Review article

An overview of central fetal monitoring systems in labour

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Abstract

A variety of systems for centralised viewing of fetal signals during labour are currently available, allowing simultaneous monitoring of multiple tracings in one or more locations. Display of maternal vital signs, ST signals and an electronic partogram are available in the majority of these systems. A few of them have incorporated computer analysis of cardiotocographic signals or combined cardiotocographic and ST data analysis. Computer analysis may elicit real-time alerts for healthcare professionals when changes associated with fetal hypoxia are detected. Central fetal monitoring systems have been installed in a large number of maternity hospitals in industrialised countries, but there is still limited evidence of their impact on perinatal indicators, on the behaviour of healthcare professionals and on related health costs.

Keywords: Cardiotocography; electrocardiography; fetal monitoring; heart-rate, fetal; signal processing, computer assisted.

Introduction

Continuous monitoring of the fetal heart rate (FHR) and uterine contractions during labour was introduced in the 1960s and has become widely disseminated in industrialised countries [10, 15, 23], despite limited evidence of benefit compared to intermittent auscultation [1].

There is evidence from randomised controlled trials [27] and from routine clinical settings [7, 19] that inadequate detection of ominous FHR features by healthcare professionals may occur, as well as a lack of appropriate response to them. This may be due, at least in part, to difficulties in guaranteeing constant access to labour rooms. Several systems for central monitoring of fetal signals have been developed to provide simultaneous display of multiple tracings on the same computer screen, in one or several locations, thereby allowing easier monitoring of signals. The need to handle digital signals has also allowed the incorporation of computer analysis of the FHR into several of them, with the aim of overcoming the well-known poor reliability of visual analysis [3, 29] to prompt healthcare professionals to act on changes that are allegedly associated with fetal hypoxia.

The aim of this article is to provide an overview of currently existing systems for central monitoring of intrapartum fetal signals, describing their main characteristics, whether they incorporate computer analysis of FHR signals and real-time alerts and how they have been evaluated. For this purpose, the PubMed database was searched for English language papers published after 1995 using the phrases: “electronic fetal monitoring” (EFM), “computerised cardiotocography” (CTG), “fetal monitoring systems” and the MeSH term “cardiotocography.” After reading the titles and abstracts, papers referring to the description and/or evaluation of systems for central fetal monitoring were selected. Further studies found in the reference list of these articles were hand searched. A total of 35 papers were reviewed. Systems for centralised fetal monitoring were also searched using the Google search engine, introducing the terms “electronic fetal monitoring” (EFM), “computerised cardiotocography,” “fetal monitoring systems” and the commercial names obtained in the PubMed search. Information on the main characteristics of these systems was extracted from published descriptions or from data obtained from official websites. An email was sent to the contact person provided by these websites requesting information on the system’s main characteristics, a description of the computer analysis that it performed, the real-time alerts that it generated and all published research available about it. Answers to these emails were obtained from OBIX™ Perinatal Data System (Clinical Computer Systems, Inc., IL, USA), Omniview-SisPorto® (Speculum, Lisbon, Portugal), and PeriCALM™ (LMS Medical Systems, Montreal, Canada and PeriGen, Princeton, USA).

Systems for central fetal monitoring

ARGUS (GMT, Frankfurt, Germany)

This system was developed by the company GMT in Germany. It displays up to eight CTG tracings on the same computer screen, as well as ST data and maternal vital signs including pulse oximetry. Visual and acoustic alarms are elicited...
for tachycardia and bradycardia. (http://www.nexus-ag.de/web/0/inter/index.php?art_id=de_2007_07_26_en_289098&fid=5600 and http://www.medicaldynamics.nl/download?id=8 accessed in August 2011). No studies evaluating this system were found in the scientific literature.

Guardian™ and INFANT® (K2 Medical Systems™, Plymouth, UK)

This system was developed at the University of Plymouth by the Perinatal Research Group [24]. It allows the display of several CTG tracings and ST data on the same computer screen, visible in multiple locations. The system integrates CTG signals with data on labour progress, analgesia, fetal blood sampling and cord blood gas values. Computer analysis is provided by the INFANT software, which integrates simple algorithms with trained neural networks to evaluate CTG features, such as baseline, variability, accelerations, decelerations and contractions. It attributes a colour-coded visual alert that will elicit a sound alert if not quickly acknowledged. (http://www.k2ms.com/IMFTS-INFANT.html. Accessed in September 2011.)

