Detection of placenta elasticity modulus by quantitative real-time shear wave imaging

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Summary

Objective: To explore the clinical values in detecting the placental elastic modulus using real-time quantitative shear wave elasticity imaging. *Methods:* A total of 30 women in the late pregnancy stage without complications and having normal, single pregnancies, as well as normal fetal growth, amniotic fluid index, and anterior placenta were selected. A real-time elasticity imaging shear wave ultrasonic diagnostic apparatus was used to randomly select regions of interest at the central and edge of the placenta. The elastography imaging mode was launched to measure the elasticity of the elastic modulus of these placental parts. A total of 15 measured values were obtained at the placental center and edge for each pregnancy case. Umbilical artery and uterine artery pulsatility index (PI) values for 18 cases were also randomly measured. *Results:* The average value of 30 placental edges of the elastic modulus (n = 15) was (7.60 ± 1.71) kPa. The average value of the 30 placental central elastic modulus (n = 15) was (7.84 ± 1.68) kPa. No significant difference was observed between placenta central and edge elastic modulus. The PI mean value of umbilical artery in 18 cases was 0.94, whereas the average PI values of the uterine artery was 0.83. No linear correlation was found among the elastic modulus, the placental uterine artery PI values, and the umbilical artery PI values ($p > 0.05$). *Conclusion:* No difference between the placental center of normal pregnancies and the edge of the elastic modulus was detected. The elastic modulus of the placenta could be obtained in the best position. The placenta varied greatly between elastic modulus. No correlation was found between the placental elastic modulus, the uterine artery, and umbilical artery PI values. Real-time shear wave elasticity imaging technology can provide morphological evidence of placental function, which may emerge as a new clinical assessment approach.

Key words: Shear; Elasticity imaging; Placental function.

Introduction

Elastography is a recently developed ultrasound (US) imaging technology, the basic principle of which is to impose an internal or external dynamic or static excitation on an tissue so that this tissue will respond to displacement, velocity, or strain, among others. Using the US imaging method, along with digital signal processing and digital image processing technology, elastography produces a visual display of information or quantifies the expression of this response. The elastic modulus is the ratio between stress (excitation) and strain (response). The elasticity imaging technique can be used to estimate tissue elastic modulus directly or indirectly [1].

The traditional static method has numerous clinical limitations because of a number of uncertain, complex factors. The shear-wave based dynamic method is a new approach that can quantitatively detect the absolute value of the elastic modulus of a region of interest by detecting the shear wave velocity triggered by acoustic radiation pulses [2]. In the formula $E = 3\rho c2$, E is the elastic modulus, c is the shear wave velocity, and is tissue density. Thus, shear-wave velocity in an organization directly represents tissue elasticity. The increased rigidity of a tissue results in faster shear wave propagation and a higher measured value.

Real-time diagnostic US shear wave elasticity imaging using supersonic shear imaging can make sound pulses of radiation continuously focused on different depths in an organization at supersonic speeds, thereby producing a "Mach cone" phenomenon, increasing the shear wave generation, improving communication efficiency, enabling flexibility in ensuring real-time imaging of shear waves, and ensuring patient safety. In addition, ultra high-speed imaging (Ultrafast) can capture a shear wave, the velocity of which is significantly lower than that of a sound, resulting in shear-wave ultra-high temporal resolution images. Furthermore, this Ultrafast feature allows the measurement of the absolute value of organization elasticity through a quantitative analysis of tissue elasticity (QBOX) system, thus improving the detection repeatability and providing a reliable basis for flexible imaging in clinical applications and studies.

Birth weight and intrauterine growth pattern determine neonatal morbidity, mortality, and long-term prognosis. These two factors can help determine whether the birth survival rate of low-for-gestational-age children is low or if the occurrence of adult degenerative diseases, such as hypertension and type II diabetes, will increase [3]. The fetal nutrient supply capacity of the placenta is a primary factor determining intrauterine growth [4]. Therefore, the diagnosis and treatment of placental insufficiency is an effective method of reducing neonatal morbidity and mortality and improving quality of life.

In the present paper, real-time shear wave elasticity imaging was used to quantitatively detect placental elastic modulus, to explore the clinical value of this technology in assessing placental function, and to provide a reference index for the diagnosis of placental dysfunction.

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Materials and Methods

General data

A total of 30 patients with singleton, late-stage pregnancies were randomly selected from April to June 2011 at the Department of Fetal Medicine Ultrasound of the First Affiliated Hospital of Jinan University. These patients were without pregnancy-related complications. They had normal fetal growth, amniotic fluid index, and anterior placenta. The patients were aged 29 ± 0.38 years (21 to 39 years), and fetal gestational age was 33.93 ± 3.99 weeks (28 to 41 weeks).

