Assessments of M-mode color echocardiography on fetal right ventricular diastolic function with umbilical cord around neck


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Abstract. – OBJECTIVE: To investigate the fetal right ventricular diastolic function under the condition of umbilical cord around neck (UCAN), and analyze the changes of the right ventricular propagation velocity (Vp), then discuss the clinical value of the color M-mode echocardiography in the evaluation of fetal ventricular diastolic function quantitatively.

PATIENTS AND METHODS: All patients enrolled were with singleton pregnancy from Cangzhou Central Hospital from December 2013 to December 2015 as the experimental group. The control group consisted of normal fetuses without UCAN and the experimental group consisted of the fetuses with UCAN. Besides, this paper analyzed values of Tei index of the left and right ventricle as well as Vp of the right ventricle diastole using color M-mode echocardiography.

RESULTS: The Vp values of the experimental group were significantly lower than those of the control group (p < 0.05); the Tei index of the right ventricle of the experimental group was significantly higher than that of the control group (p < 0.05); the Tei indexes of the left and right ventricles of the experimental group had no statistical difference (p > 0.05). The heart function and the right ventricular diastolic function were reduced in fetuses with UCAN; however, the effect of the left and the right ventricular diastolic function had no significant changes in fetuses with UCAN.

CONCLUSIONS: It had great significance to select the appropriate index of cardiac function for estimating the right ventricular diastolic function and the whole heart function of UCAN, and it is of huge practical application value in clinical practice.

Key Words: Umbilical cord around neck, Right ventricular function, Ultrasound heartbeat, Tei index, Vp.

Introduction

Larson et al2 considered that the umbilical cord around fetal neck (UCAN) with multiple loops can increase the risk of fetal distress, the fetal intrauterine ischemia, the hypoxia of fetuses, and finally affect the fetal heart function. The fetal right ventricular function is dominant, contributing more than half of the fetal cardiac output. Therefore, in that sense, the evaluation of the fetal right ventricular function is crucial. The early detection of UCAN and the fetal right ventricular dysfunction, and an active and acute treatment may exert significant influence on the prognosis of the fetuses3.

In this study, using the color M-mode echocardiography, the right ventricular Tei index and the propagation velocity (Vp) of the fetuses with UCAN were measured; at meanwhile, the application value of this method in the measurement of the ventricular diastolic function of fetal UCAN was explored and discussed.

Patients and Methods

Patients

All patients with a singleton pregnancy who were admitted to our hospital (Cangzhou Central Hospital, Cangzhou, Hebei, China) from December 2013 to December 2015 were screened by fetal echocardiography. The study contained 55 cases of diagnosed fetuses with NCAN, with gestational ages of 23-40 weeks (average 30.2 ± 1.3) and the maternal age of 23-35 (average 29.5 ± 2.1). The control group also included 55 normal cases.
with range of gestational age 23-40 weeks (average 29.8 ± 1.6) and maternal age of 21-34 (average 27.9 ± 2.7). All pregnant females in the study were aware of the accuracy and limitation of the fetal echocardiography before taking examinations. This work was approved by the hospital’s Ethics Committee and the informed consent was signed by all patients.

Inclusion Criteria
Pregnancy Conditions. According to the medical histories, the health records and the laboratory examinations of the pregnant females, the physical conditions were confirmed to be healthy without diabetes mellitus, cardiovascular disease, liver and kidney and other chronic diseases or family history of genetic disease.

Fetal Conditions. Upon screening of systematic ultrasound examination and fetal echocardiography, all fetuses had no non-cardiac structural abnormalities and intrauterine growth retardation.

Exclusion Criteria
The pregnant females with serious diseases in heart, liver, kidney and other organs, with a history of smoking, drinking, taking nonsteroidal anti-inflammatory drugs one month before the experiment, or with poor compliance of the experiment or being unwilling to cooperate, were excluded.

