university of groningen

faculty of science and engineering

BACHELOR INTEGRATION PROJECT

Blood in the birth pool

Author

T. VAN DER WAL | S3086437

Supervisors

dr. ing. H. KLOOSTERMAN
drs. C.M. REE

July 8, 2022

CONTENTS

Abstract— **Currently used visual estimation is seen to be unreliable in quantifying blood loss in water birth, which leads to increased risks of complications due to late recognition of excessive blood loss. In this study, alternative ways to quantify blood loss in water birth compared to visual estimation are researched. Multiple potential measurement methods have been proposed that have potential advantages in accuracy and reliability in quantifying blood loss by examining the optical properties of the fluid inside the birth pool. Multiple limitations are discussed in using these optical properties to quantify blood loss, however, no conclusive statement on the severity of these limitations is made. An experiment is conducted which shows that moderate fluid flow applied by a stakeholder is insufficient in deriving homogeneous spreading of components in the birth pool in a sufficiently short time frame. An evaluation is made on the suitability of the various proposed measurement methods for real-life application, however, multiple unknowns hinder the derivation of a definitive statement, thus further research is necessary.**

I. INTRODUCTION

Hemorrhages during and after labor are one of the main prevalent causes of maternal death in both developed and developing countries [1]. Many measures exist to treat hemorrhages, like effective surgical techniques, potent drugs, and extensive blood banking facilities [2]. To use these measures, accurate and fast measurement of blood loss is key [3]. Labor immersed in water, also called water birth, is increasingly occurring. Women report a more preferable birth experience, and science shows a reduction in the use of pain-relieving medication, as well as a quicker labor process [4] [5]. Apart from these benefits, risks exist as well [6]. One of the difficulties in water birth is estimating blood loss [7]. In conventional birth, blood loss can be measured by weighing items such as lap sponges and towels on which the blood has fallen. Also, visual estimation is possible [3]. In water birth, blood loss in water birth is monitored by visual estimation of the bath and the woman, and by examining the blood pressure and pulse of the woman. However, this is seen to be unreliable [7]. This leads to potentially hazardous situations, as early recognition of a hemorrhage is important [3]. A device that accurately measures the blood loss inside a birth pool could therefore be a life-saving tool. This research will focus on the possibility of developing a tool that measures blood loss in a birth pool, and consequently warns midwives when dangerous levels of blood have been lost by the pregnant woman.

II. VISUAL ESTIMATION OF BLOOD LOSS IN WATER BIRTH

As this research will focus on finding a better alternative than the currently used visual estimation for quantifying the amount of blood loss in water birth, the currently used visual estimation will be examined first. Research shows that in higher, and thus critical, blood loss volumes, underestimation occurs with a mean of 40%. Also, examining the pregnant woman on paleness, blood pressure and other factors is misleading. Pregnant women carry on average one liter of extra blood in their bodies and due to the birth process and hormones, signs like paleness and low blood pressure show up at a much later stage than normally [7].

As visual estimation generally leads to underestimation, a study has been performed in increasing midwives' performance by training them in estimating blood loss in water birth by visually examining the birth pool. While their accuracy of estimation increases, significant differences between estimated blood loss and actual blood loss still occur. For blood loss volumes of 1000 and 1100 ml, the largest volumes of the research, the mean underestimation was 30% after the training, whereas it was 40% initially [7]. Six weeks after the training the participants were asked again to estimate the amount of blood loss, and it was seen that most of the improvement due to the training had already diminished. Therefore, it can be concluded that training midwives in their visual estimation does not yield a solution to the problem of poor quantification of blood loss in water birth.

As visual estimation of the birth pool and examination of the pregnant woman are unreliable, a need exists to examine blood loss in water birth in an alternative way. Therefore, other possibilities to quantify blood loss in water birth that yields better results than visual estimation will be investigated.

III. PROBLEM ANALYSIS

The previous paragraphs have indicated that current methods of estimating blood loss in a birth pool are unreliable. A why-what analysis has been used to provide an overview of why this is a problem, and what factors are stopping the problem from being solved.

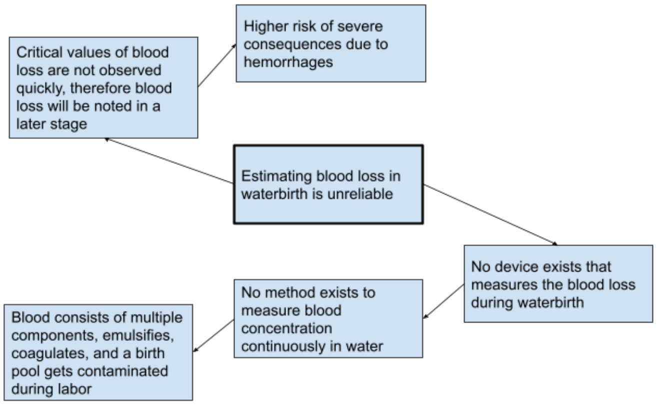


Fig. 1. This figure shows a why-what analysis. In the bold circled box, the core problem is shown. The boxes above show sequentially why this is a problem. The boxes below the core problem show sequentially what factors are stopping the problem from being solved.

The why-what analysis leads to a deeper understanding of the problem. It shows that higher risks of severe health consequences exist due to the problem. It also shows that the characteristics of blood, as well as the contamination of the birth pool, are the key reasons why the problem has not yet been solved.

IV. PROBLEM STATEMENT

No method exists that measures the blood concentration in a birth pool during labor accurately. Therefore, no accurate blood loss measurements can be made in water birth.

Excessive blood loss will be recognized later, leading to higher risks of severe medical consequences of hemorrhages in water birth.

V. SYSTEM DESCRIPTION

A system analysis will be used to further explore the system the research will focus on. An overview of the system, which is shown in figure 2 will be discussed first.

Overview of system

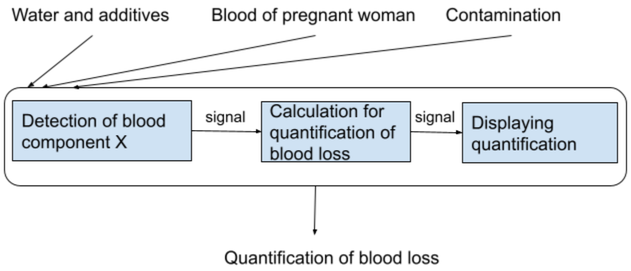


Fig. 2. This figure shows a system overview. At the top of the figure, the three inputs to the system are shown. The system of interest itself is encircled and is composed of three elements, connected by two signals. The output of the system is shown below, which is a quantification of blood loss.