A retrospective blinded study, evaluating the analysis provided by a previous version of the system in 30 high-risk labours was published in 1994 [25]. At the time, the system recommended management actions, and these were compared with those of three experienced clinicians and with the actual clinical decision. The system’s recommendations were similar to those of the experts and in no case did it recommend an action that was not supported by at least one expert.

In 1995, a similar comparison was made of 50 intrapartum cases evaluated by 17 experts from 16 different centres [26]. The system agreed with experts in the management of 67.3% of cases, for a $\kappa$ value of 0.31. It did not recommend intervention in any of the cases with normal delivery, umbilical pH $>7.15$ and an Apgar score $\geq 9$. The 11 cases in which it recommended caesarean section received a similar recommendation from 15 of the 17 experts, and it identified as many birth asphyxia cases as the majority of experts. The system is currently being evaluated in a multicentre randomised clinical trial taking place in the UK (https://www.npeu.ox.ac.uk/infant. Accessed in September 2011).

MILOU® (Medexa®, Gothenburg, Sweden)

This system was developed by the company Medexa® in Sweden. It displays CTG data, ST information, maternal vital signs and pulse oximetry on the same screen in different computer stations. (http://www.medexa.se/en/english-milou-fetal-monitoring-system-2/english-milou-fetal-monitoring-system/. Accessed in August 2011.) No studies evaluating this system were found in the scientific literature.

MOSOS® CTG (BMA, Houten, The Netherlands)

This system was developed by the company BMA in The Netherlands. It displays singleton and twin CTG tracings, as well as ST data and maternal vital signs, including pulse oximetry. Personal notes and labour progress data are also displayed. The system contains in-built alarms for signal loss, tachycardia and bradycardia. (http://www.bma-mosos.co.uk/Solutions/Products/Mososobstetricalcaresystem/CTG/tabid/177/language/en-US/Default.aspx. Accessed in August 2011.) No studies evaluating this system were found in the scientific literature.

OBTraceVue® (Philips Healthcare®, Eindhoven, The Netherlands)

This system was developed by Philips Medical® in collaboration with the Department of Obstetrics and the Laboratory of Computer Science at Massachusetts General Hospital. It allows the simultaneous monitoring of twins and triplets in different computer stations, and the latest versions display ST data. Computer algorithms detect changes in baseline, variability, accelerations, number and type of decelerations and contractions using criteria based on the National Institute of Child Health and Human Development (NICHD) guidelines. Alarms are elicited for fetal tachycardia, bradycardia, signal-loss, abnormal variability, decelerations and detection of coincidences between fetal and maternal heart rates. (http://www.healthcare.philips.com/main/products/patient_monitoring/products/scip/obstetrics/index.wpd. Accessed in August 2011.)

Devoe et al. compared the visual analysis of 50 1-h intrapartum tracings obtained after 32 weeks of gestation by four observers, among each other, and with this system. Overall, the levels of interobserver agreement for baseline rates were between 97.3% and 99%, whereas agreement between individual observers and the computer ranged between 83.5% and 88.1%. Regarding accelerations, interobserver agreement ranged from 47.2% to 61.8%, whereas agreement between observers and the computer ranged from 49.5% to 62.3%. For decelerations, interobserver agreement varied between 43.1% and 66.5%, whereas agreement between observers and the computer ranged from 35.8% to 51.1%. Regarding the occurrence of alerts within a 20-min window, interobserver agreement varied between 71.7% and 83.8%, whereas agreement between observers and the computer ranged from 76.9% to 79.2%, the latter with a $\kappa$ statistic of 0.25 (95% confidence intervals [CI] 0.19–0.3) [18].

OBIX™ Perinatal Data System (Clinical Computer Systems Inc., IL, USA)

The OBIX system was developed by the company Clinical Computer Systems, Inc. in the USA, based on earlier work by Peritronics Medical. It provides a tracing display on the same computer screen in an unlimited number of locations. Computer algorithms detect changes in FHR baseline, variability, accelerations and decelerations based on the NICHD definitions. The system generates real-time audible and visual alerts based on user-configurable FHR values (http://www.obix.com/ accessed in August 2011).

A retrospective study, conducted with an earlier version of the system in 1994, evaluated the impact that its use for 14 weeks in the labour ward and outpatient clinic of a tertiary care centre, had on perinatal indicators [32]. No differences were reported in newborn 5-min Apgar scores <7, umbilical
artery pH, neonatal intensive care unit admissions or perinatal mortality, but during the period of central monitoring there was a statistically significant increase in overall caesarean sections, as well as in caesarean section and operative delivery rates for non-reassuring fetal state.

