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REVIEW

Electrodes in external electrohysterography: a systematic literature review

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Abstract

Background In low-income countries, pregnant women do not have easy access to health care, especially in rural and peri-urban areas. In this context, they can be surprised by the uterine contractions that precede childbirth and sometimes find themselves giving birth at home or on the way to the nearest health facility (located miles away from their home). In view of the development of an external uterine electrohysterogram acquisition system for labour prediction, a review of the literature on electrodes and their characteristics is necessary.

Methods A comprehensive literature review was conducted to collate information on the use of electrodes in external EHG recording and their characteristics.

Results Wet electrodes based on Ag/AgCl redox chemistry are the most common type of electrodes for EHG, employed in different configurations on the pregnant woman's abdomen. All positioning configurations are around the vertical median axis if they are not placed directly on it. Positioning below the navel seems to be the most efficient. The number of source, reference, and ground electrodes used varies from one author to another, as does the distance between the electrodes.

Conclusion Two well-positioned source electrodes on the vertical median axis, with ground electrode on the right side of the hip and reference one on the left side, are able to generate a good external EHG recording signal. The minimum allowed inter-electrode distance is approximately 17.5 to 25mm.

Keywords Electrohysterography · Electrodes · Recording · Labour · Delivery

Introduction

Pregnancy monitoring is a vital element in the process leading up to the delivery of the foetus (Gondry et al. 1992). It allows control of the health status and well-being of both the pregnant woman and the foetus and can assist in normal development of the pregnancy up until the onset of contractions that leads to either a premature or full-term delivery. As pregnancy is characterised by recurrent contractions, it is essential to be able to distinguish between the physiologically normal and non-normal ones. In the context of countries with limited resources, where access to health care continues to be a luxury (Di Pietro et al. 2020), in Africa more than 125,000 women and 870,000 newborns die in the first week after birth every year (WHO oanfullreport 2006).

The situation is more complicated in rural and peri-urban areas where the first and second delays, respectively, due to (1) the time to make a decision to seek a health centre and (2) the time to reach the health centre (according to the three-delay model in emergency care) (Calvello et al. 2015) are inevitably extended, and the risk of death is increased. Since the number of health centres in these areas is not sufficient and the infrastructure does not allow a quick and efficient transfer of the expectant mothers, an efficient way to reduce these delays could be the prediction of labour onset early enough to ensure a delivery in a health facility. For this purpose,

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standard medical parameters have shown their limits, such as those related to invasiveness for intrauterine pressure (IUP) and inaccuracy for tocodynamometry (TOCO) (Jezewski et al. 2005). In contrast, abdomen electrohysterography (EHG) has proved to be a suitably appropriate, non-invasive measurement technique for the study of the uterine muscle activity (Kandil et al. 2013).

With the aim of creating a non-invasive and portable monitoring system (for labour prediction) that would be appropriate for the conditions and challenges of low-income countries, this paper reviews literature related to the EHG measurement technique to determine the minimum suitable requirements for construction of a future robust measurement device.

Methods

In order to carry out a literature review about the EHG recording electrodes and their positioning on the abdomen of pregnant women, 149 articles were retrieved through search engines like Google Scholar and scientific data bases such as PubMed, Wiley, NCBI, IEEE Xplore, Scopus, and Web of Science. The material and method section of each item has been browsed in order to see those that clearly describe the acquisition technique, especially with regard to the type of sensor equipment used to sense the bioelectrical signal, the sensor characteristics, and their positioning on the pregnant woman's abdomen. This allowed us to discard all the invasive techniques for acquisition of the EHG signal and other techniques for the access to the parameters of uterine contractions, such as TOCO or IUP, which are often associated with the acquisition of EHG simultaneously. Finally 39 articles, covering the period 1984–2020, were included in the present study.