The system of interest is a model of the object of study. The main technique that will be investigated to derive the quantification of blood loss is modeled in this system, which is the quantification of blood loss by detecting a component of blood in the fluid in the birth pool. It has to be noted that during the research, other methods are evaluated which do not focus on the fluid inside the birth pool, yet these will be of minor relevance and are therefore not incorporated in the system description.

A detector is used to register this component in the fluid. A signal will be produced by the detector and sent to a calculating device. This device will convert the signal to a quantification of blood loss. This could be done by taking the strength of the signal as a value for concentration, and by knowing beforehand the total volume of the liquid in the bath, the blood loss can be quantified. The derived quantification must also be displayed to the midwife. In general, the system can be considered a function: based on its input, it will generate an output, which is shown in figure 2. The system should deliver the desired output. Also, the system should meet the constraints set by the inputs and outputs, as well as from other factors it interferes with. These aspects will now be discussed.

A. Water and additives

Tap water from varying sources depending on where the labor will occur will be added to the birth pool before the labor process. The temperature will be 38 degrees Celsius when added and a total amount of 600L will be put in the birth pool. In most but not all cases, one or two kilograms of sea salt is added to the pool. Although sea salt consists mostly of NaCl, other ions are present as well, of which the concentrations are varying between different brands. No other additives are used. The possibility of using additives to aid the measuring process is unknown, as it might influence the pregnant woman or birth process. The water is continuously monitored on temperature. If the temperature reaches 36 degrees Celsius, a certain amount of water will be removed from the bath and boiling water will be added, to increase the temperature of the water back to 38 degrees Celsius.

B. Blood of pregnant women

In measuring the concentration of blood in the water, difficulties arise as blood consists of many different particles. These particles differ in weight and tend to emulsify in water. Also, blood coagulates quickly when it leaves the body [8]. Coagulation might influence many physical variables of blood, so this effect needs to be investigated. The composition of the blood of pregnant women might be different because they are pregnant, but also because individuals tend to have different compositions in blood in general. An option could be to assess what a person's composition of blood is before the labor by examining it. Also, some components might have low variations among individuals and could therefore be used without the need of measuring the concentration of the components of blood of a pregnant woman beforehand.

C. Contamination

The water in the birth pool will be contaminated. It needs to be investigated what fluids or components can enter the birth pool and what effects these components will cause in the birth pool. For example, urine and feces are regularly released into the birth pool and will lead to significant contamination.

D. Output

The output of the system is a quantification of blood loss that can be used by midwives such that action can be taken to battle severe health issues due to hemorrhages. Such quantification of blood loss could be expressed in ml to the midwife. Possibly, a warning signal could be added when a certain amount of blood loss is reached.

E. Place in a larger system

The measurement device is also part of a larger system when in use. It affects the pregnant woman and the birth process, as well as the birth pool itself. Also, the midwife keeping track of the birth process and blood loss is influenced by the measurement device.

The pool is inflatable, which can lead to difficulties in mounting the device. A disposable plastic layer is placed over the pool before filling, ensuring no significant contamination by previous use of the pool. The pool has no flat surface, which can lead to difficulties in deriving physical quantities over the whole length of the water level, or in removing coagulated blood parts from the pool.

The midwives can be trained in how to use the measurement device. The birth process of the pregnant woman could be affected by the measurement device, e.g. by increasing stress due to warning signals.

F. System boundary

The system boundaries are set as described in the system analysis. This means that in the model, as few as possible assumptions are made, to retain the necessary reliability. One could, for example, look for a device that only measures blood concentration in water, without the influence of other body fluids. However, these simplifications are not made in this study, as the method can become useless in practice. Assumptions will only be made in the process when a possibility still exists further research could counter the made assumption, thereby retaining the methods' possible use in practice.

VI. STAKEHOLDER ANALYSIS

Two direct stakeholders have consulted the science shop of the University of Groningen with the request regarding the measurement of blood loss in a birth pool. The stakeholders have a high interest in the research, but their power over the research is limited. They have considerable experience in water birth and also provide training to maternity nurses in water birth. They also rent out birth pools. It is in their interest that the research will result in a solution to the problem, as they can add such a device to the pools they rent out and contribute to the safety of water birth. The stakeholders will be consulted during the research for in-practice knowledge and referred to as 'the stakeholders' whenever information from their side is mentioned.

VII. RESEARCH OBJECTIVE

To design a concept of a method to quantify the blood loss inside a birth pool, as well as to provide a conceptual design of such a tool. The developed method should be an improvement on visual estimation in terms of reliability and accuracy based on [7], while the delay in measurement, costs, and disturbance to the pregnant woman should not be too high. The research has to be performed in ten weeks.

Scope of the research

This research will focus on a proof of concept on how to measure blood in the birth pool accurately, as well as the conceptual design of how this tool can be developed. The conceptual design can be validated and tested by an experimental setup. The development of a tool that can be used by midwives and can be produced on a larger scale itself will most likely lie beyond the available time and is therefore not included in the scope of this research. If a technical approach is deemed impossible in an early stage of the research, an instructional guide could be constructed to increase the accuracy of estimations of midwives regarding blood loss in water birth. If this is considered inappropriate in an early stage, the focus of the research will be on documenting why a technical approach is infeasible.

VIII. RESEARCH QUESTIONS

In achieving the research objective, the following research questions (RQs) must be answered.

A. RQ1: What are the requirements and the evaluation factors of the measurement method?

The measurement method should obey certain requirements to achieve the research objective. These requirements need to be known. The evaluation factors will be used in comparing different measurement methods on their performance.

B. RQ2: Of which components of blood could the concentration be monitored continuously or at sufficiently short intervals in the fluid of the birth pool and what are suitable detection methods for this component?

By assessing the concentration of a certain component of blood and knowing the concentration of that component in the blood of a pregnant woman, total blood loss can be derived.

C. RQ3: What is the rate of spreading of water-soluble components of blood in the birth pool and is it sufficiently fast for use in quantifying blood loss in different measurement methods?

To quantify blood loss based on the concentration of certain blood components in the birth pool, that component must spread homogeneously through the pool. The time it takes will contribute to the time it takes to get a reliable measurement of the blood loss, which may not be too large. Answering this question will also provide insight into how much movement is necessary in the birth pool to acquire a homogeneous spreading of components.

D. RQ4: What methods could be used to quantify blood loss in water birth that do not examine the fluid in the birth pool?