Omniview-SisPorto® (Speculum, Lisbon, Portugal)

This system was developed at the Medical School and Institute of Biomedical Engineering at the University of Porto, in Portugal [4, 9]. It allows the simultaneous monitoring of up to 16 patients on the same computer screen, accessible in an unlimited number of locations. Singleton and twin tracings, ST data, maternal vital signs, oxygen saturation and an electronic partogram are displayed [5]. (http://www.omniview.eu/ accessed in August 2011.) FHR analysis is based on the International Federation of Obstetrics and Gynaecology (FIGO) guidelines for fetal monitoring, incorporating baseline estimation, identification of accelerations and decelerations and evaluation of long- and short-term variability. The system provides real-time visual and sound alerts of different colour codes [5, 6, 12]. Combined alerts, integrating CTG and ST events, have also been incorporated based on the revised STAN guidelines [2].

Agreement on the identification of basic CTG features (baseline, accelerations, decelerations and uterine contractions) in 50 intrapartum tracings was evaluated among three experts and between the computer system and their consensus. Regarding baseline estimation, the intra-class correlation coefficient for interobserver agreement was 0.87 (95% CI 0.84–0.90), whereas for agreement between the computer and the consensus it was 0.85 (95% CI 0.46–0.93). There was agreement between observers in identification of 60% of accelerations (95% CI 48%–66%), whereas between the computer and the consensus this reached 71% (95% CI 69%–73%). Regarding decelerations, there was agreement between observers in 65% (95% CI 57%–69%) and between the computer and the consensus in 68% (95% CI 66%–70%). For uterine contractions, agreement among observers was reached in 93% of cases (95% CI 90%–95%), whereas between the computer and the consensus this occurred in 87% (95% CI 85%–89%) of them [12].

In a prospective study, a computer analysis of 148 consecutively acquired CTG+ST term singleton tracings was evaluated to compare the most serious alerts (red alerts) with the occurrence of newborn umbilical artery acidemia (pH<7.05). All cases of neonatal acidemia displayed red alerts in the last hour of the tracing, for a sensitivity of 1.00 (95% CI 0.56–1.00) and a specificity of 0.94 (95% CI 0.89–0.97) [11].

Another prospective study evaluated the impact of access to computer analysis on the reproducibility and accuracy of clinicians’ predictions of umbilical artery blood pH. The last hour of 204 intrapartum CTGs from term singleton pregnancies, monitored with a scalp electrode until very close to delivery, was randomly assigned to display or not to display the results of computer analysis, and three clinicians were asked to predict umbilical artery pH based solely on this information. A significantly higher interobserver agreement and accuracy were found in the group of tracings displaying computer analysis, which suggests that evaluation of fetal state is more reproducible and accurate in this condition [13].

A recent audit of the use of the system in a clinical setting reported that over 3 years signal quality of tracings increased (96.4% to 97.1%), signal loss decreased (7.4% to 5.8%) and the interval between tracing-end and delivery decreased (12 min to 8.4 min). However, lack of patient identification in the system still occurred in 8% of antepartum tracings and 31% of intrapartum tracings [14].

The system is currently being evaluated in a randomised clinical trial that is taking place in the UK [6].

PeriCALM™ (LMS Medical systems, Montreal, Canada and PeriGen, Princeton, USA)

This system was developed at the University of Montreal in Canada [21]. It displays CTG data, together with maternal vital signs and a labour progress graph that allows percentile comparisons with a reference population. It displays tracings in multiple working posts. Computer analysis is based on the NICHD definitions, incorporating mathematical algorithms and trained neural networks to evaluate FHR characteristics, including baseline, accelerations, decelerations, variability and contractions. It provides real-time colour-coded alerts for healthcare professionals. (http://www.perigen.com/pericalm-tracings-plus accessed in August 2011.)

Farer and Hamilton [30] evaluated the agreement between five experts and the system in assigning a five-tier colour-coded classification to 30 singleton intrapartum tracings. Observers agreed among each other in 45.5% of the cases (95% CI 42.1%–48.4%), whereas the computer agreed with them in 44.9% of the cases. Observers agreed with the majority opinion in 56.7% of the cases (95% CI 49.4%–63.9%), giving a proportion of agreement of 0.83 (95% CI 0.73–0.94) and a k value of 0.58 (95% CI 0.48–0.68), whereas the computer agreed with this opinion in 56.8% of the cases, for a proportion of agreement of 0.87 and a k value of 0.52. Observers’ assessments were within one colour code of the majority opinion in 88.6% of cases (95% CI 80.8%–96.4%), whereas with the computer this occurred in 83.1% of cases.

