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Computed dip-parameters derived from digitized FHR-curves I. The describing parameters and the method of digitizing

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Cardiotocography (CTG), i. e. the recording of fetal cardiac actions and maternal uterine contractions offers a tremendous amount of new information about the state of the yet unborn child before and during birth.

The visual interpretation of CTG until now has been subjective and is based only upon descriptive criteria. The arbitrary introduction of catchwords has muddled the CTG nomenclature and made a precise communication of research reports quite difficult. For this reason and because not every clinician can be expected to have experience in the interpretation of curves and detailed knowledge in biological feed-back systems, the evaluation of the tracings is often uncertain and published results, at times, offer confusing information.

For the reasons cited, the search for criteria which describe the informational content of CTG or even interpret them is understandable.

This part of our work will point out an **approach towards the derivation of descriptive CTG parameters**. The subsequent part will examine these parameters in reference to the content of the clinical information, and in the concluding part an evaluating CTG parameter is calculated from the descriptive parameters.

1 Methods of transferring analog CTG curves onto magnetic tape

Until CTG standards have been established from objective evaluation criteria, an on-line evaluation where patient data are directly fed into the computer

Curriculum vitae

Dr. rer. nat. JÜRGEN MORGENSTERN was born 1939 in Hamburg. He studied physics, obtained his diploma in 1965 and earned his doctorate in 1969 in the area of nuclear physics. Professor R. ELERT and Dr. K. HAMMACHER at the Department of Obstetrics at the University of Düsseldorf called for him in 1969. At the Women's Hospital he has established an intermediate computer center and carries out research of biomedical signals in perinatal medicine, particularly the fetal heart frequency.

is not meaningful. Therefore, we chose three years ago in Düsseldorf the approach of off-line data processing in which **previously recorded CTGs were evaluated**. These CTG curves on file contain frequently pathologic changes. The continuous improvement in CTG interpretation has the consequence that these changes are being avoided and thus CTG recordings are terminated by preventive obstetric procedures.

For the purpose of the evaluation we coded the clinical data of patients who had a CTG and transferred them to digital magnetic tapes. With appropriate programming several questions can be answered from the data [1]. In particular, from certain characteristics, groups of patients (for instance, those cases with pathologic neo-

Fig. 1. On the left side the photographic stencil with a CTG portion of 11.5 minutes is depicted. The oblique lines and dots are for calibration, normalization and linearization. The perforated tape depicted in the left lower picture contains the identification of the patient. The right side depicts the same CTG segment following digitization as stored in the computer.

natal states) can be compared with one another (e. g., cases with normal neonatal courses).

The CTG from groups thus selected are photographed and automatically digitized with a scanning device, i. e. processed appropriately for the computer and stored on magnetic tape. This method will be described in more detail:

All CTGs of a patient are transferred sequentially under a stencil on a 24×36 mm film in segments of 11.5 minutes each, using a 35 mm camera with a large cassette (Contarex). Fig. 1 depicts on the left side a CTG segment thus photographed. The calibration points at the beginning and end at 0 and 60 mmHg as well as 50 and 210 bpm respectively were marked on the tracings before exposure. These points insure the continuity to the next exposure. Dashes, oblique lines, and points on the stencil aid calibration, normalization and linearization. The depicted segment of a

perforated tape contains the necessary identification of the patient and the exposure. A film with 450 exposures thus contains about 5,000 CTG minutes from several patients.

Single exposures were scanned horizontally by a cathode-ray in a so-called flying spot digitizing device (FSD) (Fig. 2). This device can be explained as follows:

On a cathode-ray tube a light dot of 10μ diameter is created which — as in television — by deflection from left to right generates a line. With repetition of the process the line is being shifted vertically until the entire screen has been covered.