While research question two focuses on the components of blood in the liquid in the pool, the potential methods of this research question will focus on other systems to quantify blood loss in water birth.

E. RQ5: What experimental setup and other methods can be used to validate the measurement method?

A proposal will be made on how the proposed measurement methods could be validated in real life.

F. RQ6: What is the performance of the proposed measurement methods in an evaluation matrix?

The proposed measurement methods will be compared by the use of an evaluation matrix.

IX. MATERIALS AND METHODS

Per research question, the materials and methods will be discussed on how they will be answered.

A. Research question one

The requirements for practical aspects will be set based on stakeholder interviews. Literature research will be performed in obtaining technical requirements.

B. *Research question two*

This research question will be answered by performing extensive literature research, as well as interviewing the stakeholders and experts.

C. *Research question three*

An experiment will be conducted to answer this question. The setup and reasoning of this experiment will be discussed here. Blood will spread inside the pool due to diffusion and fluid flow. Unequal spreading of blood leads to differences in concentration in different parts of the pool. The fluid flow will be caused by the pregnant woman, as well as by the midwife. The stakeholders report a large difference in movement between different pregnant women. In practice, the midwife can stir the bath gently with her hands to increase the spreading of the blood, taking care not to disturb the pregnant woman. An experiment will be conducted to obtain the speed of spreading of blood inside a birth pool. A birth pool (Birth pool in a box, regular, professional) is filled with 600L of water at 38 degrees Celsius. Food coloring containing Allura Red AC was used of which beforehand a calibration curve was derived to assess the range of linearity of the absorption and necessary range for use. At time (t) = 0 seconds(s), a solution varying from 110ml to 190ml tap water with 6g/L Allura Red AC is gently released into the pool, at a location where blood loss is likely to occur as indicated by the stakeholders, i.e. 20cm above bottom surface, 30cm apart from the side wall on the far side of the pool (which is graphically shown in figure 3). After t = 12(s), the stakeholder stirs the bath gently for a duration of twelve seconds, using her judgment on the amount of stirring that can be applied such that the pregnant woman would not be disturbed in practice. Every twelve seconds a sample is taken from the bath, alternating between three different locations.

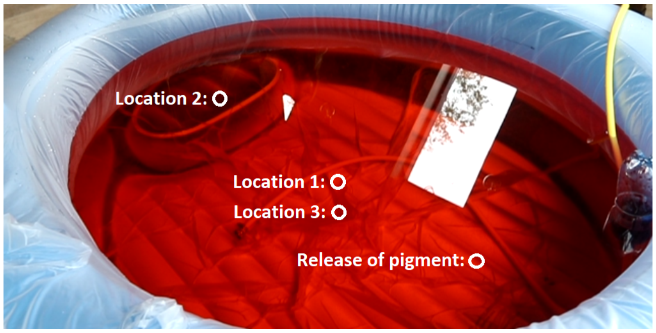
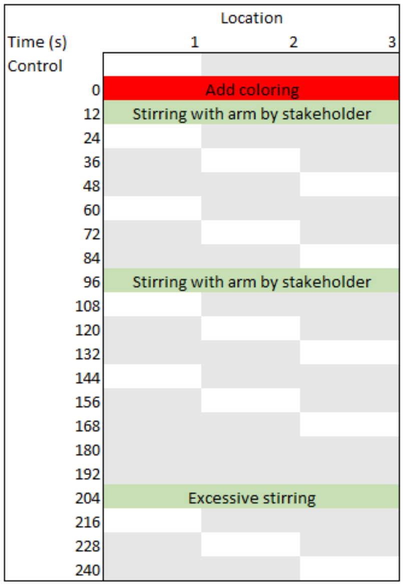


Fig. 3. This figure shows the birth pool used in the experiment and indicates at what locations the samples are taken, and where the pigment is released in the pool.

Location one is at the center of the pool, 5cm under the surface of the water. Location two is on the other far side of the pool compared to where the pigment is applied, 5cm under the surface of the water and 10cm from the side wall. Location three is at the center of the pool, 40cm below the surface of the water. At t=92(s), the bath is stirred again by the stakeholder for twelve seconds. Thereafter, every twelve seconds another six measurements are taken, resulting in four total measurements per location. After these samples, the bath is stirred excessively manually for fifteen seconds by two persons. Measurement is taken on the three locations. In figure 4 below, an overview is provided of the measurements in time.



	Location		
Time (s)	1	2	3
Control	□	▨	▨
0	Add coloring		
12	Stirring with arm by stakeholder		
24	□	▨	▨
36	▨	□	▨
48	▨	▨	□
60	□	▨	▨
72	▨	□	▨
84	▨	▨	□
96	Stirring with arm by stakeholder		
108	□	▨	▨
120	▨	□	▨
132	▨	▨	□
144	□	▨	▨
156	▨	□	▨
168	▨	▨	□
180	▨	▨	▨
192	▨	▨	▨
204	Excessive stirring		
216	□	▨	▨
228	▨	□	▨
240	▨	▨	□

Fig. 4. This figure shows a table in which it is shown what actions are performed in time during the experiment.

The measurements are performed in triplicate, by again adding pigment to the previously used fluid and following the same procedure as described above. In figure 3 the birth pool containing the pigment is shown.

D. *Research question four*

This research question will be answered by performing extensive literature research on methods performed in other fields of medicine where blood loss quantification is performed.

E. *Research question five*

This research question will be answered by performing literature research on other methods used in quantifying blood loss in laboratories.

F. *Research question six*

An evaluation matrix will be constructed based on the evaluation factors derived in answering research question one. Different weights will be assigned to different factors, indicating their importance. The evaluation matrix can consequently be used to obtain the most suitable measurement method for real-life implementation.

X. RESULTS: REQUIREMENTS OF THE MEASUREMENT METHOD

This report will use both requirements, as well as evaluation factors to assess proposed measurement methods. A requirement is seen as either a mandatory attribute or as a minimum level of performance of a certain factor. An evaluation factor must not per se be met, though might provide an advantage. Multiple requirements will be evaluation factors as well: if a minimal performance is met, the requirement is passed, but an increase in performance will lead to a better result in the evaluation factor. An overview of the requirements (Rs), evaluation factors (EFs), and the overlapping requirements and evaluation factors is shown in the table below.