Elliot et al. [20] studied the last three hours of recordings in 2472 near-term singletons. Of the 60 cases with neonatal hypoxic-ischaemic encephalopathy, the system displayed a red alert in 8.3%, it reached an orange alert in 51.7% and it reached a yellow alert in 88.3%. For the 280 cases with metabolic acidosis, these numbers were 2.9%, 30.0% and 73.2%, respectively. In cases with normal outcome, 1.7% displayed a red alert, 16.4% an orange alert and 41.8% a yellow alert.

Hamilton et al. studied 3695 term singleton tracings to determine which characteristics of variable decelerations best discriminated between cases born with metabolic acidosis and those with normal umbilical artery gases. Decelerations lasting more than two minutes [area under the receiver operating characteristic (ROC) curve 0.61], those with loss of internal variability (area under the ROC curve 0.57) and those with at least two of the following criteria: depth ≥60 bpm, lowest value ≤60 bpm or duration ≥60 s (area under the ROC curve 0.60) provided a significant discriminate capacity [22].
Sonicaid® Centrale (Huntleigh Healthcare, Cardiff, UK)

The central monitoring station was developed by the company Huntleigh Healthcare in the UK, but the original computer algorithms were developed by the Nuffield Institute for Medical Research in Oxford in association with Sonicaid Instruments. It allows the display of up to 48 single and twin CTGs on the same computer screen, accessible in multiple locations. Maternal vital signs, ST data and an electronic partogram are also displayed. The system incorporates the Dawes/Redman algorithms for analysis of antepartum CTGs, but these are not applicable in the intrapartum [16]. Configurable audible and visual alerts are also present. (http://www.huntleigh.co.uk/diagnostics/int/Product.asp?PageNumber=2502&ProductCategory_Id=222&Product_Id=457 accessed in August 2011.) No recent publications were found evaluating this system in the intrapartum period.

Trium CTG Online® (Trium Analysis Online GmbH, Munich, Germany)

This system was developed by the company Trium in Germany and displays CTG data, as well as maternal vital signs and oxygen saturation. It allows the simultaneous display of up to 12 tracings, in multiple working posts. Analysis of CTG signals is conducted according to the FIGO guidelines, and visual and sound alarms are elicited when deviations are detected in baseline estimation, assessment of long and short-term variability, accelerations, decelerations and signal loss. (http://www.trium.de/02_ctg_online/beschreibung_en.html accessed in August 2011.)

A retrospective study performed in two hospitals assessed the accuracy of the system’s classification of tracings in detecting fetal acidosis, evaluated by FBS (pH<7.21 and pH<7.25). The results showed that “suspicious+pathological” classifications obtained a sensitivity of 95% and a specificity close to 20% in prediction of both criteria for acidosis. Using only the “pathological” classification, the specificity reached 55%. The most sensitive individual FHR parameter was decelerations (72% for pH<7.25 and 89.5% for pH<7.21), whereas variability and accelerations obtained sensitivities below 50% [31].

Discussion

Several systems for centralised viewing of intrapartum fetal signals are currently available, providing simultaneous monitoring of several tracings on the same computer screen and accessible in multiple locations. Display of maternal vital signs, ST signals and an electronic partogram are available in the majority of systems (Table 1). Many of these programs incorporate computer algorithms to analyse CTG signals, providing real-time alerts for healthcare professionals. Although some of these alerts are relatively simple, similar to those incorporated in most CTG monitors, others involve a more complex analysis of FHR characteristics and can be considered “true” computer analysis of CTGs.

Computer analysis of CTGs was introduced in the 1980s [9, 17, 21, 24] in an attempt to overcome the subjectivity of visual analysis [3, 29]. The first systems were developed for antepartum monitoring, where increased baseline stability, lower signal loss and artefacts and reduced tracing length pose less challenges for signal processing and algorithm development. Intrapartum analysis is a more recent development that, to our knowledge, has only been incorporated in central fetal monitoring systems.

A few studies have compared computer analysis with that of healthcare professionals. A comparison of their results is difficult because they involved different numbers of observers and different observer experiences. Some evaluated agreement with individual observers, some with the majority and some with a consensus. Comparisons were made either for each CTG feature or for a sum of features within a certain time frame. The lack of a gold standard with which to compare computer analysis is probably one of the reasons for the limited amount of research in this area. After all, computer analysis was developed because healthcare professionals frequently disagree on their analysis.