UCAN diagnosis criteria*: when the umbilical cord around fetal neck was too tight, in the slit image of fetal nuchal skin could appear the umbilical cord of the indentation, a “U” shape or “V” shape indentation was shown if the nuchal cord was around for one loop; a “W” shape indentation was shown if the nuchal cord was around for two loops; a string beads indentation was shown when the circles were more than three loops.

Research Methods
Appliances: this study used GE Vingmed CFM 800C (Healthcare, Chalfont St. Giles, UK) color ultrasonic imaging system, with probe frequency 2.0-4.0 MHz. To measure and analyze the parameters from M-mode echocardiography, this study used LEJ-2 omnidirectional M-mode echocardiography system (Biomedical Engineering Research Institute, Fuzhou, Fujian, China).

Operation methods: the pregnant females should have a supine position or left-lateral position. Firstly, a regular ultrasonic examination was demanded on fetuses and the fetal position shall be confirmed according to the positions of the fetal head and spine. Then, were estimated in utero fetal growth and the development situation, according to the measurements of the fetal biparietal diameter, the head circumference, the femur length, the fetal heart rate, the abdominal circumference, etc.

In the calm breathing, the probe into the patient’s abdominal wall was set, the image clarity to provide a clear image to set the probe and the fetal spine in parallel was adjusted, then apical four-chamber view of a fetal heart in a two-dimensional model was obtained. The color Doppler ultrasound (Biomedical Engineering Research Institute, Fuzhou, Fujian, China) showed the right ventricular diastolic flow beam, sampling windows consisted of the right ventricle, the tricuspid valve and part of the right atrium. In order to obtain clear color M-mode flow chart of E wave for the first time and the frequency distortion of the isotach, the M-mode sample line was adjusted and made it in parallel with the right ventricular diastolic flow; then, the color M-mode to scan was opened, the first slope of the constant velocity of the frequency distortion from E wave (early diastolic flow) mapping measurement, as called Vp. The mean value of three measurements would be adopted. We used the tissue Doppler to measure the apical four-chamber view and then placed the sampling volume in the anterior lobe of the anterior cusp of tricuspid valve ring. Then, the tissue Doppler motion spectrum of the Tricuspid valve was recorded. The spectrum could display three peaks, which were systolic peak Sa, early diastolic peak Ea and late diastolic peak Aa, and the three cardiac cycles were measured and all measurements could be completed by only one physician.

The time interval between the ending point Aa peak and the starting point Sa peak in the tissue Doppler spectrum is called isovolumic relaxation time (IRT). The time interval of Sa peak is called ejection time (ET). The Tei index is the ratio of the sum of isovolumic contraction, isovolumic relaxation and ventricular ejection time. The formula of Tei index is shown as follows:

Tei Index = (ICT+IRT)/ET.

The mean values were taken by three measurements of consecutive cardiac cycles.
Echocardiography fetal right ventricular diastolic function and UCAN

Table I. Comparison of the VP between UCAN fetuses and normal fetuses.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Vp (cm/s)</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCAN</td>
<td>55</td>
<td>18.36 ± 3.94</td>
<td>8.46</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Normal</td>
<td>55</td>
<td>26.58 ± 6.03</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Statistical Analysis
SPSS17.0 statistical software (SPSS, Inc., Chicago, IL, USA) was used for statistical analysis of the data; all measurement data are expressed as mean value ± standard deviation (x ± s). t-test was used to compare the measurement data between the two groups, and the p < 0.05 was statistically significant.

Results

Ventricular Vp Value of UCAN Group and Normal Group
The Vp values of fetuses with UCAN were 18.36 ± 3.94 cm/s and the Vp values of normal fetuses were 26.58 ± 6.03 cm/s. The difference was statistically significant (Table I).

Fetal Ventricular Tei Index of UCAN Group and Normal Group
The fetal right ventricular Tei index of the normal group was 0.38 ± 0.05, the right fetal ventricular Tei index of UCAN group was 0.42 ± 0.05. The fetal right ventricular Tei index of UCAN was higher than the normal group and the difference had statistical significance (p < 0.05) (Table II).

