Magnetic resonance elastography of uterine leiomyomas: a feasibility study

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Objective: To determine the feasibility of performing in vivo magnetic resonance elastography (MRE) for uterine leiomyoma.
Design: Pilot study.
Setting: Academic medical center.
Patient(s): Six subjects planning surgical excision of uterine leiomyomas.
Intervention(s): MRE before planned surgery.
Main Outcome Measure(s): Achieving an appropriate phase signal–to-noise ratio (PSNR) in the leiomyoma to allow assessment of leiomyoma elasticity in kilopascals (kPa).
Result(s): MRE was successful in all subjects for uteri ranging from 100 to >1,000 g. Subjects had body mass indexes ranging from 23.0 to 38.0 kg/m^2. Appropriate PSNRs, ranging from 5.45 to 42.28, were achieved for leiomyomas in all subjects. Mean elasticity of uterine leiomyomas ranged from 3.95 to 6.68 kPa.
Conclusion(s): MRE is a feasible technique for studying the in vivo mechanical properties of uterine leiomyomas and demonstrates significant heterogeneity in elasticity between lesions. Further work is necessary to optimize the technique and understand the clinical utility of this technique for women with uterine leiomyomas. (Fertil Steril® 2011;95:281–4. ©2011 by American Society for Reproductive Medicine.)

Key Words: Leiomyomas, magnetic resonance, elasticity, uterus, feasibility studies, elasticity imaging techniques/methods, adult, humans, female

Leiomyomas are benign myometrial neoplasms characterized by the presence of excessive extracellular matrix (ECM) that is both structurally and functionally important (1). The ECM in leiomyomas is dynamically regulated throughout the menstrual cycle and serves as a reservoir for growth factors active in leiomyoma biology (2–4). Additionally, the arrangement of ECM proteins has been shown to be abnormal in leiomyomas, and there is evidence that there is altered mechanical homeostasis in leiomyomas leading to activation of solid-state signaling (5, 6).

Leiomyomas are typically firmer on palpation than the surrounding myometrium and therefore they are typically referred to as fibroids. The mechanical property of soft tissues measured by palpation is elasticity, which compares the ratio of a given stress to the resulting strain. Elasticity of soft tissues varies over several orders of magnitude and produces a wider range of values than captured by other types of imaging, such as x-ray absorption or magnetic resonance relaxation times (7). In vitro ultrasound strain imaging has demonstrated the elastic variability of uteri containing leiomyomas and endometrial polyps in excised hysterectomy specimens (8).

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Magnetic resonance elastography (MRE) assesses mechanical properties of in vivo tissues in a three-step process: First, an external vibrating mechanical driver coupled to the human body transmits shear waves into the relevant tissue. Second, an MRE wave-imaging sequence is designed to capture images of the propagating shear waves in the tissue. Finally, an MRE algorithm is used to analyze the resulting wave images and calculate a stiffness map of the tissue, called an elastogram (9).

In vitro and in vivo data show that elastic modulus significantly correlates with pathologic findings of diseased tissues. Data from breast specimens have consistently shown that shear modulus of various types of carcinoma are much higher than the value of normal adipose-glandular tissue (10–12). In vivo hepatic elastographic data shows that fibrotic or cirrhotic livers are much firmer than normal ones (13–19); although benign liver tumors are significantly softer than malignant ones (20).

Our hypothesis was that leiomyomas differ in elasticity. The primary aim of this pilot study was to investigate the feasibility of MRE for uterine leiomyomas and to obtain data regarding the variability of leiomyoma elasticity in vivo.

MATERIALS AND METHODS

Patient Population and Data Collection

This in vivo MRE study was conducted at the Mayo Clinic, Rochester, Minnesota. MRE has been determined to be a nonsignificant-risk procedure by the Mayo Clinic Institutional Review Board, which approved this study. Written consent was obtained from each of the participants before the study. Study procedures were in accordance with ethical standards set forth in the revised Declaration of Helsinki. Women with planned excisional surgery for uterine

TABLE 1

Characteristics of the study participants (n = 6).