Results

Sensor types and characteristics

It has long been known that uterine electrical activity can be performed through the recording of EHG on the woman's abdomen (Devedeux et al. 1993). The main objective of our research was to investigate the non-invasive acquisition of the uterine electrical activity, with a specific focus on the types of sensor equipment and its deployment on the pregnant woman's body. By far the vast majority of EHG recordings have been performed using wet electrodes. In general such electrode-based recordings consist of sensor electrodes, reference electrodes, and earth electrodes. The sensor electrode is the main electrode for measuring the physiological signal (i.e. EHG). It is (or they are) positioned at the likely location(s) in the body (i.e. the pregnant woman's abdomen) assumed to be a source or relay of a source of the physiological signal being sought. The ground electrode is used to connect the signal recording system's ground and the electrical earth for the patient safety in case of an electrical isolation default. It represents the zero potential or the common voltage point between the patient and the recording system. And, the reference electrode is an electrode used to eliminate ambient electrical activity picked up by the recording system amplifier's ground circuit. Table 1 summarises the different electrode types used in the literature and their characteristics. The Ag/AgCl is almost exclusively used to perform the EHG measurement. Only the electrodes' number, their shape (i.e. monopolar, concentric (bipolar or more) (Ye-Lin et al. 2015), matrix), and their positioning differ in the included papers.

Recently, a wireless body sensor network has been developed as a potential EHG recording kit (Allahem and Sampalli 2017). Other electrode technologies such as high-density electrode arrays have also been used (Rabotti et al. 2010). In some cases, Ag/AgCl electrodes connected to other physiological signal acquisition devices were used for EHG recording. Commercial equipment based on the electrocardiograph (ECG) L-00-S AMBU Denmark (Hao et al. 2019) and the electroencephalograph (EEG) Embla A10 (Hassan et al. 2013; Alexandersson et al. 2015) have also been co-opted for EHG measurement.

In a number of cases, EHG measurement has been carried out with a variable number of reference and/or ground electrodes (Table 1). The quantity of source electrodes varies from 2 (Planes et al. 1984; Marque et al. 1986; Gondry et al. 1992; Carre et al. 1998; Leman et al. 1999; Diab et al. 2007; Diab et al. 2010; Kandil et al. 2013; Alberola-Rubio et al. 2017; Mas-Cabo et al. 2019) to 64 (Rabotti et al. 2010) (Tables 1 and 2). Other typical characteristics reported include the diameter of the electrodes (generally circular), the distance between electrodes, and their configuration (which will be discussed in the 'Electrode positioning' section).

With regard to the diameter of the electrodes, the typical ones have a diameter of 8 mm (Marque et al. 1986; Hassan et al. 2013; Alberola-Rubio et al. 2013) or 5 mm (Verdenik et al. 2001). Sometimes, this value is expressed in terms of the surface area, i.e. 3 cm^2 (Euliano et al. 2009; Kandil et al. 2013). Other authors were more specific, giving the values for both the external (13 mm) and internal (8 mm) diameters (Alexandersson et al. 2015).

Electrode positioning

Figure 1 shows some examples of electrode positioning on the pregnant woman's abdomen according to the literature. The following subsections will present more details.