The Fetal Right and Left Ventricular Tei Index of Study Group
The fetal left ventricular Tei index of UCAN group was 0.37 ± 0.05 and the right ventricular Tei index was 0.39 ± 0.07. By comparison, the difference had no statistical significance (p > 0.05) (Table III).

Discussion
The umbilical cord around the neck is a common complication of Obstetrics. The occurrence rate is about 20%~25% of the total number of deliveries.

In the case of umbilical cord around fetal neck, stretching and winding can easily lead to the relatively short umbilical cord, umbilical arterial lumen thinning and hemodynamic changing, which will form microcirculatory disturbance, affecting fetal cardiac function such as ischemia and hypoxia, neonatal asphyxia and perinatal death.

In general, the ability of fetal cardio regulation is relatively poor; therefore, a correct estimation of fetal cardio status is crucial for in utero fetal survival environment and prognosis.

The right ventricle plays a dominant role in the fetal circulation and 63%~66% of combined cardiac output. In combination with the characteristics of blood circulation in the fetal period and the complex anatomical structure of the right ventricle, the fetal right ventricular function has been regarded as the focus of the study.

Table II. Comparison of the fetal right ventricular Tei Index between UCAN group and normal group.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Tei index</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCAN</td>
<td>55</td>
<td>0.42 ± 0.05</td>
<td>-4.20</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Normal</td>
<td>55</td>
<td>0.38 ± 0.05</td>
<td></td>
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</tr>
</tbody>
</table>

Table III. Comparison of UCAN Group Fetal Left and Right Ventricular Tei Index.

<table>
<thead>
<tr>
<th>Ventricle</th>
<th>n</th>
<th>Tei index</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left ventricle</td>
<td>55</td>
<td>0.40 ± 0.07</td>
<td>1.72</td>
<td>&gt; 0.05</td>
</tr>
<tr>
<td>Right ventricle</td>
<td>55</td>
<td>0.42 ± 0.05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Application of M-mode echocardiography in the Estimation of Fetal Right Ventricular Function

The methods of fetal heart function evaluation are divided into invasive and non-invasive. Echocardiography, as a non-invasive method to evaluate the fetal cardiac function, has been widely used in clinical practice with the advantages of safety, convenience, and strong operability.

The M-mode echocardiography was firstly brought up by a Swedish scholar along with the progress of imaging technology. On the basis of the conventional M-mode echocardiography, it includes the anatomic M-mode and the omni-directional M-mode echocardiography to make up for the deficiency of the traditional type.

The omni-directional M-mode echocardiography is able of sampling in an arbitrary direction and recording all structures of the heart in an ultrasonic section, also displaying the cardiac cycle waveforms in multiple directions. It can also show the relationship among different groups, compare the motion information, broaden up the range of measurement and application.

Peak flow velocity in early diastole (E), peak flow velocity in late diastole (a) and the E/a ratio are widely used in the evaluation of adult ventricular diastolic function; however, the scholars found out that the numerical changes of these indicators were less sensitive when used in fetus, and when the fetal cardiac disease or heart rate changes, the E and A peak velocity and E/a could not reflect the condition of the fetal cardiac function. Thereafter, the evaluation of the fetal ventricular diastolic function is one-sided.

In recent years, Tei index has been a valuable indicator to estimate the ventricular systolic and diastolic function, which is less affected by other factors than the other conventional index. It was brought up by a Swedish scholar along with the progress of imaging technology. The computational formula is Tei index = (Isovolumic Contraction Time + Isovolumic Relaxation Time)/Ejection Time, in which the Isovolumic Contraction Time (ICT), the Isovolumic Relaxation Time (IRT) and the Ejection Time (ET) are the important time phases in cardiac cycle. The changes of myocardial cell potential and utilization of ATP are all occurred in ICT and IRT to make the two-time phases even more important, thus it is theoretically possible to use Tei index for estimating the ventricular function. Also, there are researches indicating that Tei index and some measurement standards of interventional cardiac function are significantly correlated. Tei index cannot be affected by the pregnant week, the fetal heart rate and the difference ventricular shape, and does not depend on the reverse flow of the atrioventricular valve. As result, it highlights preferable stability and reflects the whole ventricular function. The reliability of Tei index has been widely demonstrated in the study of cardiac function in adults, children and fetuses.

