of 20 frames per second; 30 frames (ie, 1.5 seconds) were acquired. Strain images were generated by the same method described above. Finally, the size and shape of the lesions were compared with follow-up contrast-enhanced CT, which was carried out 2.5 weeks after the procedure. The author who processed the ultrasonic RF data was blinded to the targeted ablation size (5 × 5 × 5 cm) and the outcome of the follow-up CT scan.

Results

Ex Vivo Bovine Liver

Figure 2 shows the results of our ex vivo bovine liver phantom experiments. Figure 2a is the conventional B-mode image showing the gelatin top layer overlying the liver specimen. The RFA electrode is seen as entering from the left side of the imaging plane. A few of the tines are also visible in the image plane. Figure 2b is the pre-RFA strain image in a hot map scale showing absolute strain values in the dynamic range of 0% to 12%, where black represents little deformation (stiffer areas), and white denotes regions where there was tissue compression or elongation. Figure 2c is a strain + B-mode fusion image in which the strain image from Figure 2B is overlaid on the B-mode image. The strain image was generated from ultrasonic RF data acquired during the RFA electrode pull sequence. The results show that the compression and strain are relatively uniform above and below the hard electrode shaft (denoted by the black levels in the elasticity image along the electrode shaft position), and there is no relatively stiff area about the electrode area before RFA.

Figure 2, d–f, shows the corresponding B-mode, strain, and fusion images, respectively, for the ex vivo liver after RFA. The lesion is not detectable in the B-mode image in Figure 2d. In contrast, the strain image in Figure 2e very clearly shows an ellipsoid region centered about the RFA electrode shaft that is stiffer than the surrounding tissue. The hard electrode shaft seen in Figure 2b is still visible in Figure 2, e and f, but not as noticeable in the post-RFA relative strain image because it is now surrounded by the stiff lesion; also, the slight variations in the imaging plane and deformation between the pre- and post-RFA data acquisitions will contribute to mismatches in the needle location among the images. There is no evidence of the lesion borders in the B-mode image in Figure 2d, although there are hyperechoic areas near the electrode, possibly indicating that there are still undissipated echogenic microbubbles present as a result of the ablation. The post-RFA fusion image in Figure 2f further elucidates the relationship between the stiffer tissue and the tines of the probe.

To confirm that the lesion seen in the elasticity images is indicative of a true physiologic change in the tissue, the MR images and phantom dissection results are presented in Figure 3. The elasticity image originally shown in Figure 2e is now shown in Figure 3a with dimensions calculated from the sonographic parameters. In Figure 3b, the lesion is characterized by an increase in signal intensity in the T1-weighted image surrounded by a transition zone into the normal tissue. In Figure 3c, the ablated region is shown in tan and has a different texture; the lesion was considerably harder than the surrounding tissue on manual palpation, as should be expected from previous ex vivo study measurements. In the MR image, 2 hypointense regions on the 2 sides of the lesion match well with the 2 vessels clearly seen in the optical image, verifying that measurements from the
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two modalities encompass the same regions. All 3 imaging modalities macroscopically mark the extent of the thermal lesion, which is ellipsoid along the main electrode shaft direction. The lesion dimension along the long axis in the strain image correlates well with the same dimension shown in the MR image and in the physical caliper measurement; however, the dimension discrepancies along the short axis among the 3 measurements are greater. The long-axis diameter measurements are 39.6, 38.6, and 40.2 mm from the elasticity image, MR image, and photo measurements, respectively. The corresponding short-axis diameter lesion measurements are 25, 24.1, and 33.7 mm. If the MR image measurements are taken as the reference standard diameter measurements, the elasticity diameter measurements have a long-axis error of 2.5% and a short-axis error of 3.7%, whereas the caliper measurements have a long-axis error of 4.1% and a short-axis error of 39.8%. In this study, MRI serves as a more accurate method for quantifying the size of the ablation because the gapless image acquisition of the entire ablation volume is considered more accurate for absolute size measurements than the single dissection plane obtained. Nonetheless, MR and optical images provide objective validation