Table 1 Electrode types and characteristics

Author (year)	Electrode characteristics					**Used acquisition system** (Manufacturer/reference)
	Type	Source	Ground	Reference	Others	
Planes et al. 1984	Ag/AgCl	2	1	1	Self-adhesive	• EHG monitoring system
Marque et al. 1986; Gondry et al. 1992; Carre et al. 1998; Leman et al. 1999	Ag/AgCl	2	1	None	8 mm in diameter, 25-mm-spaced centres	• Custom-built uterine EMG patient monitoring system
Buhimschi et al. 1997; Maul et al. 2004	Ag/AgCl	4 (2 pairs)	1	none	Positioning approximately 5 cm apart	• MacLab Data Recording System (AD Instruments, Castle Hill, Australia)
Jezewski et al. 2005	Ag/AgCl	4	1	None	Not mentioned	Not mentioned
Rabotti and Mischi 2006; Rabotti et al. 2008	Ag/AgCl	11 (unipolar)	1 (DRL)	1	Not mentioned	• Maastricht-programmable acquisition system (M-PAQ)
Skowronski et al. 2006	Ag/AgCl	8	1	1	Not mentioned	• EHG recording system
Diab et al. 2007	Ag/AgCl	2	1	None	Not mentioned	Not mentioned
Fele-Žorž et al. 2008	Ag/AgCl	4	1	None	Not mentioned	Not mentioned
Rabotti et al. 2008; Rabotti et al. 2009a	Ag/AgCl	4	1 (DRL)	1	Not mentioned	• Maastricht-programmable acquisition system (M-PAQ)
Euliano et al. 2009	Ag/AgCl	8	1	1	3 cm^2	• 8-channel foetal ECG signal amplifier
Rabotti et al. 2009b	Ag/AgCl	8	1 (DRL)	1	Not mentioned	• Maastricht programmable acquisition system (M-PAQ)
Rabotti et al. 2010	HD (Grid)	64	1	None	Bipolar dimensional arrangement of the electrodes on the grid (8 × 8)	• Refa system (TMS International, Enschede, The Netherlands
Diab et al. 2010	Ag/AgCl (Beckman)	2	1	None	Not mentioned	Not mentioned
Hassan et al. 2009; Hassan et al. 2010; Terrien et al. 2010; Hassan et al. 2011; Alamedine et al. 2013, Alamedine et al. 2014	Ag/AgCl	16	1	1	4 × 4 matrix arrangement	• Embla A10 16-channel multipurpose physiological signal recorder (used for investigating sleep disorders)
Moslem et al. 2011	Grid	16	1	1	4 × 4 matrix arrangement in the grid	Not mentioned
Haran et al. 2012	Unknown	9	Not mentioned	Not mentioned	3 × 3 matrix arrangement	• OB-Tools (Migdal Ha'emek, Israel)
Kandil et al. 2013	Unknown	2	1	None	3 cm^2 in area	• Nihon Kohden machine model: MEB-9200/9300
Vasak et al. 2013	Unknown	4	1	None	Not mentioned	• Portable maternal/foetal heart rate/EMG recorder (AN24, Monica Healthcare Ltd, Nottingham, UK)
Alberola-Rubio et al. 2013	Ag/AgCl (cup wet)	5	1	1	8 mm in diameter	• Biopac ECG 100C (Biopac Systems Inc, USA)
Garcia-Gonzalez et al. 2013	Ag/AgCl	3	1	1	Not mentioned	• Monica AN24^{TM} foetal ECG and uterine contractions monitor
Diab et al. 2014	Ag/AgCl	16	1	1	4 × 4 matrix grid, interelectrode distance 2.1 cm	Not mentioned
Ye-Lin et al. 2015	Flexible tripolar concentric ring electrodes (TCRE)	2	1	None	External diameter of the outer ring, 36 mm; external diameter of the middle ring, 24 mm	• Biopac ECG 100C (Biopac Systems Inc, USA)
Alexandersson et al. 2015	Ag/AgCl	16	1	1		

Table 1 (continued)

Author (year)	Electrode characteristics					**Used acquisition system** (Manufacturer/reference)
	Type	Source	Ground	Reference	Others	
					13 mm outside diameter and 8 mm inside diameter (for each electrode)	• Embla A10 16-channel multipurpose physiological signal recorder (used for investigating sleep disorders)
Horoba et al. 2016	Ag/AgCl	5	Not mentioned	Not mentioned	Not mentioned	• Foetal monitoring systems: MONAKO and KOMPOREL (Philips FM20)
Alberola-Rubio et al. 2017	Ag/AgCl	2	1	1	Not mentioned	• Biopac ECG 100C (Biopac Systems Inc, USA)
Allahem and Sampalli 2017	Wireless body sensor networks (WBSN)	Integrated	Integrated	Integrated	Not mentioned	• EHG monitoring system proposed (by authors)
Mas-Cabo et al. 2019	Ag/AgCl	2	1	1	Not mentioned	• Iceland 16-electrodes database
Hao et al. 2019	Ag/AgCl	8	1	1	Not mentioned	• Iceland 16-electrodes database • Bespoke 8-electrodes system
Shero et al. 2020	Ag/AgCl	4	1	none	Not mentioned	• MyoWare Muscle Sensor associated to an Arduino

