

Four-Channel Tocography in Uneventful Pregnancies: A Prospective Study in Primigravidas and Multigravidas

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OBJECTIVE: *The simultaneous recording of external uterine pressure in four locations on the abdominal wall with four-channel-tocography provides new ways to describe the dynamics of uterine activity.*

METHODS: *Fifty-eight healthy primigravidas and 25 healthy multigravidas were studied prospectively with four-channel tocography during the course of pregnancy. Starting at 21 weeks' gestation, the following five intervals were defined: 21–24, 25–28, 29–32, 33–36 and more than 37 completed weeks. Eligibility criteria included informed consent, no history of malformations of the uterus, and no previous preterm deliveries. Patients were excluded for the following reasons: medication for preterm labor, cerclage, placenta previa, delivery before 37 weeks' gestation, less than three measurements completed, and patient's withdrawal of consent.*

RESULTS: *The median contraction frequency per hour was six for primigravidas and five for multigravidas, without significant correlation with gestational age. At all time periods studied, the median rate of global contractions developing simultaneously in at least three uterine segments was less than 15%; however, it was significantly higher in primigravidas than in multigravidas (14% versus 4%, $P < .001$). Both groups had more activity in the right upper quadrant of the uterus shortly before delivery.*

CONCLUSION: *Four-channel tocography provided insight into uterine activity patterns and might enable obstetricians to select clinically relevant contractions for further treatment. (J Soc Gynecol Investig 2001;8: 48–53) Copyright © 2001 by the Society for Gynecologic Investigation.*

KEY WORDS: Four-channel tocography, local contractions, global contractions, uterine activity.

Preterm labor is defined as labor occurring between 20 and 37 completed weeks' gestation.¹ It is a major cause of preterm delivery, affecting about 10% of births in the United States.² Preterm birth is the cause of at least 75% of neonatal deaths that are not from congenital malformations.²

Despite the introduction of new diagnostic techniques (eg, testing of fetal fibronectin, transvaginal ultrasound), it still remains difficult to differentiate physiologic from abnormal uterine activity during pregnancy. The influence of contractions on cervical dilation cannot be evaluated by routine contraction monitoring, and there is disagreement about how to diagnose preterm labor accurately. The diagnosis of preterm labor is traditionally made by documenting regular uterine contractions accompanied by cervical effacement or cervical dilatation.¹ However, regular uterine contractions have been defined as at least four contractions in 20 minutes or eight in 60 minutes or at least three contractions occurring within 30

minutes or more than four per hour.^{1,3,4} The requirements for cervical effacement vary between 50% and 80%.^{1,5} There is also controversy whether awaiting cervical change compromises subsequent tocolytic efficacy.^{6–8} Thus, the criteria currently used to diagnose preterm labor are not discriminative enough to serve as a reliable basis for accurate assessment and indication for subsequent treatment.

In 1949, a multichannel strain-gage tocodynamometer was designed to study the patterns of uterine contractions in pregnant women. It used three strain-gage dynamometers that recorded contractions from three different parts of the uterus simultaneously (fundus, midzone of the uterus, and the lower uterine segment).⁹ We have developed noninvasive four-channel tocography (4CT) to evaluate whether differentiation between local and global contractions and the characterization of the spatial and temporal development of uterine activity can help obstetricians prospectively identify uterine activity leading to cervical change and, therefore, requiring therapeutic intervention.

In previous studies we reported the use of 4CT in women with preterm labor and during delivery.^{10,11} There have been no previous reports of these methods on patients going to term. The goal of this study was to evaluate uterine activity

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during uncomplicated pregnancies by 4CT to establish baseline criteria for identification of abnormal frequency or coordination of uterine contractions.