There is also limited evidence on the association between elicited alerts and neonatal outcome. Again, comparisons between studies are hampered by the different criteria used for case selection and the different choice of neonatal outcomes. Two of these systems are currently under evaluation in randomised trials that have started recruitment in the UK.

Other characteristics of central fetal monitoring systems are subject to less scientific attention, but can be considered major reasons for their acquisition. Among them is the ease of long-term data storage and retrieval [8], facilitating subsequent auditing, report, cases review and medico-legal analysis, where CTG remains one of the main documentary evidences [28, 33]. Shift changes within healthcare teams may also benefit from the presence of centralised display of tracings and electronic partograms, as they allow a more convenient access to labour monitoring information.

For research purposes, central viewing systems encourage the creation of large databases and facilitate the exchange of cases among researchers. Easier access and display of traces may also be useful for undergraduate and post-graduate training.

It was expected that these systems would result in improved perinatal outcomes as a consequence of easier access to monitored signals. A very small number of studies have evaluated this, but none have shown such an effect. A retrospective study published in 1997 reported that the introduction of centralised fetal monitoring was associated with an increase in caesarean section rates, without reducing adverse perinatal outcomes [32]. Another retrospective study published in 2006, in which the central monitoring system is not mentioned, reported no significant changes in caesarean section rates, admissions to the neonatal intensive care unit or in the incidence of low 5-min Apgar scores, both in term and preterm deliveries, after introduction of central fetal monitoring [34].

It is interesting to note that, despite these discouraging results, centralised monitoring systems continue to be used in industrialised countries. Whereas the acquisition of these
<table>
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<th>System</th>
<th>Display of other data</th>
<th>Detection of CTG events</th>
<th>Real-time alerts</th>
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<tbody>
<tr>
<td>ARGUS (GMT, Frankfurt, Germany)</td>
<td>ST, maternal vital signs, electronic parogram</td>
<td></td>
<td>Fetal tachycardia and bradycardia</td>
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<tr>
<td>Guardian® (K2 Medical Systems®, Plymouth, UK)</td>
<td>ST, maternal vital signs, electronic parogram, FBS</td>
<td></td>
<td>Coloured CTG alerts: blue, yellow and red</td>
<td>[24–26]</td>
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<td>MILOC® (Medexa®, Gothemburg, Sweden)</td>
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<tr>
<td>MOSOS® CTG (BMA, Houten, The Netherlands)</td>
<td>ST, maternal vital signs, oximetry, electronic parogram</td>
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<td>OB Trace® (OB Trace, The Netherlands)</td>
<td>ST, maternal vital signs, oximetry, electronic parogram</td>
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<td>Baseline, variability, accelerations, decelerations, contractions</td>
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<td>Baseline, STV, LTV accelerations, decelerations, contractions</td>
<td>Baseline, variability, accelerations and decelerations</td>
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<td>OmniView-SiPhi® (Clinical computer systems Inc., IL, USA)</td>
<td>Baseline, variability, accelerations, decelerations, contractions</td>
<td>Baseline, variability, accelerations and decelerations</td>
<td>User-configurable alerts</td>
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<tr>
<td>Trium CTG Online® (Trium Analysis Online GmbH, Munich, Germany)</td>
<td>Baseline, STV, LTV accelerations, decelerations, contractions</td>
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<td>Coloured CTG alerts: blue, yellow, orange and red</td>
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<tr>
<td>Sonicaid® Centrale (Huntleigh Healthcare, Cardiff, UK)</td>
<td>Baseline, variability, accelerations, decelerations, contractions</td>
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<td>User-configurable alerts</td>
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STV = short-term variability, LTV = long-term variability.
systems represents a substantial investment for hospitals, they may also lead to a reduction in costs with CTG paper, an aspect that requires appropriate evaluation. It is not known whether they can or should lead to a reduction in the number of healthcare professionals attending the labour ward. No studies were found on the impact of these systems on the clinical behaviour of healthcare professionals or on their opinion towards the utility of the technology. Finally, patients’ perception of care with central monitoring has also yet to be evaluated, namely whether it affects the time that staff spend with labouring women. In summary, despite their wide use in industrialised countries, there is limited evidence on the effects that these systems have in routine clinical care.

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Conflict of interest statement

D. Ayres-de-Campos and J. Bernardes are developers of the Omniview-SisPorto® system. The Institute of Biomedical Engineering receives royalties for the commercialisation of this system, which are entirely re-invested in research.

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