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Evaluating the progress of the labour with sample entropy calculated from the uterine EMG activity

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Abstract. The aim our study was to investigate the possibility to follow–up the progress of the labour by using electromyographic signals obtained from the uterine corpus and cervix. In order to interpret electromyographic signals, we used sample entropy, i.e. the measure of time - series regularity, which we calculated from uterine corpus and cervix electromyographic signals. Approaching the childbirth during a normal labour, the increased regularity in uterine corpus muscles and cervical muscles activity is indicated as a decreasing trend in the sample entropy values. Effectiveness of the oxytocin drug is reflected in reduced sample entropy values calculated from electromyographic signals of the uterus after each dose change of oxytocin. A delay in the labour, which is a result of cervical circular muscles active contractions, corresponds to greater sample entropy values calculated from the electromyographic activity of the cervix.

Keywords: sample entropy, electromyographic (EMG) signals, cervical dilatation, labour progression

Spremljanje poroda z vzorčno entropijo, izračunano iz elektromiografskega zapisa maternice

Povzetek. V študiji smo izračunali vzorčno entropijo (SampEn) elektromiografske (EMG) aktivnosti materničnega telesa in materničnega vratu med porodom. Vzorčna entropija je mera regularnosti časovnega niza. Zanimalo nas je, kako se vrednosti SampEn spreminjajo pri normalnem poteku poroda ter kako se zastoj poroda in počasi napredujoči porod, stimuliran z oksitocinom, odražata na spreminjanju vrednosti SampEn. S približevanjem otrokovega rojstva se regularnost mišične aktivnosti materničnega telesa in materničnega vratu poveča, kar se kaže kot padajoči trend vrednosti SampEn. Učinkovitost zdravila oksitocin, ki pospešuje porod, se odraža v zmanjšanih vrednostih SampEn, izračunanih iz EMG aktivnosti materničnega telesa. Zastoj poroda, ki je lahko posledica dodatne aktivnosti cirkularnih mišic materničnega vratu, se odraža v povečanih vrednostih SampEn, izračunanih iz EMG aktivnosti materničnega vratu.

Ključne besede: vzorčna entropija, elektromiografski (EMG) signali, širjenje materničnega vratu, napredovanje poroda

1 Introduction

The uterus is unique among the smooth muscular organs. At term, the uterine corpus quiescent state is converted to a highly contractile state and the cervix dilates and retracts. Differences between the uterine corpus and cervix are regulated by independent mechanisms during a normal labour, although synergistically, they assure a successful labour [1-4].

To achieve the cervix role in pregnancy, its smooth muscle fibres, lying also longitudinally but more or less in a circular pattern, should contract satisfactorily and actively contribute to the closing of the cervical canal. In fact, due to electrical coupling between the uterine corpus and cervix, uterine corpus electrical signals may propagate through the cervix as well. Studies based on recording cervical and uterine electromyographic (EMG) activity indicate that through the latent phase of the labour the EMG activity of both parts is synchronically grouped into bursts [4-7]. But the smooth muscle fibres present in the cervix act also partly independent of the uterine corpus. In our previous studies, we found asynchronous EMG bursts that could be attributed to the independent muscle activity of a relatively unripe cervix [8]. In the early latent phase, the bursts are often superimposed on the permanent background activity. Moreover, the cervical muscle activity, recorded transversely in the cervix, is present through the entire course of the labour and contributes to the duration of the latent phase [9].

Progress in the labour is typically followed by measuring cervical dilatation and fetal head descent. Both values are outlined graphically as a partogram (see part A of Figures 1-4). The values for the cervical dilatation range along the scale from 0 to 10 cm. If the

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cervical dilatation lags more than two hours behind the expected dilatation, the labour is considered to be abnormal. The values of the head station range on the scale of the partogram from -5 to 5 cm. Presently, determination of the fetal head station and cervical dilatation is carried out solely by palpation, and is therefore highly subjected to errors [5].

Different methods and instruments have been designed for accurate measurement of cervical dilatation, fetal head descent or progress of the labour as a whole [5,10] but none has found its way to clinical practice. The aim of present study was to investigate the possibility to follow–up progress of the labour by using electromyographic (EMG) signals obtained from the uterine corpus and cervix. In particular, we focused on the early recognition of a labour that is becoming disfunctional. To achieve this goal, the sample entropy (SampEn) was calculated to register changes in regularity of the signals. By using entropy methods, the complexity (or its opposite, i.e. regularity) of stochastic processes can be measured. In general, the values of entropy increase with complexity of the signal and decreases with its regularity [11,12,13].