In a previous study we reported that the origin of uterine contractions during delivery was predominantly in the right upper quadrant of the uterus.¹¹ Most of the contractions with clear propagation pattern originated on the right upper side, continued to the left and then spread to the right lower part of the uterus. The highest relative intensity of uterine contractions was also measured in the right upper quadrant. The rate of operative deliveries for failure to progress was lower when a predominant right upper (ie, physiologic) origin of labor was apparent.¹¹ Measurements using 4CT in women with preterm labor showed that a predominant origin of contractions in the right fundal region of the uterus and the reproducibility of a center of dominance (defined as the location with the highest sum of amplitudes) were significantly associated with preterm labor.¹⁰

METHODS

We used 4CT to prospectively study 83 women at multiple time points, approximately every 4 weeks, during their pregnancy. Starting with 21 weeks' gestation, the following five intervals were defined: 21–24, 25–28, 29–32, 33–36 and more than 37 completed weeks. Gestational age was calculated from the date of the last menstrual period and was confirmed by first-trimester ultrasound.

Instead of the one transducer used in external tocodynamometry, we placed four transducers over all quadrants of the uterus (fundal area right and left side, lower uterine segment left and right side) to gain information about the distribution of contractions and to be able to assess activity in each uterine segment separately. Examinations were usually done in the morning.

Pregnant women 18 years and older were candidates for this study. Eligibility criteria included informed consent, no history malformations of the uterus, and no previous preterm deliveries. Patients were excluded for the following reasons: medication for preterm labor, cerclage, placenta previa, delivery before 37 weeks of gestation (preterm), less than three measurements completed, or patient's withdrawal of consent.

Instrumentation

The four-channel tocograph developed in the research section of the Department of Obstetrics and Gynecology, Ruhr-University Bochum, Marienhospital Herne (Germany), was used for this study. The device consists of four tocometric transducers interfaced with a portable computer (model Z180, Zenith, St. Joseph, MI). The signals were saved on standard 3.5-inch diskettes after analog-to-digital conversion (12-bit resolution, 2-Hz sampling rate) and processed by custom software. The 4CT recordings were visually evaluated offline with an interactive graphic and mouse-operated, self-developed software program. Traces of contractions were scanned using pattern recognition algorithms.

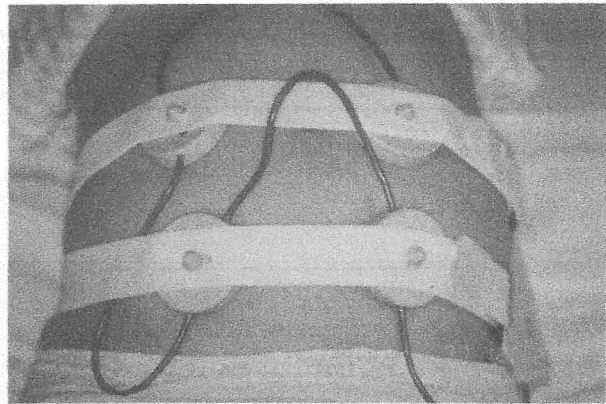


Figure 1. Position of the transducers on the abdomen.

Definitions

This study was done to establish a baseline for further 4CT investigations, so we would like to define 4CT findings as follows. The contraction frequency is the number of contraction complexes per hour. An attempt was made to exclude uterine irritability when contraction frequency was scored. Uterine irritability was defined as multiple contractions within 1 minute with less than 15 seconds between contractions. A contraction was recognized as such if the curve had a duration of at least 30–40 seconds. A contraction complex encompasses all contractions recorded by the different transducers referring to one uterine contraction. Local contractions are contractions that are recorded in only one or two transducers. Global contractions are recorded in at least three of the four transducers. The origin of contraction is the transducer site in which the contraction is detected first, with the onset occurring at least 1.5 seconds before contraction is detected in all other transducers. The contribution of each transducer to the contraction complexes per measurement is defined as participation of each uterine quadrant.

Procedure

To assure the greatest possible compliance, measurements were taken at the patient's home or at the office of the attending physician. The four transducers were fixed on the left and right side over the fundal area and the lower uterine segments with an elastic canvas tube (Figure 1). Measurements took 60 minutes each and were taken with the patient in a comfortable semi-fowler position.