Subject	Age (y)	Gravidity/ parity	BMI	Hormonal status	Race	Indication for surgery	Surgery
1	34	1/1	24.2	Premenopausal/ secretory phase	Caucasian	Enlarging uterus, menorrhagia	Hysterectomy
2	37	2/0	33.7	Premenopausal	African-American	Enlarging fibroids	Myomectomy
3	40	2/1	23.1	Premenopausal/ proliferative phase	Asian	Degenerating fibroid and preterm labor	Myomectomy
4	44	0/0	30.7	Premenopausal/ proliferative phase	Caucasian	Increasing heavy menses and bulk symptoms	Hysterectomy
5	60	3/3	38	Postmenopausal	Caucasian	Enlarging myoma in menopause	Hysterectomy
6	36	1/1	23.7	Premenopausal/ noncycling on OCP	Asian	Probable recurrent adenomyosis	Diagnostic hysteroscopy

Note: BMI = body mass index, kg/m^2; OCP = oral contraceptive pill.

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leiomyomas between April 2008 and March 2009 were eligible for inclusion.

Magnetic Resonance Elastography

MRE scans were performed on a 1.5-T whole-body imager (Signa, GE Healthcare, Milwaukee, WI, USA). Participants were imaged in the supine position with a 19-cm-diameter passive driver placed on their abdomen above the uterus together with a custom-built four-element phased-array magnetic resonance imaging (MRI) coil. Continuous acoustic vibrations at 60 Hz were transmitted from an active driver in the equipment room to the passive driver through a flexible vinyl tube, which transmits shear waves into the uterus. A modified two-dimensional (2D) gradient-recalled echo–based elastography pulse sequence was used to collect wave images with the following parameters: imaging plane axial or sagittal; field of view (FOV) 24–42 cm; matrix 256 × 64; fractional-phase FOV 0.75–1; flip angle 30°; number of excitations (NEX) 1; bandwidth 15.63–31.25 kHz; TR 50 ms; TE 24.9–28.5 ms; slice thickness 4–5 mm; slice position through the uterine fibroid; phase offsets 4 or 8; motion encoding (MENC) 30.7–31.7 μm/π-radian; motion-sensitizing gradient (MSG) frequency 60 Hz; and MSG direction right-left, anterior-posterior, and superior-inferior. MRE wave images were collected on the respective three MSG directions.

The three MSG directional wave images were processed into a quantitative elastogram with units of kilopascal (kPa) using a previously described 2D local frequency estimation (LFE) MRE inversion algorithm (21, 22). Before applying the 2D LFE algorithm, the low-spatial-frequency background bulk motion and the high-spatial-frequency noise were removed from the wave data with a broadband gaussian bandpass filter (16.67–111.11 waves/m). Two-dimensional directional filtering with eight evenly spaced angles and a 2D Butterworth bandpass filter with the same bandwidth were also applied to the wave data to improve accuracy of the 2D LFE algorithm, which is limited by the low phase signal–to-noise ratio (PSNR) caused by complex wave interferences. The directional filter separates the complex wave fields into components propagating in different directions and analyzes each of them separately (23). All of the patient data were processed consistently with the same parameters. Regions of interest (ROIs) were drawn manually on the elastograms to

TABLE 2

Magnetic resonance imaging (MRI) characteristics, pathology findings, and magnetic resonance elastography (MRE) data.

	MRI characteristics			Pathology findings			MRE data	
Subject	T1 images	T2 images	Gadolinium enhancement	Histologic diagnosis	Diameter of largest myoma (cm)	Wt. of excised tissue (g)	PSNR	MRE (kPa)
1	Iso	Dark	Heterogeneous	Leiomyoma	22	1,640	42.28 ± 15.54	5.18 ± 1.1
2	Iso	Dark	Homogeneous	Leiomyoma	11.8	525	22.63 ± 8.00	5.52 ± 1.07
3	Iso	Heterogeneous	No enhancement	Leiomyoma	22.5	930	7.09 ± 1.24	3.95 ± 0.92
4	Iso	Dark	Homogeneous	Adenomyosis and leiomyoma	8.5	175	5.45 ± 1.67	6.68 ± 1.04
5	Iso	Dark	Homogeneous	Leiomyoma	4.5	99.6	6.86 ± 0.83	5.19 ± 0.26
6	NA	NA	NA	NA			30.7 ± 11.2	4.04 ± 0.73

Note: PSNR = phase signal–to-noise ratio.

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