2 Methods

2.1 Sample Entropy

SampEn is a negative natural logarithm of the probability that two sequences similar for *m* points remain similar at the next point, where self-matches are not included [10, 11, 12]. Thus, a lower value of SampEn indicates more regularity in the time series.

Formally, given N data points from a time series {x(n)}={x(1), x(2), …, x(N)}, to define SampEn, one should follow these steps:

1) Form N-m+1 vectors X(1), …, X(N-m+1) defined by X(i)=[x(i), x(i+1), …, x(i+m-1)], for $1 \le i \le$ N-m+1. These vectors represent m consecutive values of the signal, commencing with the i-th point.

2) Calculate the distance between X(i) and X(j), d=[X(i), X(j)], as the maximum absolute difference between their respective scalar components:

$$d\left[X(i), X(j)\right] = \max_{k=1,2,\ldots,m}\left(\left|x(i+k) - x(j+k)\right|\right). \tag{1}$$

3) For a given X(i), count the number of j ($1 \le j \le$ N-m, $i \ne j$), such that the distance between X(i) and X(j) is less than or equal to $r \cdot$SD and calculate $B_r^m(i)$:

$$B_r^m(i) = \frac{1}{N-m-1}\sum_{j=1, j\ne i}^{N-m}\Theta\left(r \cdot SD - d\left[X(i), X(j)\right]\right). \tag{2}$$

Where Θ is the Heaviside function (Θ(z≥0)=1) and (Θ(z<0)=1), SD is the standard deviation of the signal x(n) and r is a tolerance window [5, 6, 7].

4) Calculate B_r^m as:

$$B_r^m = \frac{1}{N-m}\sum_{i=1}^{N-m} B_r^m(i). \tag{3}$$

5) Increase the dimension to m+1 and calculate $A_r^m(i)$:

$$A_r^m(i) = \frac{1}{N-m-1}\sum_{i=1, j\ne i}^{N-m}\Theta\left(r \cdot SD - d\left[X(i), X(j)\right]\right). \tag{4}$$

6) Calculate A_r^m as:

$$A_r^m = \frac{1}{N-m}\sum_{i=1}^{N-m} A_r^m(i). \tag{5}$$

7) Calculate sample entropy defined as:

$$SampEn(m, r, N) = -\ln\left(\frac{A_r^m}{B_r^m}\right). \tag{6}$$

2.2 Patients and EMG recording

The investigation was approved by the National Medical Ethics Committee, and an informed consent was obtained from all 32 patients enrolled in the study. Patients included in the study were all undergoing their first labour at the age from 19 to 35 years. After admission to the delivery room, the values of cervical dilatation and fetal head descent were outlined into the partogram.

The patients were divided into three groups with regard to their partograms: normal labour, labour with delay in an active phase of the labour and slowly progressing labours stimulated by the oxytocin drug. Depending on the patient state and the state of the labour, an obstetrician decide whether to measure only the uterine corpus or only cervical EMG. The measurement details were already described in our previous studies focused on difference between the cervix and uterine corpus muscle activity during the labour [9].

The group of “normal labours” included 13 patients. 6 of them had cervical and uterine corpus EMG records, 7 of them had a cervical EMG record. The group of “slowly progressing labours stimulated by oxytocin” included 4 patients and all of them had cervical and uterine corpus EMG records. While 13 patients in the group “labours with a delay in an active phase of the labour” had a cervical EMG record and 2 patients from this group had cervical and uterine corpus EMG records.

2.3 EMG analysis

EMG signals were first detrended and band-pass filtered (0.1 – 3 Hz) using the Butterworth digital filter of the second order. We decreased the sampling rate of the EMG signals by keeping every second sample. SampEn (m = 2, r = 1) was calculated on 4500 data points, therefore, the SampEn value was available every 8.2 minutes. Signal processing was made in Matlab.

3 Results

To present each type of the labour observed, we will outline five labours. Each figure presents one labour. The figures are in general composed of three parts; in part A, the partogram of the labour is shown, in part B, the values of SampEn obtained from EMG of the uterine corpus are shown and in part C, the values of SampEn obtained from EMG of the cervix are shown. On the absciss there is time in hours in each part of the figure; on the ordinate there is cervical dilatation (marked with squares) and head station range (marked with circles) in part A, while in parts B and C of the figure there are the SampEn values obtained from EMG of the uterine corpus and cervix, respectively. In the figures, the border between the latent and the active phase of the labour is marked with a grey zone. The border between the latent and the active phase was determined by the obstetrician as a 3-4 centimetre cervical dilatation.