Evaluation

Four-channel tocography data were saved on diskette, copied onto the hard drive of a laboratory computer, and analyzed with a fully automated program that had been developed previously.¹⁰ This software scans the tocography tracks for patterns typical of contractions and then detects the start, peak, and end point of each contraction. By way of time comparison, the program is able to identify the same contraction in each of the four channels. The data obtained were used to calculate the following variables for each measurement: fre-

Table 1. Age, Duration of Pregnancy, and Mode of Delivery

| | Primigravidas (n = 47) | | | Multigravidas (n = 22) | | | U test P |
|------------------------------------|------------------------|---------|---------|------------------------|---------|---------|-------------|
| | Mean | Minimum | Maximum | Mean | Minimum | Maximum | |
| Age (y) | 27 | 17 | 39 | 32 | 24 | 40 | <.001 |
| Duration of pregnancy (wks + d) | 39 ± 5 | 37 ± 0 | 42 ± 5 | 40 ± 1 | 39 ± 0 | 41 ± 4 | .14 |
| Spontaneous delivery (n) | | 36 | | | 18 | | |
| Forceps (n) | | 5 | | | 2 | | .6 |
| C (n) | | 6 | | | 2 | | |

quency of contractions, percentage of global and local contractions, the relative contribution to the origin of contractions for each transducer site, and the frequency of participation in the contraction process.

Statistical evaluation was performed separately for primigravidas and multigravidas. Median values and ranges were used for data presentation and comparison of 4CT parameters (eg, contraction frequencies, involvement of individual lead sites). The differences in central tendencies of both groups were examined using the Mann-Whitney *U* test. Differences in the relative frequency distribution were calculated using the χ^2 test. Paired data were examined using the Wilcoxon test. Statistical significance was accepted at a *P* value < .05.

RESULTS

Eighty-three consecutive patients (58 primigravidas and 25 multigravidas) were evaluated for eligibility. In the group of primigravidas two women were excluded because of tocolytic treatment, one because of a cerclage, and six because of preterm deliveries before 37 weeks' gestation. Two patients were excluded because they had participated in two measurements only. Of the remaining 47 patients, 15 women had five, five women had four, and 27 women had three measurements each. Thus, this group of patients provided a total of 176 measurements with a total of 1370 contractions found by automatic analysis.

In the group of multigravidas, three women were excluded secondary to premature contractions with tocolytic treatment. Twenty women provided five measurements each. In one case each, four and three measurements were taken. Thus, a total of 107 measurements with 707 contractions were evaluated. Table 1 shows the age distribution, length of the pregnancy, and

type of delivery for these women. The body mass index taken at the beginning of pregnancy ranged from 18.0 to 33.6 kg/m² (mean 24.8 kg/m²).

There were no significant differences between primigravidas and multigravidas in duration of pregnancy or mode of delivery (Table 1). The median contraction frequency of primigravidas was higher than that of multigravidas. This difference was significant at the end of pregnancy (*P* = .013, Table 2). The median contraction frequency for all five measurements was six per hour for primigravidas, and five per hour for multigravidas (*P* = .34).

In each time interval, the relative frequency of global contractions was higher in primigravidas than in multigravidas (Table 3). The overall percentage of global contractions in primigravidas was 14% compared with 4% in multigravidas (*P* < .001).

Figures 2 and 3 show the relative participation and origin of contractions for each transducer location. Toward the end of pregnancy the right fundal area gained increasing influence. Primigravidas and multigravidas had an increase in activity in the right upper quadrant of the uterus with increased participation (Figure 2) and more frequent origin of contractions (Figure 3) in this location compared with the other quadrants. Multigravidas showed the lowest uterine activity in the right upper quadrant in the third measurement (29–32 weeks' gestation) with a consecutive increase toward the end of pregnancy. In primigravidas, continuously increasing activity in the right upper quadrant was apparent beginning with the first measurement.