Positioning of source electrodes

With regard to the (source) electrodes' arrangement on the pregnant woman's abdomen, several configurations can be distinguished, although all of them are around the navel and take into account the horizontal and vertical median axes of the uterus (Fig. 1). Some authors place some or all of the source electrodes on the vertical median axis, as in Planes et al. (1984) and Marque et al. (1986), where the two source electrodes were positioned in this way, and in Jezewski et al. (2005), where there are 4 source electrodes concerned. Rabotti et al. (2008) used 4 electrodes but placed two on the lower part (below the navel) of this axis. The two remaining electrodes were placed symmetrically on either side, always below the navel. Similarly Hassan et al. confirmed the positioning on the vertical median axis, using two electrodes (numbers 7 and 8) located on this axis among the 16 electrodes positioned (in the form of a 44 matrix grid) on the pregnant woman's abdomen (Hassan et al. 2009, 2010). Alamedine et al. did the same and suggested that this provides greater access to the EHG signal during pregnancy (Alamedine et al. 2013). Moslem et al. adopted the same configuration with their 16 electrodes and also considered the electrodes two by two vertically to obtain bipolar signals with a good signal-to-noise ratio (Moslem et al. 2011). The same arrangement was also adopted (Hassan et al. 2013; Alexandersson et al. 2015) with regard to the 4 × 4 matrix grid configuration; however, the third column was positioned on the median axis. On the other hand, Diab et al. located their two source electrodes above the horizontal median axis of the uterus (Diabet al. 2007; Diab et al. 2010).

According to Rabotti et al. (2008), the positioning adopted for the electrodes could potentially increase the signal-to-noise ratio. Skowronski et al. positioned half of their 8 source electrodes on the median axis (without specifying which one) of the abdomen (Skowronski et al. 2006), the other half being positioned two by two laterally on either side. Fele-zorz et al. adopted a 2 × 2 matrix positioning around the navel, the latter being in the centre with its 4 source electrodes (Fele-Žorž et al. 2008). In this arrangement, we find part of the configuration from Rabotti et al. (2008) by considering the two electrodes horizontally under the navel. In Euliano et al. (2009), there is a combination of previous configurations (Jezewski et al. 2005; Fele-Žorž et al. 2008). The configuration adopted by Rabotti et al. (2009a, b) is the same as for Rabotti et al. (2008) with a duplication of the positioning above the navel, since the former makes use of 8 electrodes.

Vasak et al. decided to use both median axes by positioning the electrodes two by two on each of these axes on either side of the navel (Vasak et al. 2013). Alberola-Rubio et al. proceeded in the same way, but below the navel with 5 electrodes, one of which is central (Alberola-Rubio et al. 2013). Garcia-Gonzalez et al. adopted an improved version of the configuration in (Rabotti et al. 2008), by bringing the