R only	Both EF and R	EF only
1. Quantification	2. Accuracy	11. Continuity
	3. Reliability	12. Scientific readiness
	4. Ease of use	13. Water movement
	5. Disturbance	14. Objectivity
	6. Costs	
	7. Delay	
	8. Contamination	
	9. Disturbances	
	10. Limitations Hb	

TABLE I

THIS TABLE SHOWS FACTORS THAT ARE REQUIREMENTS (R) ONLY, EVALUATION FACTORS (EF) ONLY, AND FACTORS THAT ARE BOTH. AS SHORTENED WORDS ARE USED TO INDICATE THE REQUIREMENTS AND EVALUATION FACTORS, A NUMBER IS ASSIGNED TO THESE FACTORS TO PREVENT MISTAKES IN REFERENCING.

The 14 requirements and evaluation factors in this table are explained one by one below. How the measurement methods will precisely be rated using the evaluation factors will be explained in chapter XIV.

Requirements

1) Quantification of blood loss instead of speed and time measurement: All measurement methods must quantify blood loss. While this seems trivial, in practice, midwives also pay attention to when the blood loss occurs, and at what speed it occurs. That could lead to a measurement method that does not quantify blood loss, but keeps track of the time and speed of blood loss, and will warn the midwife in case of a sudden increase in blood loss for example. However, different causes of obstetric blood loss exist which all have different dynamics, and can have different dynamics of themselves as well. According to a midwife, some ruptures can lead to a liter of blood loss in a matter of minutes, while other blood losses may take place in over an hour before a critical level of blood loss is met. In addition, in current guidelines for the Netherlands, a blood loss of either 500ml or 1000ml is an indication to take action [9]. Due to these reasons, it is impossible to design a suitable measurement method that works solely on the speed of blood loss and/or time of blood loss. In addition to the requirement of quantification, the range of blood loss that the device needs to be able to quantify is set from 100 to 1000 ml, based on [7].

Both requirements and evaluation factors

2) Accuracy: The required accuracy of the measurement method must be an improvement compared to visual estimation. The study of [7] has been performed using simulated blood loss in a birth pool and recording the pool, and consequently letting midwives provide their estimate on the amount of blood loss online. An average underestimation of 40% in the estimation of critical volumes of blood loss (one and 1.1 liter) occurs. The requirement on accuracy can consequently be estimated on at most 40% average error.

3) Reliability: If the measurement method shows significantly less blood loss than what has occurred due to a reliability issue, the hemorrhage might remain unnoticed, leading to severe consequences. This problem imposes the largest threat when the midwife would normally, without measurement method, have recognized the hemorrhage by visual estimation, yet now by thrusting the measuring method consciously or unconsciously, neglects her visual estimation. In this way, the measurement method introduces a new threat instead of an improvement over visual estimation. Therefore, the reliability of the measurement method must be proven. It is an acceptable possibility that the measurement method is not reliable in all situations, as long as it can be easily determined by the midwife whether the conditions are suitable for the measurement method and its results can therefore be used or not. Also, however undesired, it is acceptable that the measurement method in some situations might overestimate the amount of blood loss.

4) Ease of use: Although inaccurate blood loss quantification due to the use of visual estimation can lead to severe health issues and ultimately maternal death, it can not be concluded that midwives will accept a large difficulty in operating the measurement method. In practice, a more easy-to-use measurement method will be used more frequently than a more difficult and time-consuming one. Factors contributing to the perceived ease of use will be the time necessary and the difficulty of the setup and use of the measurement method. Apart from the willingness of the midwife to use the measurement method, the method may also not be too hard to use as the midwife needs to have sufficient time and attention to guide the birth process.

5) Disturbance to pregnant woman: Women opting for water birth are known to value the birth experience highly [10]. Disturbances in their birth process, e.g. disrupting their attention, are strongly undesired. Only in case of significant indications of a severe hemorrhage, disturbances to the woman and her birth process are tolerable. Disturbance can be caused in a variety of ways: the size of a potential device can hinder the amount of space inside the birth pool. Noise and warning lights made by a potential device can interrupt the focus or relaxed state of the woman. Measurements that need to be taken from the woman, e.g. blood pressure or blood samples, are not desired in general as well. However, the stakeholders have indicated that a significant part of the women would possibly tolerate the need for a blood-finger prick test.

6) Costs: Costs are divided into costs for use, training and maintenance, costs for production, and development of the measurement method. It is difficult to estimate the maximum tolerable costs of the measurement method. Although blood loss during childbirth is one of the main causes of maternal death, maternal death is very uncommon in developed countries. A very rough estimate could be made using a quality of adjusted life years (QALY) approximation, using the number of fatalities due to postpartum hemorrhages in the Netherlands. However, this will lead to an inaccurate image, as it is uncertain how the measurement concept would influence the number of fatalities. Also, high blood loss can indirectly lead to complications or intensive care unit admission which leads to other additional costs, or even fatality reported under other causes (heart attack e.g.). The final performance of the measurement method will also contribute to the maximum tolerable costs. The stakeholders have reported that multiple midwifery practices do not engage in water birth, indicating a key reason for the lack of quantifying blood loss. These clinics might be willing to pay considerably to the measurement method.

7) Delay: The acceptable delay between when the actual blood loss has occurred, and when that blood loss will be administered by the measuring method. The precise dynamics of the blood loss during delivery are unknown in scientific research. Therefore, the stakeholders have been contacted for an estimate, leading to an estimate of maximally five minutes of acceptable delay, as a liter of blood can be lost in this time.

8) Prone to contamination of pregnant woman: The degree to which a measurement method is susceptible to contamination like feces, urine, amniotic fluid, and sweat.

9) Prone to disturbances: The degree to which a measurement method is susceptible to the following disturbances: ambient lighting, temperature, turbidity, movement of water, blood clots (optical hindrance), and others.

10) Limitations hemoglobin measurement: clotting, hemolysis, oxygenation, and decay: Shows the degree to which a measurement method is susceptible to the limitations due to measuring hemoglobin. These limitations will be discussed in chapter XI.

Evaluation factors only

11) Continuity of measurement: A continuous measurement method is able to continuously quantify blood loss autonomously. A semi-continuous method can either quantify blood loss within intervals or 60 seconds, or can quantify the blood loss continuously, but human intervention is needed to score the quantification,e.g. in visual estimation. The advantage of a continuous method is that information can be obtained on the dynamics of blood loss in water birth, which can be used to either identify a hemorrhage earlier or for an increased scientific understanding of the dynamics of postpartum hemorrhage.

12) Scientific readiness: The number of academic papers on the proposed measurement methods varies over the different proposed methods. The scientific background of a method is an advantage, as unforeseen factors might have been investigated already.