There were no significant differences between groups. However, with regard to participation and origin of contractions in the right upper segment, primigravidas tended to show

Table 2. Frequency of Contractions per Hour in Primigravidas and Multigravidas

| | Weeks of gestation | | | | | Total number of contractions |
|-------------------|--------------------|-------|-------|-------|------|------------------------------------|
| | 21–24 | 25–28 | 29–32 | 33–37 | >37 | |
| Primigravidas | | | | | | |
| n | 16 | 47 | 47 | 47 | 19 | 1370 |
| Median | 7 | 5 | 4 | 7 | 9 | |
| Range | 0–20 | 0–23 | 2–20 | 0–21 | 4–20 | |
| Multigravidas | | | | | | |
| n | 20 | 22 | 22 | 22 | 21 | 707 |
| Median | 4.5 | 3.5 | 7 | 6 | 7 | |
| Range | 0–4 | 0–2 | 0–12 | 0–6 | 0–8 | |
| <i>P</i> (U test) | .059 | .39 | .19 | .77 | .013 | |

Table 3. Percentage of Global Contractions

| | Weeks of Gestation | | | | |
|---------------------------|--------------------|-------|-------|-------|--------|
| | 21-24 | 25-28 | 29-32 | 33-37 | >37 |
| Primigravidas | | | | | |
| <i>n</i> | 16 | 47 | 47 | 47 | 19 |
| Median | 12% | 25% | 14% | 11% | 20% |
| Range | 0-44% | 0-64% | 0-39% | 0-52% | 0-75% |
| Multigravidas | | | | | |
| <i>n</i> | 20 | 22 | 22 | 22 | 21 |
| Median | 0% | 0% | 4% | 0% | 13% |
| Range | 0-33% | 0-50% | 0-50% | 0-50% | 0-100% |
| <i>P</i> (<i>U</i> test) | .13 | .003 | .16 | .021 | .068 |

a higher frequency of contractions, whereas multigravidas had a more general fundal dominance (increasing influence of both upper segments).

For both groups combined, the percentage of the origin of contractions in the right upper quadrant increased from 20% at 29-32 weeks to 25% at term (Wilcoxon *P* < .001). Patients did not report any discomfort during the recordings and were comfortable in the semi-fowler position.

Figure 4 shows a 4CT recording of 30 minutes with a contraction pattern of fundal dominance. The uterine activity (measured as the frequency and origin of contractions in each uterine quadrant) was highest in the right fundal transducer followed by the left fundal transducer.

DISCUSSION

The contraction frequencies measured in both groups during this study were significantly higher than previously reported.¹²⁻¹⁵ Possible explanations of this phenomenon include (1) the automatic evaluation procedure might detect a contraction

based on its typical bell-shaped curve. We intentionally did not specify any additional requirements for the contraction amplitude in order to take the relative character of this signal into account and to obtain a contraction frequency, which was independent of the amplitude. (2) Zahn¹⁵ counted clearly visible contractions, Main et al¹² included contractions of at least 2 mm in height, Moore et al¹⁴ only those higher than 5 mm, and Katz et al¹³ excluded contractions of the low-amplitude, high-frequency type. The absence of such limitations might explain the higher number of contractions detected in our study.

Four-channel tocography appeared to be more sensitive than the single-channel transducer technique, which cannot detect many local contractions. The mean contraction frequency for all measurements with multigravidas was 6.6 per hour when all four transducers were used, and the value decreased to less than half if only contractions in the right upper uterine segment were registered. Thus, the number of contractions detected depended directly on the number of

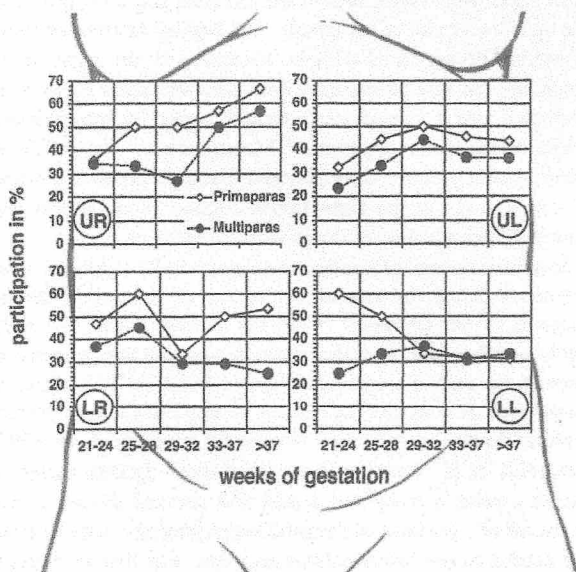


Figure 2. Relative participation (%) of each uterine quadrant in contractions during the course of pregnancy of primigravidas and multigravidas. UR = upper right quadrant; UL = upper left quadrant; LR = lower right quadrant; LL = lower left quadrant.