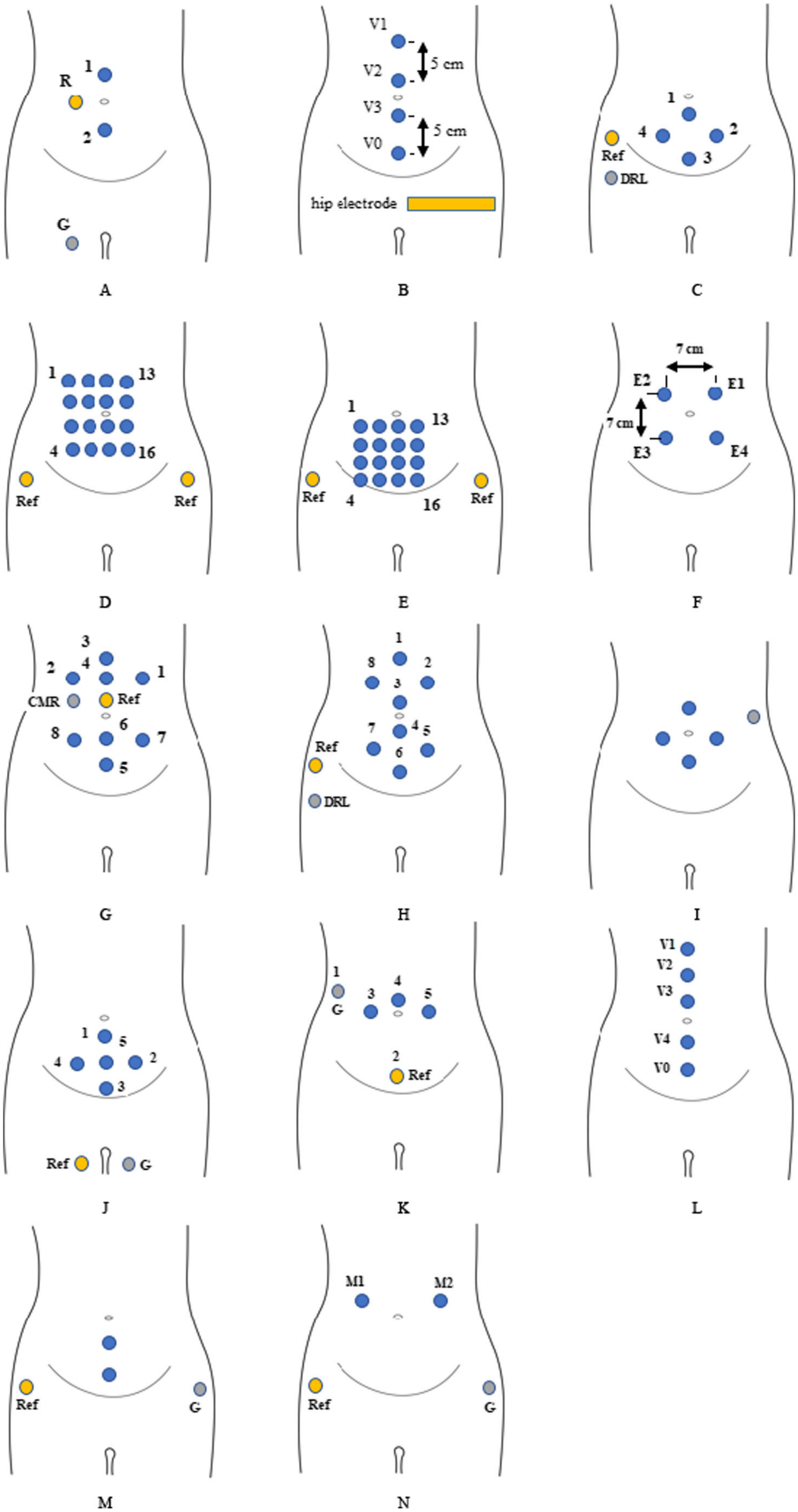
Table 2 Electrodes' number and EHG/electromyography (EMG) parameters studied