This cathode ray is being depicted through an objective lens on a film and simultaneously on a grid whereby the lines run vertically to the grid. Grid lines and the intervals are each 20μ . Light penetrating the grid intervals and the transparent areas of the image is accepted by a photomultiplier. The signals from the grid are counted by a 12 bit binary counter. This counter is only then counted by a computer (CAE 90—10) if the photomultiplier noted

Fig. 2. Schematic arrangement for digitization of photographed CTG curves. PM: photomultiplier, MT A: magnetic tape A.

Fig. 3. The data processing pathway from the CTG paper curve to the digital magnetic tape.

change in lightness of the image behind the CTG image to be digitized, i. e. if a FHR or labor curve was crossed. The double line (Fig. 1, left upper half) serves as a reference point. When this double line is found the counter is reset to zero so that the content of the counter for the number of the signals from crossed-grid lines is a measure for the distance of the curve from the double line. The 4 oblique lines situated beneath the double line define the Y-coordinate of the scanning line, i. e. they indicate the number of seconds of digitization.

If after the crossing of the double line and a oblique line (Fig. 1, left half from top to bottom) there is a value for fetal heart frequency (transparent area of the film) the counter is being read and transmitted to the core of a computer (Fig. 2). After the scanning of an image, the content is stored on magnetic tape, A.

Fig. 3 depicts the further processing schematically. The magnetic tapes A with the input from the CAE computer are processed further in a larger computer. Programs are written in IBM-FORTRAN IV.

The program system initially reconstructs the digital information from the FSD and the data are transferred onto another magnetic tape B with a time reference (seconds). The B tapes are the basis for the evaluation of the data on the HP 2116 B computer of our Women's Hospital. Programs for reading the tapes and for data processing were written in ASSEMBLER language. In view of the small (only 16 K) core, the respective frequency and contraction data were written in one 16 bit computer word: The terminal magnetic tape C in each record contains identification characteristics and 60 frequency-contraction words. The right portion of Fig. 1 depicts the same CTG portion, following digitization as found on magnetic tape C. The conformity is evidently good.

In order to meet objections that the digitization of one per second is too low to investigate short

Fig. 4. Above: Simulated heart frequency curve and correlated histogram. Middle: Heart frequency curve sampled at one per second and correlated histogram. Below: Heart frequency averaged over one second with correlated histogram.

term variations we simulated a heart frequency with a random generator (Fig. 4, top). The curve underneath depicts the expected rectangular frequency distribution. If the generator curve is sampled in the same relation as in the digitization of the fetal frequency curve described, curve 3 in Fig. 4 is found. The correlated frequency distribution is also rectangular. If instead of the correct sampling, the mean FHF over one second is chosen, curve 5 in Fig. 4 is derived; as expected the correlated frequency distribution is not anymore rectangular. This already known finding means that the amplitudinal characteristic of the FHR is preserved only with a sampling method, not with the averaging method.

2 Descriptive parameters from areas of deceleration of the fetal heart frequency

After it had been established that original data were not altered by digitization, the intended evaluation of contraction-related deceleration areas was begun. An automatic method of finding these areas without visual aid was not used for the following reasons:

1. Without visual control artifacts which cannot be eliminated by the program without a large loss of information of "genuine" data falsify the result.
2. For the evaluation the knowledge of the base line frequency before and after the area is required. This determination is easy for isolated areas, however, may be very difficult if areas follow each other closely and if there are marked oscillations.

For these and other reasons the segment for the calculation of the base line frequency before and after deceleration and the position of the peak of the contraction slope were roughly determined visually. From these values the program computes automatically all parameters describing one deceleration area.