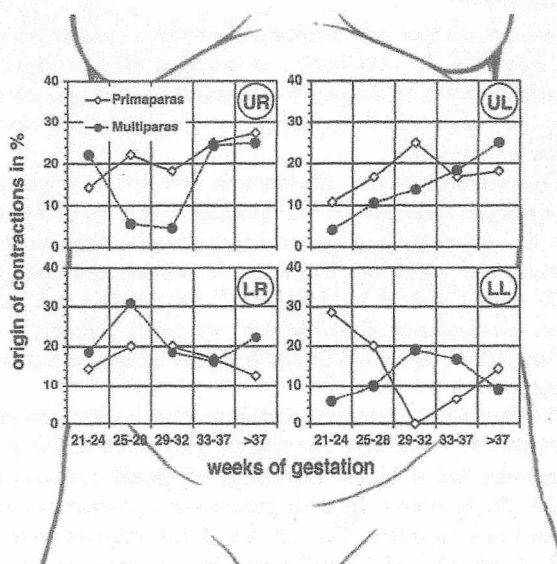


Figure 3. Origin of contractions in each uterine quadrant during the course of pregnancy of primigravidas and multigravidas (%). Abbreviations as in Figure 2.

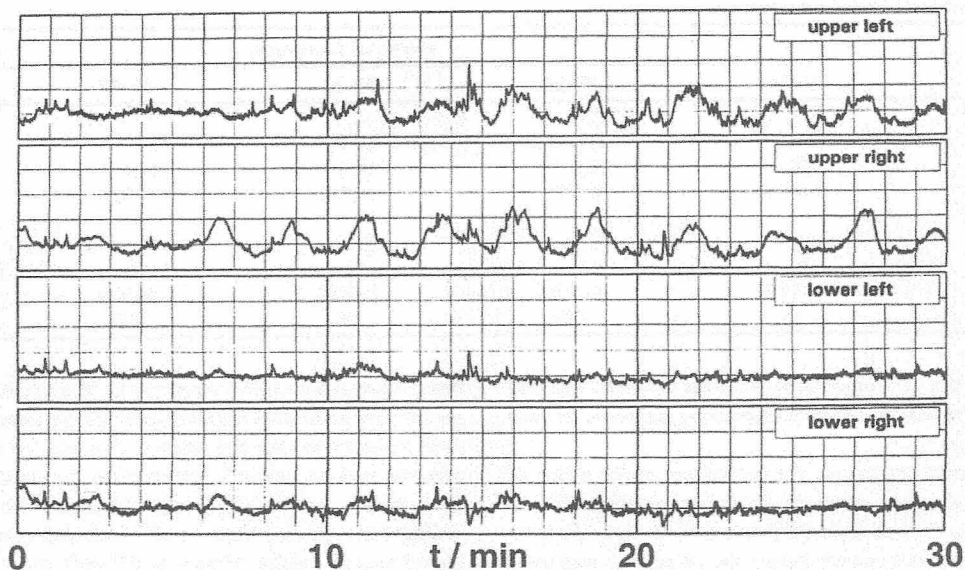


Figure 4. Four-channel tocography (30 minutes) in a primigravida (23 $\frac{3}{4}$ weeks) with fundal dominance of uterine activity.

transducers used. Unfortunately, it is very difficult to apply a standardized pressure to each section of the abdomen, because the week of gestation, the circumference of the abdomen, and the amount of adipose tissue can influence the pressure. Because we did not want to use invasive monitoring we cannot exclude that those confounders contributed to the number of contractions detected.¹⁶

The rejection of contractions that were poorly defined or too small by previous definitions appeared to be closely related to the slowly increasing frequency of contractions during pregnancy, because the intensity and detectability of contractions increased.^{13,15}

We did not base our definition of a uterine contraction on the height of the amplitudes, so our data did not show a correlation between frequency of contractions and gestational age. The contraction frequency increased insignificantly closer to term (Table 2).