13) No excessive water movement necessary: Measurement methods that are performed by taking samples need excessive stirring, based on the experiment performed in this research. Excessive stirring might be difficult to realize in practice, and might also lead to significant disturbance of the birth process.

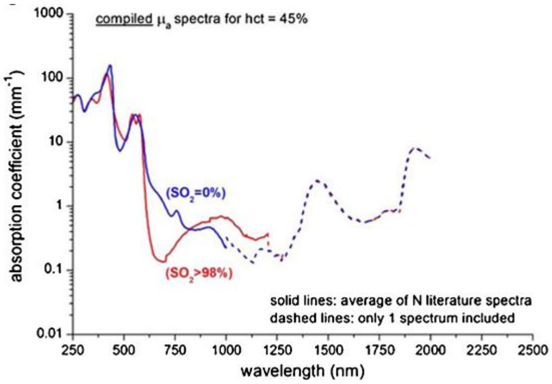
14) Objectivity of measurement: In objective measurement methods, the midwife's personal opinion and biased judgment will not influence the result of the quantification of blood loss.

XI. RESULTS: DETERMINATION OF THE CONCENTRATION OF A BLOOD COMPONENT BY OPTICAL PROPERTIES LIQUID INSIDE THE BIRTH POOL

Before research question two can be answered, the optical properties of the liquid inside the pool need to be discussed, as multiple measurement methods in research question two use these optical properties, and these optical properties are influenced by many factors. The discussion of optical properties of the liquid in the birth pool will be discussed in this chapter. The optical properties of the pool can be examined by measurement methods as a whole, e.g. by visual estimation, or by taking samples of the liquid in the birth pool. Therefore, effects that influence the optical properties between different samples will be evaluated as well (e.g. inadequate spreading).

1) Optical properties of whole blood: In whole blood, red blood cells dominate the absorption in the wavelength range of 250-1100 nm by two to three orders of magnitude compared to other blood components. Only in pathological conditions, other components might contribute to the absorption in whole blood in the range of 250-1100 nm. In wavelengths larger than 1100 nm, water absorption is substantial [11]. Hemoglobin, in all its different forms, accounts for nearly all light absorption in red blood cells. Therefore, the optical characteristics of whole blood are dominated by hemoglobin. Individual differences in optical properties of whole blood are mainly caused by an increase in the hemoglobin concentration and the amount of oxygenation of hemoglobin. Increasing levels of hemoglobin concentration lead to linearly increased absorption, whereas the oxygenation of hemoglobin leads to a change in absorption of certain wavelengths [12].
As hemoglobin dominates the light absorption in the 250-1100 nm range, hemoglobin will be the main focus of the rest of this chapter.

2) Different forms of hemoglobin: Multiple different forms of hemoglobin exist. Most prevalent in human blood are oxyhemoglobin and deoxyhemoglobin, followed by carboxyhemoglobin, methemoglobin, and fetal hemoglobin.



These different forms all exhibit different absorption spectra. The absorption spectra of oxyhemoglobin and deoxyhemoglobin are shown in figure 5. In arterial blood, approximately 97.5% of the total hemoglobin concentration consists of oxyhemoglobin, whereas in venous blood this number is approximately 75% [12]. This difference in oxygenation is mainly caused by the partial pressure from oxygen, yet is also influenced by pH level, temperature, and other factors [13]. It is unknown what the oxygenation of hemoglobin will be in the birth pool. Although no severe decay of hemoglobin is expected based on the study of [14], no specific information is found on how the different forms of hemoglobin will respond, and transform, in the liquid inside the birth pool.

3) Hemoglobin concentration in the birth pool: To derive effective measurement methods, an estimation needs to be made of what the concentration of hemoglobin will be in the birth pool. The hemoglobin concentration in the blood of pregnant women is generally lower due to pregnancy, resulting in average values of 11-16g/dl. However, the incidence of anemia in the industrial world is 18% (lower than 10.5g/dl) [15]. Therefore, it can be concluded that hemoglobin concentration in the blood of pregnant women varies significantly. A hemoglobin concentration of 11 g/dl until 16 g/dl will be assumed in the blood of the woman in calculating the expected level of hemoglobin in the pool. As the measurement method should be able to measure values between 100ml and 1000ml of blood loss accurately based on the research of [9], this would result in a range of 11 (11 g/dl * 100 ml) to 160 (16 g/dl * 1000 ml) grams of hemoglobin released in the pool. Based on a water volume of approximately 600 liters in the birth pool of interest (Birth pool in a box, professional, regular), this would result in hemoglobin concentrations of 18.3 mg/l until 266 mg/l in the birth pool.

4) Hemolysis: Hemolysis is the destruction of red blood cells, such that hemoglobin is released into the surrounding medium. The occurrence of hemolysis in the birth pool is important for the following reasons:

- Hemoglobin dissolved in water will not precipitate after centrifuging, while intact red blood cells containing hemoglobin will. Therefore, hemolysis strongly limits the possibility to separate hemoglobin from the components in blood plasma [16].
- The absorption values of hemoglobin encapsulated in red blood cells is different from the absorption values of homogeneously spread hemoglobin. Hemoglobin in suspension will have a flattened absorption spectrum compared to homogeneously spread hemoglobin. If needed, the method of Duysens [17] can be used to quantify this difference. [12].
- Lysed red blood cells might still have absorption capacity, which is yet unknown.
- In a birth pool, red blood cells could sink in the pool, whereas free hemoglobin will dissolve and will possibly spread more evenly in the water.

Rate of hemolysis

Whether hemolysis occurs, and at what rate, depends on the tonicity of the surrounding fluid to the red blood cell. A calculation based on the osmolarity instead of the tonicity of the surrounding fluid is not accurate, as the human red blood cell is permeable to multiple different solutes [18]. It is assumed that the tonicity of tap water is close to the tonicity of distilled water, as the osmolarity in tap water is low compared to the tonicity of 0.9% saline. Therefore, the results in table II, which are based on the rate of hemolysis in different concentrations of NaCl solutions, will be used to obtain a grasp on what rate hemolysis will occur in the birth pool.

% NaCl	Amount hemolysis	Necessary time
0.9%	None	n.a.
0.45%	Partial	n.a. [19]
0.33%	Full	30 minutes [20]
0.17%	Full	Unknown
0.00%	Full	3.75 seconds

TABLE II

THIS TABLE SHOWS THE CONCENTRATION OF NACL, AND THE CORRESPONDING SPEED AND AMOUNT OF HEMOLYSIS. THE BOTH RESULTS 'N.A.' ARE USED AS TIME IS NOT QUANTIFIED FOR FULL HEMOLYSIS IN THESE SOLUTIONS.