Method

A real-time shear wave elasticity imaging US diagnostic apparatus (Supersonic AixPlorer, probe SE12-3, frequency 3 MHz to 12 MHz, Supersonic, France) with a mechanical index, MI < 1.0, and heat index, TI < 0.5, was used in the current study. The edge of the placenta and the central organization were positioned using conventional 2D ultrasound. Regions of interest were randomly selected. The pregnant women breathed when the fetus was quiet to avoid excessive pressure on the abdominal wall. Once the elastography mode was started, three measurements were frozen after an image was stabilized. Q-BOX was then used to assess the measurements.

The diameter of the sampling frame was set to 15 mm. Each measurement included a maximum, minimum, average, and standard deviation, less than 30% of which was considered as an effective measure. The average was taken as part of the elastic modulus of the placenta. A total of 15 of the measured values were obtained in the center and edge of the placenta of each pregnant woman (Figure 1). Finally, umbilical artery and uterine artery PI values of the 18 cases were randomly measured.

Statistical analysis

Measurement data are shown as mean ± standard deviation. The elastic modulus of the placental center and the edge were compared using a paired t-test. The relationship among the placenta elastic modulus, the umbilical artery, and uterine artery PI values were compared using linear correlation analysis; $p < 0.05$ was considered statistically significant. Statistical analysis was conducted using an SPSS 17.0 package.

Results

Comparison of the elastic modulus

The placental edge elastic modulus was measured in 30 groups (n = 15). The maximum was 12.36 ± 1.77 kPa, and the minimum was 5.15 ± 1.31 kPa or an average of 7.60 ± 1.71 kPa. The central placenta elastic modulus was also measured in 30 groups (n = 15), where the maximum was 12.73 ± 1.12 kPa, and the minimum was 5.30 ± 0.87 kPa or an average of 7.84 ± 1.68 kPa. No statistically significant difference was found between the central placenta and the edge of the elastic modulus (t = 0.529, $p > 0.05$) (Table 1).

Placental distribution of elastic modulus

The average elastic modulus of each placental edge and the central elastic modulus were determined. The maximum was 12.53 ± 1.24 kPa, and the minimum was 5.34 ± 1.24 kPa, with a mean of 7.70 ± 1.61 kPa (Table 1, Figure 2).

Table 1. — *Placenta central, marginal and average elastic modulus of 30 cases.*

No.	Placenta central elastic modulus (kPa)	Elastic modulus edge of the placenta (Kpa)	Placenta average elastic modulus (Kpa)
1	7.53 ± 2.42	7.55 ± 1.58	7.54 ± 2.02
2	9.54 ± 2.21	9.67 ± 2.54	9.60 ± 2.34
3	7.04 ± 1.29	6.83 ± 0.98	6.93 ± 1.63
4	8.04 ± 1.40	8.70 ± 1.79	8.36 ± 1.63
5	8.18 ± 1.38	7.57 ± 1.62	7.88 ± 1.52
6	6.67 ± 1.20	6.66 ± 0.93	6.66 ± 1.07
7	7.34 ± 1.25	6.61 ± 0.91	6.98 ± 1.17
8	7.45 ± 1.29	7.73 ± 2.04	7.58 ± 1.67
9	9.53 ± 1.35	8.80 ± 1.62	9.17 ± 1.51
10	11.10 ± 1.30	9.53 ± 1.45	10.15 ± 1.56
11	6.54 ± 0.76	6.48 ± 0.88	6.51 ± 0.81
12	10.50 ± 1.99	10.7 ± 1.74	10.57 ± 1.84
13	5.30 ± 0.87	5.74 ± 1.08	5.57 ± 1.02
14	6.64 ± 1.24	7.81 ± 1.60	7.33 ± 1.56
15	7.49 ± 1.90	9.01 ± 1.60	8.25 ± 1.89
16	6.07 ± 0.77	9.01 ± 1.60	6.43 ± 1.15
17	6.21 ± 1.10	6.64 ± 1.36	6.44 ± 1.25
18	5.89 ± 1.29	6.82 ± 1.34	6.37 ± 1.38
19	5.57 ± 1.15	5.15 ± 1.31	5.34 ± 1.24
20	7.29 ± 1.12	8.03 ± 1.11	7.66 ± 1.17
21	9.01 ± 1.62	8.16 ± 1.07	8.57 ± 1.42
22	6.71 ± 1.36	6.34 ± 1.46	6.54 ± 1.40
23	6.83 ± 1.40	5.43 ± 0.85	6.15 ± 1.35
24	6.50 ± 1.35	6.84 ± 0.71	6.67 ± 1.07
25	8.12 ± 1.50	9.66 ± 1.10	8.87 ± 1.52
26	7.69 ± 1.35	8.85 ± 1.64	8.17 ± 1.57
27	6.82 ± 0.67	7.65 ± 0.74	7.29 ± 0.79
28	6.46 ± 1.16	5.42 ± 0.84	5.96 ± 1.13
29	8.41 ± 1.06	10.38 ± 1.44	9.03 ± 1.59
30	12.73 ± 1.12	12.36 ± 1.77	12.53 ± 1.24