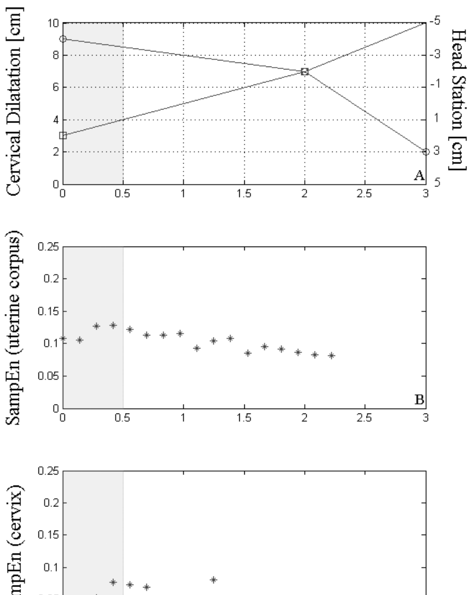

Figure 1. Active phase of a normal labour presented with a partogram (A), where the cervical dilation is marked with squares and the head station with circles. The SampEn values are calculated from the uterine corpus (B) and cervical EMG (C). The grey zone (part B and C) separates the latent (on the left side of the zone) and the active (on the right side of the zone) phase.

Slika 1. Aktivna faza normalnega poroda je prikazana s partogramom (A), kjer je dilatacija materničnega vratu označena z kvadrati in spuščanje in obračanje vodilnega dela ploda z krogi. Vrednosti SampEn so izračunane iz EMG materničnega telesa (B) in vratu (C). Sivo področje označuje mejo med latentno (na levi strani sivega področja) in aktivno (na desni strani sivega področja) fazo poroda.

3.1 Normal labour; Cases 1 & 2

The partograms in Figures 1A and 2A represent the progress of the normal labour; dilatation of the cervix is progressing in the course of time and the head of the fetus evenly drops to the birm, without any delay.

Observation of the labour presented in Figure 1 started at a 3 cm cervical dilatation, i.e. at the beginning of an active phase of the labour. The SampEn values calculated from EMG of the uterine corpus are above 0.1 at the beginning of the active phase of the labour (Figure 1B) and, while approaching the childbirth, reduce below 0.1. The SampEn values calculated from EMG of the cervix are between 0.05 and 0.1 at the beginning of the active phase (Figure 1C) and, while approaching the childbirth, they reduce below 0.05.

Our observation of the labour presented in Figure 2 started in the latent phase of the labour. The SampEn values calculated from EMG of the cervix amount to 0.1 during the latent phase (Figure 2c). They start to reduce at the beginning of the active phase, and, as in the previous case, reduce below 0.05 while approaching the childbirth.

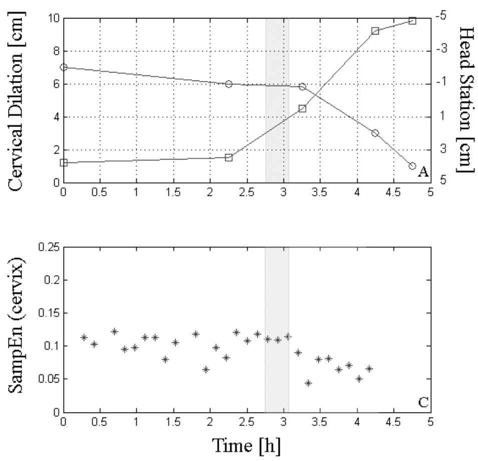

Figure 2. Latent phase of a normal labour presented with a partogram (A), where the cervical dilation is marked with squares and the head station with circles. The SampEn values are calculated from the cervical EMG (C). The grey zone (part C) separates the latent (on the left side of the zone) and the active (on the right side of the zone) phase.

Slika 2. Latentna faza normalnega poroda je prikazana s partogramom (A), kjer je dilatacija materničnega vratu označena z kvadrati in spuščanje in obračanje vodilnega dela ploda z krogi. Vrednosti SampEn so izračunane iz EMG materniga vratu (C). Sivo področje označuje mejo med latentno (na levi strani sivega področja) in aktivno (na desni strani sivega področja) fazo poroda.