Despite the positive evaluation of Tei index in the estimation of fetal cardiac function, the limitation lies in the fact that it is relatively difficult to distinguish the changes in ventricular diastolic function and systolic function. Traditionally, the atrioventricular valves diastolic flow frequency spectrum is considered as the indicator of evaluating the left ventricular diastolic function, but as the fetal heart rate is too fast to divide A and E peak at most of the time, it is unable to accurately measure the peak. The Vp spectrum of the heart is less influenced from the cardiac preload and afterload, and also not affected by changes in the heart rate. Therefore, it does not appear pseudo-normalization and can be commonly used as an indicator of the fetal ventricular diastolic function. Nishihara et al studied Vp and the time constant (Tau) such as parameters of cardiac catheterization. Tau is recognized as a golden standard for estimating the ventricular diastolic function. The study showed that Vp was negatively correlated with Tau and there was no significant correlation E, A and E/A and Tau.

Effect of UCAN on The Right Ventricular Function in Fetus

As known, the umbilical cord is a vital bridge to ensure the survival of the fetus in the mother’s womb. It is an important channel to obtain nutrients and oxygen from the mother’s body; in the course of gestation, the umbilical cord can be wrapped around any part of the fetus, in which the umbilical cord around the neck is the most common situation. However, the umbilical cord around the neck will affect the fetal blood circulation disorder in different degrees and severe cases will also cause fetal intrauterine hypoxia and ischemia. It has been found that the occurrence rate of fetal distress in UCAN was higher than that in normal fetuses. Fetal umbilical cord around the neck of fetal amniotic fluid combined with fetal heart function abnormalities often suggests intrauterine distress; if the treatment cannot be carried
out in time, it can cause serious complications, and even result in fetal death\textsuperscript{19}. Nevertheless, the fetus in utero cannot be reached directly by doctors and it is difficult to perform when cardiac function changes occur. Thus, it is more difficult to estimate the fetal cardiac function. When the fetal UCAN occurs, it is especially necessary to estimate the fetal cardiac function in an accurate and correct manner to improve the prognosis of the fetus, reducing the neonatal mortality rate and the perinatal complications, which is of important clinical significance in perinatal medicine.

The normal fetal umbilical cord consists of an umbilical vein and two umbilical arteries, in which the umbilical vein delivers oxygen and rich nutrients blood to the fetus and the umbilical artery returns fetal metabolic products to the placenta. In the fetal period, the patent foramen and the arterial duct are in open state\textsuperscript{19}. The umbilical vein in the liver is separated into two branches with one joining with the portal venous, through the liver tissue and hepatic vein, finally merged with the inferior vena cava while the other one is merged with the inferior vena cava through the venous catheter directly.

The inferior vena cava projects into the right atrium. Partial blood with rich oxygen in the inferior vena cava floods through the oval foramen into the left atrium, and then pumps into the aorta through the left ventricle in the supply of coronary artery, brain and fetal blood circulation. Another part of the blood in the right atrium is mixed with the superior vena cava blood from the fetal head and the upper part of the body flows into the right ventricle, of which the blood is mainly used for the supply of fetal abdominal organs and lower body blood circulation. Since the fetal lungs are not fully developed, the lung tissue and the blood vessels are in the state of contraction, high pulmonary artery pressure and large pulmonary vascular resistance. Only a small amount of blood in the right ventricle enters into the pulmonary artery, and most of the blood flows in the aorta descendens via arterial catheter. A small portion of the blood supplies to the abdominal organs and the lower body circulation of the fetus, where most of the blood still flows back to the placenta through umbilical artery.