Figure 2. Ex vivo bovine liver elasticity results for pre- and post-RFA data acquisitions. a, Conventional B-mode image before RFA showing the specular reflections off the RFA electrode shaft and tines. b, Ultrasound-based elasticity strain image from data collected before RFA. The relative absolute strain scale is shown; dark red/black denotes an area of no deformation or relatively stiff tissue, and white denotes an area of deformation or softer tissue. c, Strain image in b overlaid on top of the B-mode image in a red-green-blue scale (fusion mode). d–f, Corresponding conventional B-mode, strain, and strain + B-mode images, respectively, for post-RFA results. Although no clear margins of an ablation area are identified in the B-mode image (d), a well-defined obvious ellipsoid zone of increased stiffness (dark red area) is evident on the strain image (e). The overlaid fusion image (f) combines the morphologic B-mode information with the functional data generated by the strain image (e)
that the ultrasound-based elasticity image does indicate the general contour of physical ablation changes that could not accurately be confirmed in conventional B-mode imaging.

Ex vivo experiments were performed for 3 additional lesions with a similar correlation of measurement results across the optical, MR, and strain images as presented for the case in Figure 3. However, because of the limited sample size, sample variation statistics are not presented. The main ex vivo study hypothesis, to determine whether the strain image information correlates with pathologic tissue changes, is confirmed with the sample ex vivo case presented above.

In Vivo Clinical Case

The preintervention images for the 37-year-old patient are shown in Figure 1 and described above under “In Vivo Data Collection.” Figure 4 shows a series of conventional B-mode, strain, and fusion strain + B-mode images for preablation and postablation imaging data. The B-mode image in the plane of the electrode before ablation (Figure 4a) shows a subtle hypoechoic mass corresponding to the hypodense metastasis on CT as well as posterior shadowing caused by the metal shaft of the electrode. Strain images (Figure 4, b and c) before ablation show a focal oval area of relative stiffness penetrated by the RF
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electrode, consistent with the firm tissue of a metastasis from an adenocarcinoma.

After the ablation, the sonogram in Figure 4d, also obtained in the plane of the probe, shows a subtle poorly defined hypoechoic zone distal to the shaft and tines of the electrode, which was larger than before ablation. This area was interpreted as shadowing artifacts generated by the metal shaft and tines with a possible additional degree of tissue edema as a reaction to the thermal impact of the ablation. Postablation strain images, shown in Figure 4, e and f, show a well-defined round zone, measuring 5.5 cm in diameter, of considerably lower strain compared with preablation strain images and the untreated tissues of the surrounding liver parenchyma after RFA. However, some portions of the stiffer area are obscured by shadowing artifacts from the electrode shaft, as seen on pre-RFA images, because strain images were generated on the basis of the same B-mode images described above.

Seventeen days after the procedure, the patient returned with shortness of breath. Contrast-enhanced CT of the chest and upper abdomen performed at admission showed a 5.3-cm non-vascular almost round portion of liver tissue within the right hepatic lobe, representing the ablation zone, which covered and, as intended, surpassed the area of the formerly seen 2.2-cm metastasis (Figure 5). The treated metastasis could not be identified. A large right-sided pleural effusion was also noted (of which only a small portion is shown). A chest tube was placed to evacuate the effusion, and the patient was discharged after a short course of hospitalization with subtotal resolution of the effusion and, after removal of the chest tube, no further symptoms or distress. At the time of the writing of this arti-

Figure 4. Elasticity strain imaging results before (a–c) and after (d–f) RFA. a, Conventional B-mode image before RFA showing the expandable RFA electrode deployed within the lesion (semicoronal view, intercostal access, B-mode). b, Ultrasound-based elasticity strain image from data collected before RFA. The relative absolute strain scale from 0% to 11% strain is shown; dark red/black denotes an area of no deformation or relatively stiff tissue, and white denotes an area of deformation or softer tissue. A small oval zone (orange, arrows) of stiffer-than-normal (white) liver parenchyma is penetrated by the tines of the RFA electrode, potentially corresponding to a firm metastasis or an adenocarcinoma. c, Strain image in b overlaid on top of the B-mode image in a red-green-blue scale (fusion mode). d–f, Corresponding conventional B-mode, strain, and strain + B-mode images after the RFA. d, Subtle hypoechogenic alteration of the tissue in the vicinity of the ablation (asterisk) not well correlated with subsequent strain images. e, Clear round zone of increased stiffness (arrows) not seen on strain images before ablation (b). f, fusion strain + B-mode image with the ablation probe and size measurement of the stiff ablation zone in the orientation of the needle tract.
cle, the patient was alive and well and under close oncologic surveillance; she had complete tumor remission 6 months after the procedure.