Authors, year	Source electrodes' number	EHG/EMG parameters studied
Planes et al. 1984	**2**	• Uterine electrical activity recording and processing
Marque et al. 1986	**2**	• Physiological contraction duration and frequency (long duration/low frequency) • Labour contraction duration and frequency (short duration/high frequency)
Carre et al. 1998	**2**	• Uterine EHG signal denoising
Gondry et al. 1992	**2**	• Analogical study of mechanical activity (tocograph) and electrical burst (EHG) • Digital analysis of electrical burst corresponding to a mechanical activity
Buhimschi et al. 1997	**4 (2 pairs)**	• Study of the correlation between EMG activity and patient symptoms • Study of the relationship between EMG burst and intrauterine pressure (IUP) • Comparison between EMG activity and tocograph tracings
Leman et al. 1999	**2**	• Contractions' evolution during pregnancy and group of delivering classification
Maul et al. 2004	**4 (2 pairs)**	• Electrical burst energy determination
Jezewski et al. 2005	**4**	• Contraction detection • Contraction intensity estimation • Spectral parameters estimation • TOCO and EHG comparison
Rabotti and Mischi 2006	**11**	• IUP estimation from EHG signal and correlation with reference IUP
Skowronski et al. 2006	**8**	• IUP prediction from external EHG signals
Maner and Garfield 2007	**4**	• PS parameters used as input in artificial neural networks (ANN) algorithm for EHG classification in term and preterm/labour and non-labour groups
Diab et al. 2007	**2**	• Real EMG signals (PD and DT) modelling with 16 order autoregressive (AR) model • Simulated uterine contractions generation • Signal decomposition (scales and wavelet-type selection) • Parameter variance extraction (5 for each contraction) • EMG signals classification
Rabotti et al. 2008	**4**	• IUP estimation from EHG analysis • Estimated IUP comparison to invasively recorded IUP
Fele-Žorž et al. 2008	**4**	• Parameter calculation • Techniques evaluation for recorded signals classification in term or preterm groups according to time of delivery
Rabotti et al. 2009a, 2009b	**8**	• CCF estimation • EHG signals propagation analysis
Euliano et al. 2009	**8**	• Centre of uterine activity (CUA) determination • Spatiotemporal patterns of uterine electrical activity investigation
Hassan et al. 2009	**16**	• Synchronization between labour and pregnancy contractions analysis
Rabotti et al. 2010	**64**	• EHG signal propagation analysis • Estimate conduction velocity of a single action potential
Hassan et al. 2010	**16**	• Labour and pregnancy contractions classification from EHG bursts signals
Diab et al. 2010	**2**	• 10 frequency parameter extraction • Uterine EHG signal's classification
Terrien et al. 2010	**16**	• Extract time-frequency parameters • Evaluate reconstruction methods performances • Evaluate reconstruction signals synchronization
Hassan et al. 2011	**16**	• Test signal's nonlinearity significance • Differentiate pregnancy and labour contractions • Comparison between three nonlinear methods (approximate entropy, correlation entropy, time reversibility)
Moslem et al. 2011	**16**	• Frequency-related parameter extraction • Classify frequency-related performance
Haran et al. 2012	**9**	• Differences' evaluation between contractions' parameters (contraction's onset, peak, time to nadir, duration, and intensity) measured by IUP and EUM • Correlations estimation

Table 2 (continued)

Authors, year	Source electrodes' number	EHG/EMG parameters studied
Arora and Garg 2012	**16**	• Extract EHG signal features • Reduction of EHG signal feature • Classification in preterm or term pregnancy groups
Hassan et al. 2013	**16**	• Comparison of nonlinear correlation coefficient parameters with median and peak frequency of power spectrum density
Alamedine et al. 2013	**16**	• Linear (mean frequency, peak frequency and deciles D1…D9, and EHG non-stationarity (from WT) w1…w5) parameter extraction • Nonlinear (Tr, LE, SE, VarEn)parameter extraction • EHG classification
Kandil et al. 2013	**2**	• Patterns of uterine action potential determination
Vasak et al. 2013	**4**	• EMG prospection for first-stage labour identification
Alberola-Rubio et al. 2013	**5**	• Temporal correlation of detected contractions by IUP with contractions detected by TOCO and EHG • Presence of maternal ECG in EHG recording estimation • EHG signal quality estimation
Garcia-Gonzalez et al. 2013	**3**	• Characterization of EHG contractions (nonlinearity of EHG determination)
Diab et al. 2014	**16**	• Sensitivity to direction change testing
Alamedine et al. 2014	**16**	• Extract linear, nonlinear, propagation parameters • Parameters distribution representation • Signals classification
Alexandersson et al. 2015	**16**	• EHG signals' recording and database creation
Horoba et al. 2016	**5**	• Contraction's inconsistency estimation • Comparison between TOCO and EHG signals • EHG signal frequency parameter extraction • Automated EHG analysis
Alberola-Rubio et al. 2017	**2**	• Features extraction • Signals classification
Mas-Cabo et al. 2019	**2**	• Features extraction • Signals classification • Threatened preterm labour patient identification
Hao et al. 2019	**8**	• EHG recording device development • Uterine contraction monitoring
Shero et al. 2020	**4**	• EHG linear parameter assessment • True labour diagnosis