Table 2. — *Relationship between placenta elastic modulus, umbilical artery and uterine artery PI values in 18 cases.*

No.	Elastic modulus of the placenta (Kpa)	Umbilical artery PI values	Uterine artery PI values
1	7.54 ± 2.02	0.86	0.78
2	9.60 ± 2.34	0.91	0.8
3	6.93 ± 1.63	0.76	0.97
4	8.36 ± 1.63	0.88	0.66
5	6.98 ± 1.17	1.06	0.83
6	10.15 ± 1.56	0.92	0.85
7	10.57 ± 1.84	1.16	0.87
8	5.57 ± 1.02	0.71	0.84
9	7.33 ± 1.56	1.02	1.11
10	6.44 ± 1.25	0.93	0.63
11	6.37 ± 1.38	1.01	0.77
12	5.34 ± 1.24	1.1	0.88
13	8.57 ± 1.42	0.89	0.9
14	6.15 ± 1.35	1.37	0.72
15	6.67 ± 1.07	0.85	0.66
16	8.87 ± 1.52	1.02	1.03
17	8.17 ± 1.57	0.66	0.77
18	7.29 ± 0.79	0.74	0.85

No linear correlation was shown among placenta elastic modulus value, umbilical artery PI, uterine artery PI.

Relationship among the placenta, umbilical artery elastic modulus, and uterine artery PI values

A total of 18 pregnancy cases were randomly selected to measure umbilical artery and uterine artery PI values.

Fig. 1

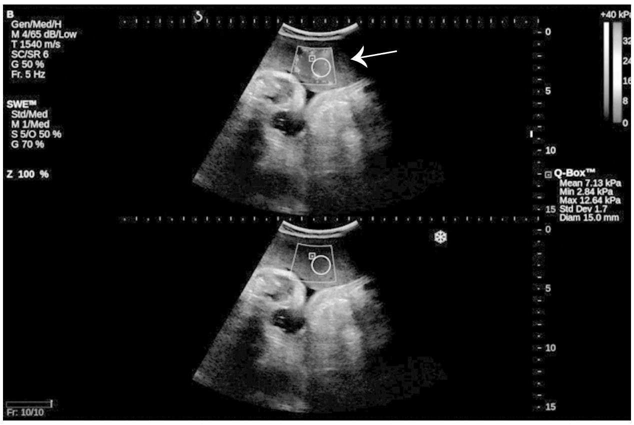

Fig. 2

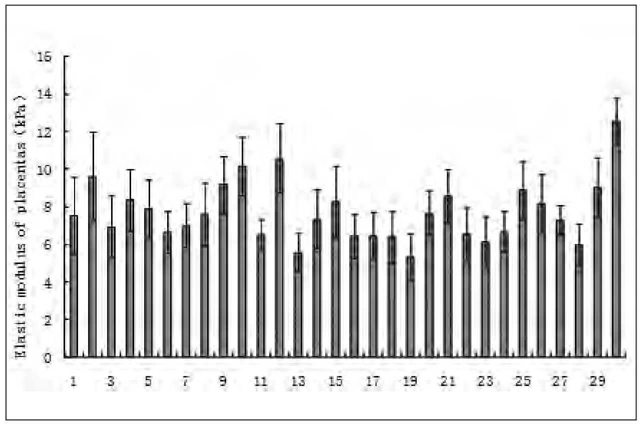

Figure 1. — Placental elastic modulus determination.
The blue area (see arrow) show the elasticity imaging parts, the inner the sampling window of 15 mm in diameter, and the figure below shows the corresponding two-dimensional image.
Figure 2. — Placenta elastic modulus distribution in 30 cases.

The maximum value of umbilical artery PI was 1.37, and the minimum was 0.66, or an average of 0.94. Uterine artery maximum PI was 1.11, and the minimum was 0.63, or an average of 0.83. Umbilical artery and uterine artery PI values were less than the corresponding 95th percentile for gestational age [5, 6]. The correlation coefficient of the placenta and the umbilical artery elastic modulus PI values were r = 0.10, t = 0.40 ($p > 0.05$). No linear correlation was found among the placenta, umbilical artery elastic modulus PI value, and the uterine artery PI values (Table 2).