Fig. 5 illustrates the derived parameters (P). The solid curve above is the original tracing of an FHR deceleration. The two curves underneath repeat this FHR curve. The bottom curve is the original tracing of the correlated contraction. In order to describe the initial and terminal state

Fig. 5. Contraction-related FHR deceleration area with hatched area 1 and area 2 (second curve from above) and time parameters by approximation lines (second curve from below).

of the FHF deceleration, the mean FHR, the so-called base-line frequency, (horizontal line before and after the dip in Fig. 5) is derived from intervals of at least 15 seconds before and after the dip (P1, P2). Besides this mean FHR the fluctuation is computed from the original data. The fluctuation before, within, and after the dip is an objective value for the oscillation of the FHR (P3, P4, P5). For the calculation of the fluctuation, the original data are smoothened over 25 seconds by the moving-average process. We called the arithmetic mean of the absolute differences between the original and smoothened data "fluctuation." For the exact description of a dip it is necessary to determine the time and duration of characteristic changes of the FHR. For this purpose, as depicted in Fig. 5,

each dip is approximated with 6 lines. Each line is a best fit through the data points. One line is drawn through the base-line frequency before the dip, one through the decrease of the FHR to the dip minimum, and one through the duration of the minimum. The rise from the dip minimum to the base-line frequency after the dip is described by the fourth and fifth lines, while the 6th line is positioned through the base-line frequency after the dip. This approximation by lines which occurs fully automatically, thus serves only the definition of the time interval parameters from the intersection of the lines. For clarification these intersections are labelled in Fig. 5 with the letters A—F. Thus the following parameters are defined by the respective intersecting points:

decrement time (P6): A, B

duration at minimum (P7): B, C

recovery time (P8): C, E or C, F

total duration (P9): A, F.

Summary

A method of data processing for the derivation of descriptive cardiotocography (CTG) parameters for the areas of deceleration is described. For the evaluation the relevant perinatal clinical data are coded. With a program, patient groups with certain common characteristics are established. All correlated CTGs are digitized, i. e. transformation of analog curves into equidistant time series. For this purpose CTG curves are photographed under a stencil. The films with about 450 exposures each of 11.5 minutes of CTG are scanned automatically electronically and written as digital series on magnetic tape.

The quality of the digitization is discussed. It is shown that the amplitude of the digitized curves corresponds without distortion to the original curves.

The data tapes are evaluated with the compact computer of the Women's Hospital. In programming the limits of a

Area parameters are calculated from the sums of the values between the corresponding intersecting points:

Total Area (P10): A, F

Area 1 (P11): A, E

Area 2 (P12): D, F

Area 3 (P13): W, F.

In the area curve (Fig. 5) area 1 and area 2 are emphasized by contrasting hatched lines. The amplitude of the dip (P14) is derived from P1 and P2 and the FHF at dip minimum (P15). The duration at half amplitude (P16) is calculated from P6, P8, and P14. The lag time (P17) is defined as the time W, B.

From these parameters described in detail, others are calculated so that a total of 30 parameters are derived from each deceleration area. These are transferred to the result magnetic tapes together with the identification data.

small computer and the demands for ease of application and high flexibility had to be considered. The final evaluation considers the areas of deceleration of the fetal heart frequency and the corresponding contractions. From each of these areas, typical parameters descriptive of the dip are derived. For the determination of the time parameters, each area of deceleration is approximated by six lines (Fig. 5). The derivation of 17 parameters is discussed in detail. Others are derived from these so that there is a total of almost 30 parameters.

The parameters of each area of deceleration are stored on magnetic tape together with identification data. These parameters are then analyzed statistically for further evaluation.

Keywords: Asphyxia index, decelerations, parameters of deceleration, digitized data, electronic data processing, frequency distributions, fetus.

Zusammenfassung

Computer-Auswertung von Dip-Parametern aus digitalisierten fetalen Herzfrequenzkurven I. Beschreibende Dip-Parameter und Methode der Digitalisierung

Es wird der Datenverarbeitungsweg zur Ableitung beschreibender Kardiotokographie(CTG)-Parameter für Dezelerationsgebiete beschrieben. Zur Auswertung werden die perinatalogisch interessanten klinischen Daten verschlüsselt. Anhand eines Programmsystems werden

Patienten-Kollektive mit bestimmten gleichen Merkmalen gebildet. Sämtliche zugehörigen CTG's werden digitalisiert, d. h. es wird eine Umsetzung der analogen Kurven in äquidistante Zeitreihen vorgenommen. Dazu werden die CTG-Kurven unter einer Schablone fotografiert. Die Filme mit je etwa 450 Aufnahmen von 11,5 Min. Dauer der CTG-Strecke werden in einer automatischen Scanner-Anlage von einem Elektronenstrahl abgetastet und als Zahlenstrang auf Magnetband geschrieben.