3.2 Slowly progressing labour stimulated by oxytocin; Case 3

A slowly progressing labour is presented in Figure 3. The time of the oxyitocin dose change, is marked in Figures 3B,C with the vertical line and the new dose is written. The SampEn values calculated from EMG of the uterine corpus are 0.05 at the end of the latent phase. At the beginning of the active phase of the labour (Figure 3B), the SampEn trend is increasing. SampEn amounts to 0.15 at a 4 cm cervical dilatation. After the dose of oxytocin is increased to 20 gtt, the SampEn values calculated from EMG of the uterine corpus are reduced. The SampEn values drop to 0.05 in one hour. After one hour they start to increase again. Each dose of oxytocin results in reduction of the SampEn values, but they start to increase again in the next 30 – 60 min. The increasing trend is present until the next change of the oxytocin dose.

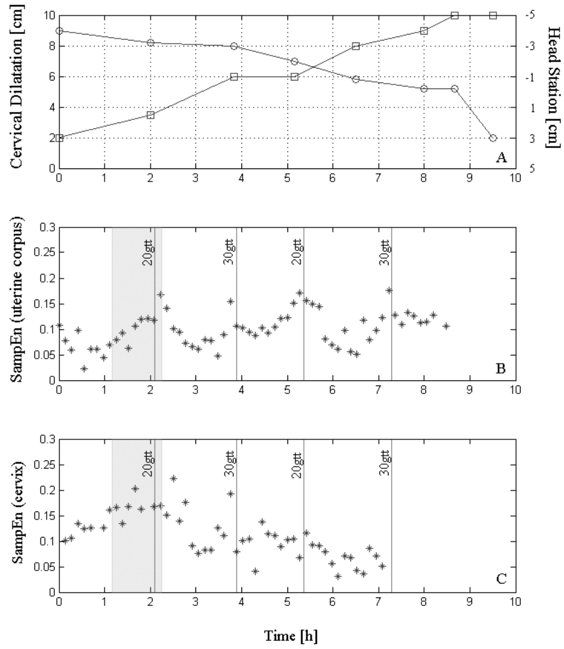

Figure 3. Progress of a slowly progressing labour stimulated by oxytocin presented with the partogram (A), where cervical dilatation is marked with squares and the head station with circles. The SampEn values are calculated from cervical EMG (C). The grey zone (part B and C) separates the latent (on the left side of the zone) and the active (on the right side of the zone) phase. The lines mark the time when a specific dose of oxyitocin began being given to the patient. The given dose is written on the line.

Slika 3. Potek počasi napredujočega poroda stimuliranega z oksitocinom, prikazan s partogramom (A), kjer je dilatacija materničnega vratu označena z kvadrati in spuščanje in obračanje vodilnega dela ploda z krogi. Vrednosti SampEn so izračunane iz EMG materniga vratu (C). Sivo področje označuje mejo med latentno (na levi strani sivega področja) in aktivno (na desni strani sivega področja) fazo poroda.

The SampEn values calculated from the EMG activity of the cervix (Figure 3C) are about 0.15 at the end of the latent phase. At the beginning of the active phase they start to decline and they keep the reducing trend in the course of time. While approaching the childbirth, the SampEn values drop under 0.05 as in the case of a normal labour. The influence of the oxytocin dose change can not be noticed in the SampEn values calculated from the EMG activity of the cervix as well.

3.3 Labour with a delay; Case 4

In Figure 4A, a partogram of a labour with a delay is shown. The curve with a descending trend, representing the fetal head station, has the same value for nearly two hours before continuing the descending trend. During this time, the cervical dilatation rising trend is limited, too. The SampEn values calculated from the EMG activity of the cervix (Figure 4C) are round 0.1 at the beginning of the active phase of the labour. But instead of decreasing to 0.05 and below 0.05 when approaching the childbirth, the SampEn values rise up to 0.2 at the time of stagnation. The SampEn values drop to 0.1, when, according to the partogram, the labour progresses again by a progressive dilatation of the cervix and fetal head station. While approaching the childbirth, the SampEn values reduce to 0.05 as in the case of a normal labour.