Discussion

Radio frequency ablation has been shown to be an effective treatment alternative, with favorable outcomes, to surgical resection for appropriately selected malignant lesions of the liver and other organs. However, oncologic complications include higher rates of local tumor recurrence. This is particularly the case for RFAs performed percutaneously, for which the local recurrence rate is reported to be as high as 60% for tumors larger than 5 cm. Recurrence rates with laparoscopic and open approaches for tumors of 3 to 5 cm are slightly lower than those of percutaneous therapy: 21.7% versus 25.9%, respectively. Other factors negatively influencing complete ablation include tumor histologic features (such as metastases, which have a less favorable prognosis than hepatocellular carcinoma after RFA), a subcapsular location, and a location in close proximity to large vessels. Without a mechanism for immediately evaluating the extent of a percutaneous tumor ablation, a patient may be left with residual disease that goes undetected until the next follow-up imaging examination, which in most practices is performed 6 to 12 weeks after the procedure because this interval is thought to give the best accuracy in distinguishing between enhancement within a residual tumor and that due to procedurally induced inflammation.

Ex vivo experiments have shown the feasibility of elastography as a method for identification and quantification of RFA zones. The ex vivo bovine results here confirm, at least for application in one image plane, the use of elasticity imaging as a suitable tool to provide additional information on the RFA lesion size that may not be found on conventional B-mode imaging. It is important to note that the relative strain values are associated with the force induced by the needle pull/push; this means that the force is centered around the RFA electrode, and there is little stress induced in areas far away from the source. Varghese and coworkers showed preliminary results from in vivo porcine RFA elasticity strain images using the RFA electrode (in a stage controller) to induce an internal compression force. They used a cross-correlation analysis with pre-compression and post-compression (1%) ultrasonic RF data frames. Their results compared the elasticity image with gross pathologic findings and indicated a correlation between the elastographic image features and the lesion borders, although no measurements were reported. Fahey et al reported in vivo bovine liver RFA monitoring results using an elasticity imaging technique based on acoustic radiation force impulse imaging (ARFI), which uses acoustic
pulses to generate localized small strains at ultrasound focus positions instead of using the electrode as a force generator. Their acoustic radiation force impulse image measurements showed a maximum lesion diameter of 2.5 cm after RFA, and their optical image after dissection showed a maximum lesion diameter of 3 cm; they associated the discrepancy in sizes with different imaging/dissection planes.

The multimodality ex vivo images presented in Figure 3 confirm that the elasticity strain image identifies the lesion formed by RFA. The post-RFA ex vivo lesion is demarcated in the elasticity image shown in Figure 2, e and f, as a stiffer ellipsoidal lesion surrounded by softer tissue; the lesion cannot be easily identified in the corresponding B-mode image in Figure 2d. In Figure 3, the diameter measurements taken on the elasticity and the MR images were taken along similar axis positions and close to the same imaging plane because the phantom was intact for the sono-graphic and MR images. For the gross pathologic specimen photograph, the phantom was cut along the approximate sonographic plane, but it was difficult to ensure that the exact desired plane cut was achieved. The caliper measurement on the gross pathologic photograph was used in image software as a distance reference; the lesion diameter measurements on the photograph were extrapolated in the image software by correlating the image pixel distance with the caliper measurement to provide approximate diameter measurements along the same lesion axes as taken on the sonographic and MR images. Each of these images shows good correlation in measurements, but it is noted that they all reflect different tissue characteristics (color change on the gross pathologic specimen, water content on the MR image, and tissue stiffness on the elasticity image) yet convey the physiologic changes that occur because of ablation (Figure 3). The low error in diameter measurements between the MR and elasticity images indicates that the elasticity image provides valid information about the tissue changes that occur in the ablated area. The larger error between the MR and optical images may have been due to the difference between the imaging plane and gross pathologic slice, as mentioned above.