The addition of 1kg of sea salt to the birth pool leads to an approximate NaCl concentration of 0.17%, whereas the addition of 2kg of sea salt will lead to an approximate NaCl concentration of 0.33%. Due to the lack of information on the rate of hemolysis in a 0.17 % saline solution, it is unknown at what rate hemolysis will occur, however, it can be hypothesized that it will be significantly faster than 30 minutes. The results shown can only be used as an indication, as the assumption that tap water does not have a significant influence on the tonicity of the fluid has not been verified.

Strive for full, partial, or no hemolysis?

In obtaining accurate results in quantifying blood loss based on the hemoglobin concentration, it is speculated that full and fast (less than two minutes) hemolysis is preferable over partial hemolysis, as absorption values will be constant over all hemoglobin molecules, and the possibility of the sinking of hemoglobin inside red blood cells is reduced. Also, hemoglobin will be less likely to form in blood clots, as will be discussed in the next paragraph. Fast and full hemolysis will be promoted by an as low as possible tonicity of the birth pool. Therefore, it might be advised that no sea salt must be added to the liquid in the pool. Next to obtaining as fast as possible hemolysis, one could alternatively strive for no significant hemolysis in the birth pool at all. This would be done by adding more sea salt to the birth pool, such that an 0.9% saline solution is obtained. This might have other advantages as well for the birth process, although this requires further research [21]. The advantage would be that no mixture between lysed red blood cells and non-hemolysed red blood cells would occur, which leads to difficulties whenever the percentage amount between the different forms is unknown.

5) Blood clotting in birth pool: It is indicated by the stakeholders that blood clots in the birth pool are present in almost all water births. As particles present inside these blood clots will not spread homogeneously in the fluid in the blood pool even after excessive stirring, various measurement techniques will not account for the components inside the blood clots. Therefore, it needs to be known what components are present in blood clots and in what amount. However, blood clots can have a wide variety of concentrations of different components, e.g. varying red blood cell and fibrin concentrations [22] [23] [24]. Blood clots present in the birth pool can have formed under a variety of circumstances. The formation of blood clots can have started in the bloodstream of the pregnant woman, in the amniotic fluid of the uterus, or in the liquid of the birth pool. Therefore, the composition of the blood clots in the pool can be even more varying than the variety of clots in regular hemostasis. The concentration of hemoglobin inside blood clots needs to be known when measurement techniques based on hemoglobin will be applied. The stakeholders performed a non-scientific experiment, where they put a blood clot with a volume larger than 100 ml in a water-filled birth pool. They did not observe any coloring of the surrounding water. Therefore, it is speculated that blood clots that have already formed before they enter the pool will release negligible amounts of hemoglobin as red blood cells encapsulated in fibrin might be prevented from hemolysis, although this is not based on scientific data. On the other hand, it is speculated that blood clots that form in the pool itself will contain hemoglobin in much lower concentrations if the red blood cells will all be lysed and the hemoglobin will already be spread freely in the liquid before coagulation occurs. Therefore, the blood clots formed in the pool would not influence the absorption from the liquid in the pool significantly, if full hemolysis has occurred in the birth pool. These hypotheses must be tested, as blood clots that would contain, and remain to have, significant amounts of hemoglobin, will hinder the possibility of hemoglobin to dissolve in the liquid in the birth pool.

6) Spreading of hemoglobin in birth pool: It is assumed that the spreading of dissolved hemoglobin in the pool will follow equal spreading to other soluble molecules, as most of the spreading in the birth pool is caused by fluid flow instead of diffusion, which is concluded based on visual estimation during the experiment. Therefore, the results of research question three, the experiment on the spreading of a pigment in the birth pool, can be used to obtain the speed of the spreading of hemoglobin in the birth pool, assuming that the hemoglobin will be lysed from the red blood cell.

Results on research question three: spreading of pigment in a birth pool.

As previously mentioned in the materials and methods section, the experiment is performed by adding a solution containing Allura Red AC to a birth pool in a place where blood loss is likely to occur. At certain time intervals, the bath is stirred and samples are taken at three different locations, after which spectrophotometry is applied to derive the concentration of Allura Red AC in the different samples. Figures 6, 7 and 8 show the results of the spreading experiment for the three different locations.

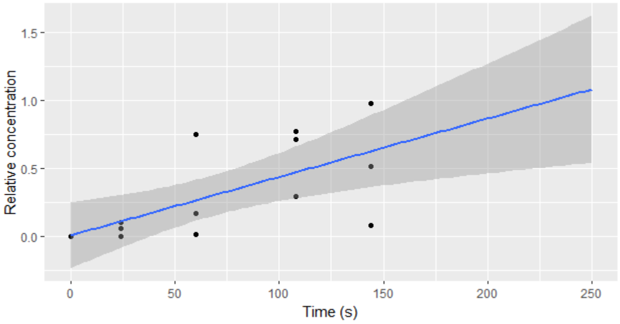


Fig. 6. Spreading pigment at location one. The y-axis shows the relative concentration: a value of 0.0 is equal to the concentration of Allura Red AC before the addition of extra pigment and a value of 1.0 equals the concentration of Allura Red AC when the added pigment is homogeneously spread. The x-axis shows the time in seconds. The blue line is the result of the linear regression analysis. The gray area surrounding the blue line shows the confidence intervals of the linear line: with 90% confidence, the blue line lies within that area.

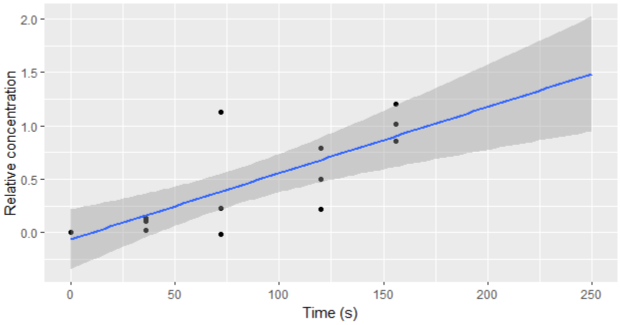


Fig. 7. Spreading pigment at location two. Explanation is provided in the caption of figure 6.