Fig. 1 Examples of electrodes' positioning on a pregnant woman's abdomen (blue dot, source electrode; yellow dot, reference electrode; grey dot, ground electrode)



electrodes horizontally back to the level of the median line passing through the navel and by bringing the electrodes up to the vertical median line so that the lower part of the one above is in contact with the upper part of the navel (Garcia-Gonzalez et al. 2013). Shero et al. proceeded similarly except that in their case the upper electrode is well above the navel and distinct from it (Shero et al. 2020). As noted above, Horoba et al. positioned all of their five electrodes on the vertical median axis with three electrodes above and two below the navel (Horoba et al. 2016), whereas Alberola-Rubio et al. were satisfied with two electrodes on the vertical median axis below the navel (Alberola-Rubio et al. 2017). Conversely, Mas-Cabo et al. positioned their two source electrodes symmetrically to the vertical median axis above the navel (Mas-Cabo et al. 2019).

Reference and ground electrodes' positioning

As far as ground and/or reference electrodes are concerned, generally there are a number of different solutions: two reference electrodes without ground electrode (Hassan et al. 2009, 2010; Terrien et al. 2010; Hassan et al. 2011; Moslem et al. 2011; Alamedine et al. 2013; Alamedine et al. 2014; Diab et al. 2014), or one reference electrode without ground electrode (Marque et al. 1986; Carre et al. 1998; Leman et al. 1999; Diab et al. 2007; Diab et al. 2010), or ground electrode associated with a reference electrode (Planes et al. 1984; Skowronski et al. 2006; Rabotti et al. 2008; Euliano et al. 2009; Rabotti et al. 2009a, 2009b; Garcia-Gonzalez et al. 2013; Alberola-Rubio et al. 2013; Alexandersson et al. 2015; Alberola-Rubio et al. 2017; Hao et al. 2019; Mas-Cabo et al. 2019), or ground electrode without reference electrode (Buhimschi et al. 1997; Maul et al. 2004; Jezewski et al. 2005; Rabotti et al. 2010; Kandil et al. 2013; Vasak et al. 2013; Shero et al. 2020). Some authors did not use any of these at all, or if they did, they did not report it in their work. As regards to their positioning, it varies a lot from one author to another.

In the case of two reference electrodes, they are positioned on each side of the patient's hip (Hassan et al. 2010; Hassan et al. 2013; Alamedine et al. 2013), or on each thigh (Alberola-Rubio et al. 2013). In the case of a single ground electrode, it is positioned on the right side of the hip (Maul et al. 2004; Kandil et al. 2013; Shero et al. 2020), or on the left side (Vasak et al. 2013). In the case of reference and ground electrodes, the reference electrode is positioned under the navel and the ground one on the right side of the hip (Skowronski et al. 2006; Garcia-Gonzalez et al. 2013), or each of them on one side of the hip (Alexandersson et al. 2015; Alberola-Rubio et al. 2017; Mas-Cabo et al. 2019), or the ground electrode on the right side of the hip and the reference one on its left side (Hao et al. 2019), or the ground electrode on one of the thighs and the reference one on the horizontal median axis passing through the navel (Planes et al. 1984), or both in the centre side by side near the navel with the reference electrode just above the navel (Euliano et al. 2009), or the reference electrode on the right side of the hip and the ground electrode on the right leg (Rabotti et al. 2009a, 2009b). In the case of a single reference electrode, it is positioned on the patient's right thigh (Verdenik et al. 2001), or on the left side of the patient's hip (Jezewski et al. 2005), or on the right side of the patient's hip (Rabotti et al. 2008), or on any side of the patient's hip (Diab et al. 2007; Diab et al. 2010).