Our study showed a difference in contraction frequency between primigravidas and multigravidas (Table 2). In four of five measurements primigravidas had a higher frequency of contractions, which was significant for the last measurement (<37 weeks). Zahn¹⁵ and Main et al¹² described the independence of frequency of contractions and parity probably secondary to their opinion-based exclusion of certain contraction patterns.

Another sign of increased uterine activity in primigravidas compared with multigravidas was the phenomenon that primigravidas had a higher percentage of global contractions (Table 3). However, in both groups most contractions remained of local origin. The fact that all the pregnant women studied had uneventful pregnancies with term deliveries might explain the overall higher percentage of local contractions. In contrast, a previous study investigating patients with preterm labor by 4CT showed almost 50% global contractions.¹⁰ This

comparison might indicate that a high rate of global contractions can be interpreted as a sign of increasing effectiveness of uterine activity carrying a risk of prematurity, if observed early in pregnancy. In investigations using 4CT during delivery and preterm labor, there was a correlation between the origin of contractions in the right upper quadrant and the efficacy of labor.^{10,11}

During delivery the origin of contractions was predominantly in the right upper quadrant of the uterus. Most of the contractions with clear propagation patterns originated in the right upper side, continued to the left side, and then spread to the right lower part of the uterus. The highest relative intensity of uterine contractions was also measured in the right upper quadrant. The rate of operative deliveries for failure to progress decreased when a predominant right upper (ie, physiologic) origin of labor was apparent.¹¹ Measurements using 4CT in patients with preterm labor showed that a predominant origin of contractions in the right fundal region of the uterus was associated with a shorter duration of pregnancy.¹⁰

Synchronization of contractions is generally regarded as an important factor for increasing dilation of the cervix during pregnancy and delivery.¹⁶⁻¹⁸ In the present study, the right fundal area became more dominant as a contraction pacemaker towards the end of pregnancy (Figures 2 and 3). This could be interpreted as a sign of increasing synchronization of uterine motility in the normal and uneventful pregnancy. In 1949, Reynolds et al¹⁹ used a three strain-gage dynamometer to record uterine activity and found that cervical dilatation was the result of a gradient of diminishing physiologic activity from the fundus to the lower uterine segment, and that in dystocia the contraction pattern deviated from this effective pattern. Shinmoto et al²⁰ evaluated quality differences between various contractions in preterm and term labor by monitoring two contraction curves simultaneously with one tocodynamometer

attached to the middle part of the uterine fundus and the other to the caudal part of the uterus with a distance of more than 15 cm. They defined contraction curves as concurrent when they were recognized in the upper and lower uterine segment simultaneously and as synchronized when the peaks of two such concurrent contractions occurred within 1 mm of each other. The percentages of both concurrent and synchronous contractions were significantly higher during the active phase of labor. Synchronization of contractions was found to be one of the most important factors in producing a strong expulsive force. It was suggested that their method might provide important information for understanding the quality of contractions and would aid in determining whether oxytocin or tocolysis should be given in term or preterm labor.

According to the American College of Obstetricians and Gynecologists² there are no established criteria for the initiation of tocolytic therapy. Four-channel tocography apparently permits assessment of increasing synchronization of uterine activity. Not only can the frequency of contractions be monitored, but their origin and the relative contribution of each uterine quadrant can also be determined. Having determined baseline data for 4CT interpretation in normal pregnancies, further studies are necessary to evaluate increasing synchronization as a possible sign of significant premature contractions. Such studies might show whether 4CT can be used to establish criteria for tocolytic therapy or dose adjustment. For those studies it will be necessary to take into account potential confounders, such as time of day of the examination, blood pressure, relationship to meals, and time of last intercourse. The first prototype of this instrument has been available since April 2000.

In conclusion, 4CT, especially with online interpretation, might identify a group of women at high risk for preterm labor needing further intensive evaluation and surveillance and to distinguish those from women with uterine irritability (contractions without a demonstrable cervical change in effacement or dilatation).⁶

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