For the in vivo studies, the strain images are noisier than those from the controlled experimental ex vivo data. One of the reasons for this is that the signal-to-noise-ratio of the in vivo RF data is relatively low compared with the ex vivo case; this is due to the deep location of the in vivo lesion in a patient with a large habitus. The addition of in vivo cardiac pulsation can also affect data collection during the electrode needle pull and release phases. Nevertheless, the correlation between the measured size of the ablation zone in our patient by contrast-enhanced CT (5.3 cm) and strain imaging (5.5 cm) was convincing, given the use of a curvilinear transducer, free-hand generation of strain images even without a needle guide, and the proximity to the pulsating heart. This was particularly surprising because we chose to examine a relatively obese patient with a difficult target lesion to visualize. We explain the difference in measurements between the two methods of 2 mm by a slightly different rotational imaging plane (the RFA electrode tract was used to verify correctness of at least 1 CT plane slice) or by the presence of early small perifocal edema located immediately adjacent to the thermal zone, which might have led to increased tissue stiffness, making the edema indistinguishable from the ablation zone for strain-based elastography; however, we currently have no method to validate these two hypotheses. Frame-to-frame tissue motion/deformation as the underlying principle for strain imaging seems to be relatively robust and applicable, independent of the distance of the target to the transducer when using the RF electrode to generate the force, making this a promising tool for evaluation of the ablation zone in patients with larger body habitus. Further technical advances such as real-time implementation of ultrasound-based elastography and automated analysis tools may provide immediate feedback of the ablation result during or shortly after the procedure without the need for time-intensive postprocessing algorithms.

Limitations
One limitation of this method is that we used a manual technique to generate the strain data. Varghese et al[13] described high reproducibility of a mechanically automatically generated data set, which was easier to use ex vivo. For practicality,
we decided to evaluate the method using the operators’ subjective sense of gentle and consistent motion. This might have resulted in inaccurate and inconsistent sets of strain data. The compression-based strain elasticity algorithm performs a 2D correlation that could partially compensate for in-plane motion but is not able to detect out-of-plane motion.

Another limitation lies in the nature of the clinical procedure, which was indicated on the basis of clinical needs. We did not validate the elastography results with a pathologic specimen because no clinical indication for subsequent surgical resection of the tumor was present in our patient. Instead, we used contrast-enhanced CT as a reference, which was performed 2.5 weeks after the ablation and therefore may not accurately reflect the actual size and shape of the original ablation zone at the time of the procedure. Changes in the sizes of ablation zones have been described to occur within the interval between the time of the procedure and imaging surveillance weeks and months later.4

Furthermore, we did not evaluate the value of the method in displaying the tumor and the ablation zone at the same time. We are aware that various tumors might show various degrees of stiffness when compared with the surrounding parenchyma; tumors might be softer, equal to, or stiffer than liver tissue and equally stiff as the ablation zone itself. The goal in this study was to show that the method can be used to display the stiffness of the ablation zone, which is ideally planned to be larger than the initial tumor size. This ablation size assessment would be required to ascertain the completeness of the ablation. Because tumors might be as stiff as the ablation zone itself, one limitation of the suggested approach may be that the tumor and the ablation zone are indistinguishable from each other, and subsequently, the method might not be ideal for displaying both entities at the same time. However, other sonographic modalities such as B-mode and intravenous contrast-enhanced imaging in combination with elastography may aid in visualizing the treated tumor and the ablation zone simultaneously.

Conclusions
In this feasibility study, we have described, to our knowledge for the first time, the use of ultrasound-based percutaneous elastography as a monitoring tool for RFA in a patient. Prospective studies exploring the entire ablation volume rather than representing only one elastography plane with pathologic correlation are needed to assess the robustness and value of this method.

In summary, we have shown the feasibility of RFA electrode probe–generated strain imaging ex vivo and have described the clinical potential of ultrasound-based elastography in RFA procedures. Real-time ultrasound-based elasticity imaging will have the ability to determine ablated organ regions during the same interventional procedure and to aid in determining the need for additional ablations in the same treatment session. It may specifically serve as a cost-efficient and simple monitoring tool in an environment where no contrast-enhanced imaging modality is available or feasible.

References
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