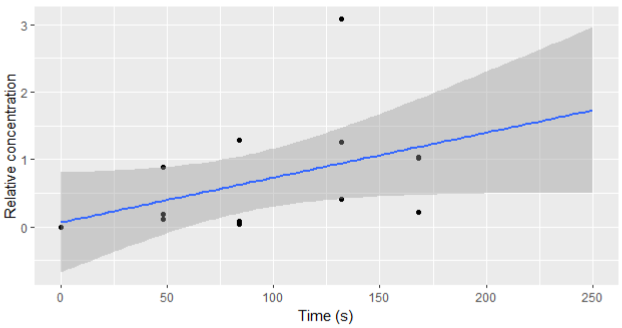


Fig. 8. Spreading pigment at location three. Spreading pigment at location two. Explanation is provided in the caption of figure 6.

Linear regression analysis has been performed to derive a general idea of how much time it will take minimally before the relative concentration is equal to 1.0 at each location. This linear regression analysis does not quantify how much time it will take before homogeneous spreading has occurred: homogeneity of the spreading will not be a linear function, and an average value of one does not indicate homogeneous spreading yet. The linear regression analysis is used to show how much time it would minimally take; in reality, it will take significantly longer. In analyzing the results of the graphs, the intersections of the linear equation and the relative concentration of 1.0 are examined, which yield the following results as shown in table III:

Location	Time (s)
1	210
2	170
3	140

TABLE III

This table shows the results of the intersections of the linear equation with a relative concentration of 1.0 for the three different locations

Therefore it can be concluded that the time it takes for homogeneous spreading to occur will be significantly larger than the indicated time of 210 seconds for location one, 170 seconds for location two, and 140 seconds for location three based on the linear regression analysis. In addition to this, the confidence intervals shown in the graph indicate very high uncertainty in this linear regression analysis. Based on these confidence intervals and the time necessary based on the linear regression analysis, it can be concluded that with the amount of stirring that has been performed by the midwife the spreading of hemoglobin in the birth pool will take significantly longer than 140 seconds, and the speed of spreading will be too varying to be useful in quantifying blood loss.

Spreading of pigment after excessive stirring

After excessive stirring, the average measured concentrations at the three locations were scaled to a value of 1.0. The results are shown in table IV:

Measurement	Location 1	Location 2	Location 3
1	1,02	0,98	1
2	0,92	1,00	1,08
3	1,02	1,00	0,98

TABLE IV

This table shows the scaled results for the relative concentration at the three different locations after excessive stirring, for three different measurements.

The standard deviation for this value of 1.0 is 0.042. Therefore, it is concluded that after 15 seconds of excessive manual stirring, the homogeneity of hemoglobin is sufficient to be useful in quantifying blood loss.

7) Optical properties in liquid due to contamination: While hemoglobin dominates the absorption spectrum of 250-1100 nm in whole blood, it can not be concluded hemoglobin will continue to do this in the birth pool. Although hemoglobin concentration is quantifiable by spectrophotometry in free plasma hemoglobin assays, containing comparable concentrations of hemoglobin, it is unknown how the presence of contamination, like feces, urine, sweat, and amniotic fluid, will affect the optical properties of the birth pool.

8) Concluding on optical properties of liquid in birth pool: It has been shown that hemoglobin is dominating the optical properties of blood, and therefore as well the optical properties in the birth pool due to blood. However, measuring hemoglobin in the pool by its optical properties comes with multiple limitations. A pre-measurement of the pregnant woman's hemoglobin is necessary, as values vary too much individually. Significant stirring is necessary to derive sufficiently homogeneously spreading of hemoglobin in the liquid in the pool. Other limitations which are known, but need further investigation to quantify their influence, are the hemoglobin content in blood clots, oxygenation of hemoglobin, possible decay of hemoglobin, the rate of hemolysis, and the influence of contamination.

Although the use of optical properties of the liquid in the birth pool comes with significant challenges, methods based on the optical properties will now be evaluated on their potential use.

XII. RESULTS: MEASUREMENT METHODS BASED ON THE DETERMINATION OF THE CONCENTRATION OF A BLOOD COMPONENT IN THE BIRTH POOL

The results discussed in this chapter directly answer research question two. In discussing the measurement methods, first, their measurement principles will be explained. The chapter is structured as indicated in the following overview.

A. Measurement principles based on the determination of hemoglobin
   1) Measurement principle: Visual estimation of hemoglobin concentration
      - **Aided visual estimation, color card**
      - **Aided visual estimation, color card, sample**
      - **Aided visual estimation, lights in pool**
   2) Measurement principle: colorimetry
      - **Colorimetric approach**
   3) Measurement principle: spectrophotometry
      - **Direct optical spectrophotometry**
      - **DO spectrophotometry in pool**
      - **Chemical added spectrophotometry**

B. Measurement principles based on determination of non-hemoglobin blood components
   1) Measurement principle: Measuring the concentration of a blood component in the pool without a pre-measurement of the concentration of that component in the blood of the pregnant woman:
   2) Measurement principles based on other blood components inside the pool

A. Measurement principles based on the determination of hemoglobin

All methods described in this section will quantify the concentration of hemoglobin by use of optical properties to quantify the blood loss. The limitations discussed in the section ‘Concluding on optical properties of liquid in the birth pool’ apply to these methods.

1) Measurement principle: Visual estimation of hemoglobin concentration:

1) Measurement principle: Visual estimation of hemoglobin concentration: Visual estimation is used currently in water birth and in conventional birth as well to quantify blood loss [7] [25]. In water birth, midwives compare the color of the pool to their idea of how much blood loss it equates to, where increasing darkness of the pool corresponds to an increase in blood loss. The increase in color in the liquid in the pool caused by blood is due to an increase in hemoglobin concentration. In conventional birth, visual aid in visual estimation has been seen to improve accuracy [26].

Measurement method: Aided visual estimation, color card. In this method, the darkness of the pool can be compared to different colors of a color card, which will consequently indicate how much blood is lost for that particular color.

The color card could incorporate different parameters, like hemoglobin concentration of the blood of the woman, depth and volume of the pool, and amount of blood clots in the pool to improve accuracy. Color cards are used in different fields of science: e.g. in determining skin color variations [27], determining urine concentration [28] and determining concentration of bilirubin in plasma [29].

Measurement method: Aided visual estimation, color card, sample. In this measurement method, a sample will be taken from the pool, and this sample will be visually compared with a predetermined color card. The sample could also be put on a specially designed paper for increased color differentiation, as is done in the WHO hemoglobin color scale [30].