In the adult’s body, normally, the circulation mainly depends on the left ventricle, but the fetus blood circulation depends on both the left and right ventricular, among which, the right ventricular output accounts for about 65% of the total supply; therefore, the right heart is predominant in the fetal heart and the right ventricle plays an important role in the fetal blood circulation\textsuperscript{20}. Nevertheless, the heart is composed of the left and right ventricles, in which the left and right heart is considered as a whole and also influences each other. Moreover, the left and right ventricle derive from different origins with different structures. The right fetal ventricle has rich trabecular muscle of saddle shape and the left ventricle is conical with smooth inner membrane.

In the previous studies on cardiac function\textsuperscript{21}, it mostly concerned the left heart system and the right heart function was often inferred from the comparison with the left heart function. In clinical cases, the left ventricular systolic function is usually described by the commonly used terms ejection fraction (EF) and the shortening fraction (FS), but the right ventricle intima is usually incomplete and the description was often missed, so these indicators for the right ventricular function were not suitable for the description; however, the right ventricle was often affected by the post load, resulting in measurement deviation of the right ventricular diastolic function, the ventricular volume and the ejection fraction (EF). In the fetal period, the right ventricle has complex anatomic structure and takes a larger part in the blood circulation. Although it is difficult to estimate the right ventricular function, the function of the right ventricle has been focused as a key of pregnancy\textsuperscript{22}.

On the early stage, the correct estimation of the right ventricle of the fetus can affect the whole and comprehensive estimation of the fetal heart function, and plays a key role in the clinical intervention and prognosis. Tei is one of the many indicators about the right ventricular function as brought up in recent years.

In this study, the $V_p$ value of the UCAN group was significantly lower than that in the normal group ($p < 0.05$), showing that the right ventricular diastolic function of the UCAN group was decreased. The Tei index of the right ventricle of the UCAN group was higher than that in the normal group ($p < 0.05$), which was consistent with previous studies, showing that the UCAN affected the fetal right ventricular function possibly because of umbilical vessels pull tension and compression, narrow lumen, change of the hemodynamic, increased resistance and left ventricular afterload when the UCAN occurred. There was compensatory changes in the left and right ventricular by increase in acting. With a long period, it would result in loss of compensation...
and decrease of left and right ventricular diastolic and systolic function. The fetus obtains oxygen from the mother’s body through umbilical vein compression, followed by blood reduction, which leads to fetal myocardial ischemia. Hypoxia, with the increase of the myocardial cells of anaerobic respiration and ATP production, is reduced, and the fetus will eventually occur metabolic acidosis. With the increased resistance of the umbilical artery circulation, it is difficult to discharge the acidic metabolites produced by the anaerobic fermentation of cardiomyocytes, which can aggravate the injury of the myocardium. Hypoxia and acidosis, all make the energy metabolism of myocardial cells blocked, myocardial contraction force received inhibition, and ultimately leading to fetal heart function is affected eventually.

There was no significant difference in the Tei index between the left and right ventricle of the UCAN group (p > 0.05), showing that the influence of the cord around the neck on the left and the right ventricular function of the fetus was basically the same, perhaps because although the right ventricle in fetal cardiac function occupies an important position, the left and the right ventricles are deemed as a whole. The decrease of the right ventricular function may affect the left ventricular compensatory response; then, it is necessary to estimate the overall heart function.

**Conclusions**

As a noninvasive and quantitative method of estimation of cardiac function, the color M-mode echocardiography is widely used in the clinical practice; therefore, it is of great significance to select appropriate index of cardiac function for estimating the right ventricular diastolic function and the whole heart function of UCAN, and it is of huge practical application value in clinical practice.

**Conflict of Interest**

The Authors declare that they have no conflict of interests.

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