Inter-electrodes' distance

There is no clear guideline regarding the inter-electrode distances. It is smaller in some cases, with electrodes situated close together at a distance of 17.5 mm (Alexandersson et al. 2015). In other cases, a wider spacing is adopted 25 mm for the inter-electrode distance (Marque et al. 1986; Diab et al. 2007; Alberola-Rubio et al. 2013). Other authors expressed a cm order of magnitude distance or did not give much detail about this.

Numbers of electrodes used and parameters studied

In this section, we tried to investigate whether there is a link between the number of electrodes used and the complexity of the parameters studied by the authors concerning the collected signals. Table 2 summarises the number of (source) electrodes and the parameters studied by the authors. As it can be seen, the study of complex EHG signal characteristics can be done with many electrodes (although not all electrodes are used in this case), i.e. 2, 3, or 4 electrodes. However, for deeper signal and velocity investigations, a large number of electrodes are required, i.e. 11, 16, and 64.

Discussion

This review was performed to explore the possibilities of optimising the number and positioning of the electrodes on a pregnant woman's abdomen for an acquisition of an EHG signal. The literature suggests that two well-positioned source electrodes are sufficient to collect a good EHG signal from the pregnant woman's abdomen. An increase in the number of electrodes was shown to be useful in the sense of providing the ability to explore signal propagation and to achieve best positioning via increased sampling. When electrode matrix grids are used, they are considered two by two vertically. This may imply an efficiency of signal acquisition from a bipolar point of view rather than a monopolar one and in vertical rather than horizontal positioning. The efficiency in the acquisition of the signal is surely increased when the electrodes are positioned on the vertical median axis (Planes et al.

1984; Marque et al. 1986; Jezewski et al. 2005; Hassan et al. 2009, 2010) or symmetrical to this axis and below the navel (Rabotti et al. 2008). Indeed, positioning on or around the vertical median axis below the navel therefore seems to be one of the best EHG signal acquisition positions as proved by several authors (Rabotti et al. 2008). Specifically in the case of bipolar positioning on the vertical median axis, this would have the advantage of reducing common mode noise and promoting greater access to the EHG signal throughout pregnancy (Alamedine et al. 2013).

Although the set inter-electrode distance varies greatly from one author to another, a distance of 17.5 to 25 mm seems to be the minimum. Similarly, the positioning of the ground and reference electrodes is very varied, although it is common practice to place the ground electrode on the right hip, which would have the advantage of reducing interference (Rabotti et al. 2008). Nevertheless, many authors used a ground electrode associated to a reference one in many configurations. Although taking into account the advantage of positioning the ground electrode on the right side of the hip, we considered that positioning the reference electrode on the left side of the hip is one of the best cases.

Overall, and within the framework of our literature acquisition system, we suggest that:

- In terms of the number of electrodes, two source electrodes are largely sufficient with one ground electrode associated to a reference one
- Two source electrodes should be positioned at the level of our acquisition belt in such a way that they are on the vertical median line below the navel when worn
- Ground electrode should be placed such that it is on the right hip of the patient and the reference one on the left side of the hip

  Minimum inter-electrode distance between the two source electrodes should be 17.5 or 25 mm.

Conclusions

Here, we have reviewed published accounts of the external acquisition of an EHG signal. The types of electrodes used in the literature were explored as well as their characteristics and positioning. Our studies have shown that two well-positioned source electrodes are sufficient for effective access to the EHG signal. The vertical median axis, below the navel, was found to be the most optimal position. Otherwise, it is always necessary to remain below the navel symmetrically to the same axis. As far as reference and ground electrodes are concerned, according to the literature, a single ground electrode positioned on the right side of the hip is sufficient. Otherwise, one electrode of each type on one side of the hip can be used. In terms of the distance between the electrodes, a minimum of 17.5 or 25 mm is adopted in the literature. Beyond the establishment of a portable EHG acquisition system, these essential specifications will be useful for anyone studying electrical conductivity measurements of EHG in pregnancy contractions and preterm labour.

Declarations

Conflict of interest The authors declare no conflict of interest.

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