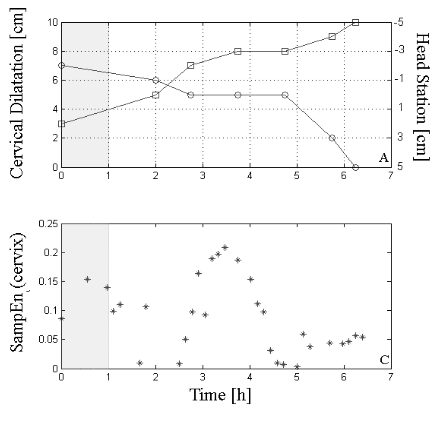

Figure 4. Progress of the labour with a delay presented with a partogram (A), where the cervical dilation is marked with squares and the head station with circles. The SampEn values are calculated from the cervical EMG (C). The grey zone (part C) separates the latent (on the left side of the zone) and the active (on the right side of the zone) phase.

Slika 4 Potek poroda z zastojem prikazan s partogramom (A), kjer je dilatacija materničnega vratu označena z kvadrati ter spuščanje in obračanje vodilnega dela ploda z krogi. in vrednostmi SampEn izračunanih iz EMG materniga vratu (C). Sivo področje označuje mejo med latentno (na levi strani sivega področja) in aktivno (na desni strani sivega področja) fazo poroda.

4 Discussion

The SampEn values calculated from the uterine corpus and cervical EMG activity provide a new insight in the uterine corpus and cervix activity. Instead of analyzing just bursts (contractions) in the EMG signals [16,20,21,22], we calculated the SampEn values from relatively long nonoverlaping segments (8.2 minutes) through the whole EMG records, that usually last for hours. In this way, the latent as well as the active phase of the labour is followed-up by SampEn values, which are the measure of the signal regularity.

In the case of a normal labour, the EMG activity of the uterine corpus muscles and cervical muscles is, while approaching the childbirth, progressively regular. The uterine corpus and cervixs EMG activities are mostly grouped into bursts which are synchronized with each other, and with uterine contractions. While approaching the childbirth, the intensity of the EMG activity of the cervix is usually smaller than that of the corpus. According to the calculated SampEn values, the regularity of the EMG activity of cervical muscles is more pronounced than the regularity of the EMG activity of the uterine corpus muscles. SampEn values calculated from the EMG activity of uterine corpus are slightly above 0.1 at the beginning of the active phase of a normal labour and, while approaching the childbirth, reduce below 0.1. The SampEn values calculated from the EMG activity of the cervix are 0.1 during the latent phase and at the beginning of the active phase and, while approaching the childbirth, drop below 0.05.

If the labour progress is slow, oxytocin is given to the patient to activate the process that results in repeatable and effective contractions of the uterine muscles. As shown in Figure 3, each dose of oxytocin cause more regular contractions of the uterine corpus muscles for approximately one hour and consequently the SampEn values calculated from the EMG activity of the uterine corpus have been reduce in the time after oxytocin is administered (Figure 3B). When the oxytocin dose becomes too small to act efficiently, the SampEn values raise again due to an irregular uterine muscles activity. Our results suggest that it would be possible to follow the oxytocin efficiency by measuring the EMG activity of the uterine corpus and calculating SampEn values simultaneously. Namely, when three consecutive values of SampEn have an increasing trend, oxytocin is no longer effective.

On other hand, the influence of oxytocin can not be noticed in the SampEn values calculated from the cervical EMG. Olah et al. [23] have suggest that the cervix may contract in response to oxytocic stimulation during the latent phase of the labour. According to our results, in the active phase, the influence of oxytocin is not connected to the cervical muscles activity; it seems that cervical muscles act independently from oxytocin at least in the active phase of the labour.

A delay in the labour (Figure 4), noted in the partogram as stagnation in the cervical dilatation and fetal head descent, is accompanied by a less regular EMG activity of the cervix then during the active phase of the normal labour. An additional regularity in the EMG activity of the cervix can be registered in a considerable decrease in the SampEn values (up to 0.2). As the regularity in the EMG activity of the cervix is increased, the SampEn values drop to normal values and the labour progresses. It should be noted that the EMG activity of the cervix was measured in a circular direction. Therefore, the additional complex EMG activity detected by SampEn probably represents the circular muscle fiber activity, which may hinder effective dilatation of the cervical canal during the active phase of the labour [10] and consequently cause its delay. By measuring the cervical EMG activity and calculating SampEn simultaneously, such a delay in the active phase of the labour can be noticed in approximately 25 min – immediately after three consecutive SampEn values increase over 0.1.

Our results confirm that the progress of the labour can be monitored by recording the cervical and/or uterine EMG activity and simultaneously calculating SampEn.

5 Acknowledgment

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