Discussion

Elasticity imaging technology has been clinically used for over ten years. This technology was initially used to identify benign and malignant breast lesions. The usefulness of this technology has been widely recognized through a large-sample, multi-center clinical study [7]. The elasticity imaging of the thyroid, prostate, and other organs provides a reliable basis for identifying and diagnosing diseases [8, 9].

The real-time shear wave elasticity imaging technique has been used in quantitative studies of abdominal organs. This technique is a preferred approach because of its imaging depth, reproducibility, and measurability, among other superior aspects. This imaging technique reportedly allows a close correlation between liver fibrosis type and tissue elasticity values [10]. However, no relevant reports have been carried out on real-time elastography of the placenta.

Exploring the causal relationship that results in the further dysfunction of placental complications in pregnancy is the ultimate goal of this series of studies. Using shear wave elasticity imaging for real-time expression, the present study sought to determine whether placenta-specific morphology or the morphological changes occurring during pregnancy indirectly reflect placental function.

In the present study, all cases involved normal pregnancies. Fetal growth and development corresponded to gestational age. Amniotic fluid index was normal. The umbilical artery and uterine artery PI values were within the normal range, that is, the clinical significance of placental function was normal. Therefore, the measured elasticity of the placental modulus should also be normal. A 10 cm detection depth for the SE12-3 probe was the most appropriate. The depth of the posterior wall of the placenta at late pregnancy usually exceeds 10 cm, as was the anterior placenta in the current study.

During the measurement process, the results can be affected by the high sensitivity of the instrument, fetal movement, breathing activity, and excessive pressure to the abdominal wall. These confounding factors were avoided. Measurements were also frozen after three image stabilization to improve measurement accuracy and repeatability. In addition, the interference of the above-mentioned factors on the measured values increase heterogeneity. The sampling window was placed at a lower elasticity. The average standard deviation of less than 30% can also minimize measurement error.

The edge and central areas of normal pregnancy placental elastic modulus were measured. No significant difference between the two was found using a paired t-test, indicating that the placental center and edge can both represent the placental elastic modulus. This finding indicates that the posterior wall of the placenta could also be measured extending to the wall. The edge elastic modulus of the depth within 10 cm represents the placental elasticity modulus. This condition resolves the effect of the location of the placenta on the measured values during the sampling process.

The placental elastic modulus ranged from 12.53 ± 1.24 kPa to 5.34 ± 1.24 kPa, or an average of 7.70 ± 1.61 kPa. The significant variations in the elastic modulus may be attributable to the following. First, the method by which the varying degrees of placental tissue calcification in different parts could affect the elasticity value changes during late pregnancy was unclear. Second, the relationship between the results and sample size might require further exploration.

The best indicators of the placenta are: 1) Abnormal umbilical artery PI values resulting from abnormal placental function; 2) Abnormal uterine artery PI values resulting in placental dysfunction; and 3) Umbilical artery and uterine artery PI values before and after the load. The present study found no linear correlation among the umbilical artery, uterine artery PI values, and the corresponding placenta elastic modulus, suggesting that the elastic modulus of the placenta may be a specific or sensitive indicator of placental function measurement. The occurrence of jet lag when the elastic modulus and placental blood flow index became unusual, and the factors that resulted in the difference in severity require further study.

The capability of the placenta to transfer nutrients depends on several factors, including the maternal–fetal nutrient exchange surface area, the overall shape and ultrastructure of the placenta, blood flow, and the concentration of transport proteins, nutrients and anabolic hormones, among others [11]. Current clinical evaluation of placental function also depends on several factors, including the placental area that indirectly reflects the exchange volume [12], the direct reflection of placental perfusion flow index [13], the indirect reflection of the perfusion of the fetal placenta (umbilical artery) or the artery resistance index (uterine artery) of the mother, and the reflection of the synthesis of placental hormones and biochemical parameters [14].

However, no approach can accurately reflect placental function at present. Therefore, the relationships among intrauterine growth retardation, gestational hypertension, diabetes, and other pregnancy complications, as well as placental function and pregnancy outcome cannot be explored. Information on these relationships will clinically guide the timely termination of a pregnancy.

Real-time shear wave elasticity imaging is a method for tissue characterization, which can indirectly reflect the placental forms through the placenta elastic modulus and can provide the morphological basis for assessing placental function. The present work has demonstrated that the proposed approach could become an emerging technology in providing better clinical diagnosis based on abnormal placental function, following the paths taken by three-dimensional US, Doppler, hormone levels, and other related methods.

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