Auf die Güte der Digitalisierung wird eingegangen. Es wird gezeigt, daß das Amplitudenverhalten der digitalen Kurven dem der Originalkurven unverfälscht entspricht. Die Datenbänder werden auf dem Kompaktrechner der Frauenklinik ausgewertet. Bei der Programmierung mußte die Besonderheit eines Kleinrechners und die Forderung nach leichter Anwendung und hoher Flexibilität berücksichtigt werden. Die eigentliche Auswertung bezieht sich auf wehenbedingte Dezelerationsgebiete der fetalen Herzfrequenz. Aus jedem dieser Gebiete werden typische, den

Dip beschreibende Parameter abgeleitet. Zur Bestimmung einiger Zeit-Parameter wird jedes Dezelerationsgebiet durch 6 Geraden angeglichen (Fig. 5). Auf die Ableitung von 17 Parametern wird näher eingegangen. Weitere berechnen sich aus diesen, so daß sich insgesamt eine Parameterzahl von fast 30 ergibt.

Für jedes Dezelerationsgebiet werden die Parameter zusammen mit Identifikationsmerkmalen auf Magnetbänder geschrieben. Zur weiteren Auswertung werden diese Parameter statistischen Analysen unterworfen.

Schlüsselwörter: Asphyxie-Index, Dezelerationen, Dezelerations-Parameter, digitalisierte Daten, elektronische Datenverarbeitung, Fet, Häufigkeitsverteilungen.

Résumé

Les paramètres Dip computés dérivés de courbes FHR digitalisées I. Les paramètres descriptifs et la méthode de digitalisation

Le présent article décrit le processus du traitement des données en vue de la dérivation de paramètres cardiotocographiques (CTG) descriptifs pour les zones de décélération. A titre d'évaluation, on chiffre les données cliniques intéressantes sur le plan périnatalogique. A l'aide d'un système programmé, les patients sont répartis en groupes selon des caractéristiques similaires précises. Toutes les cardiotocographies (CTG) s'y rapportant sont digitalisées, c. à. d. sous transposition des courbes analogues en séries de temps équidistantes. Pour cela, les courbes de CTG sont photographiées sous cliché. Les films de 450 vues environ chacun à 11,5 min de droite CTG sont analysés par un rayon électronique dans une installation Scann automatique et enregistrés sur bande magnétique comme phase de numérotation.

Le présent article évoque le bien-fondé de la digitalisation et expose comment le relevé des amplitudes des courbes

digitales correspond véritablement à celui des courbes originales.

Les bandes de données sont évaluées sur l'ordinateur compact du service de maternité. Pour la programmation, il a fallu tenir compte de la particularité d'un petit ordinateur et de la nécessité d'une application facile et d'un maniement très souple. L'évaluation propre se réfère aux zones de décélération, consécutives aux douleurs, de la fréquence cardiaque foetale. De chacune de ces zones sont dérivés des paramètres types, décrivant le Dip. Pour définir quelques paramètres de temps, chaque zone de décélération est compensée par six droites (Fig. 5). Une attention particulière a été portée sur la dérivation de 17 paramètres à partir desquels on a pu en calculer d'autres, de sorte à atteindre au total près de 30 paramètres.

Pour chaque zone de décélération, les paramètres sont inscrits sur bande magnétique avec les caractéristiques d'identification. Pour plus ample évaluation, ces paramètres sont soumis à des analyses statistiques.

Mots-clés: Décélération (paramètre de), données digitalisées, foetus, index d'asphyxie, traitement électronique des données.

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