The possible advantage of taking a sample, apart from the possibility to put it on a specially designed paper, will be explained by the use of the law of Lambert-Beer. The law of Lambert-Beer states that the absorption is linearly correlated to the extinction coefficient, the concentration of the component, and the optical path length, where an increase in these factors leads to an increase in the absorption. In a birth pool, the optical path length is approximately 50 cm from the surface of the fluid until the bottom of the pool. When a sample is taken from the pool, the optical path length can be arbitrarily chosen. Therefore, it is possible to choose the optical path length that yields the most accurate results for quantifying blood loss.

The inaccuracy caused by directly measuring from the pool will be illustrated using the following figure.

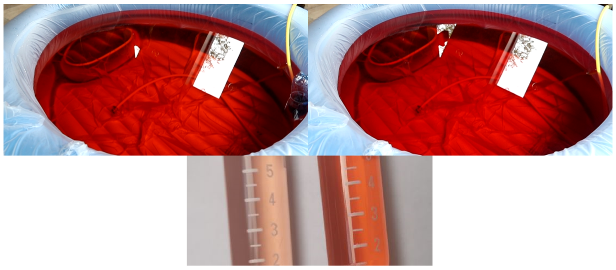


Fig. 9. This figure shows two pictures of a birth pool: the concentration of Allura Red AC is three times higher in the right birth pool compared to the left birth pool. The picture below shows two tubes in which the right tube also contains three times as high a concentration of Allura Red AC compared to the left tube

In figure 9 it is seen that the birth pools show almost no visible difference in color, while the two samples show a clear color difference. In this example, Allura Red AC is used, which has no significant absorption in wavelengths larger than 600 nm [31]. The lack of color difference is caused by maximization of absorption in which Allura Red AC does absorb light. An increased concentration of the pigment will not lead to more noticeable absorption, as the wavelengths larger than 600 nm will not be absorbed. By taking a sample and reducing the optical path length sufficiently, the absorption is not maximized and the differences in concentration can be noticed. In a birth pool environment, fewer differences in color in higher concentrations of hemoglobin occur as well [32]. As hemoglobin has minor absorption in all visible wavelengths, differences in color due to an increased concentration of hemoglobin are still noticeable in the bath at high concentrations of hemoglobin. However, due to the maximization of absorption in certain wavelengths, the increase in hemoglobin concentration becomes less visible in higher concentrations. Therefore, taking a sample from the pool will most likely increase accuracy, as color differences will become more noticeable.

Measurement method: Aided visual estimation, lights in pool. This method can be regarded as a form of spectrophotometry, where the human eye will replace the sensor of the spectrometer, and will only look for the full extinguishing of the light. Lights of a predetermined wavelength and intensity can be placed in the pool at a certain depth. As the absorption spectra of hemoglobin are known, it can be deducted at which concentration of hemoglobin the lights should become nearly invisible. By placing multiple lights with different wavelengths in the pool, different concentrations are needed to extinguish the light, and in this way, a scale can be obtained that could be used to identify the amount of blood loss. It is hypothesized that a range of wavelengths can be chosen that are specific and constant for different forms of hemoglobin, instead of being absorbed by contamination. The lights could beforehand be adjusted by the hemoglobin concentration of the blood of the pregnant woman. The setup of the lights must ensure that the light source will have an equal distance to the surface of the liquid in different water births. This method is not based on any scientific papers.

2) Measurement principle: colorimetry: The type of colorimetry used here is described by the quantification of color, thus must not be confused with the chemical assay colorimetry. In the birth pool environment, colorimetry analyzes photographic information, and can consequently derive the amount of blood- and non-blood components. With the use of the hemoglobin level of the pregnant woman and the volume of liquid inside the canister, total blood loss can be derived. This principle is used in the application Triton developed by Gauss Surgical Inc., designed for surgical procedures [33], and validated for use in canisters [34].

Measurement method: Colorimetric approach. The measurement method proposed based on colorimetry is called the colorimetric approach. A smartphone is installed near the birth pool, such that its camera can monitor the fluid inside the pool. An application will be used that continuously analyzes the color of the liquid, and by using a previously determined hemoglobin level of the pregnant woman, the total blood loss can be continuously computed and displayed. Alternatively, to potentially increase accuracy, a sample of the bath could be taken and put in a canister, which will then be analyzed.

3) Measurement principle: spectrophotometry: The measurement principle ‘spectrophotometry’, which includes both direct optical and chemical added spectrophotometry, is widely used in measuring the plasma free hemoglobin concentration in concentrations generally lower than 10 mg/dl [35]. As this plasma free hemoglobin concentration is comparable to the hemoglobin concentration in the birth pool, assays used in determining plasma free hemoglobin concentration in blood plasma could potentially be used in determining the hemoglobin concentration in a birth pool. Various direct optical, as well as added chemical spectrophotometric assays, exist, and have been evaluated in scientific research on multiple aspects [16]. Maulinauskas [35] indicates all different assays show similar results in hemoglobin diluted in saline, yet show different results when interferents from blood plasma like bilirubin were added. Therefore, it is difficult to determine which free plasma hemoglobin assay will yield the best performance in determining the hemoglobin concentration of the liquid of the birth pool based on scientific research, as the interferents in the birth pool vary from the interferents of typical blood plasma. Therefore, it is proposed more research is needed on what specific free plasma hemoglobin assay should be used to quantify blood loss in the birth pool. Two types of methods, instead of specific assays, will be proposed and discussed for their (practical) use in quantifying the blood loss in a birth pool: direct optical spectrophotometry and added chemical spectrophotometry.

Measurement method: Direct optical spectrophotometry. In the proposed method ‘Direct optical spectrophotometry’, a sample will be taken from the birth pool and analyzed in a spectrometer. As mentioned previously, multiple different assays exist using this technique, e.g. the technique of Cripps (1968) [36] and the Harboe method (1959) [37], and no conclusion will be made on which method is preferable for use in a birth pool. Direct optical spectrophotometry methods can be used in automated analyzers [38], but also in specialized user-friendly analyzers such as the Hemocue, which measures the hemoglobin level of whole blood [39]. Potentially, a device similar to the Hemocue could be developed to quantify the blood loss in the birth pool based on its hemoglobin concentration.

Measurement method: DO spectrophotometry in pool. Instead of taking a sample from the pool as in the proposed measurement method ‘Direct optical spectrophotometry’, a submersible spectrometer, as used e.g. in the research of [40], can also be placed inside the pool. The apparatus can automatically compensate for ambient lighting. While submerged in the pool, the spectrometer can output continuous measurements, or at least within intervals of only several seconds, which can be converted into the quantification of the blood in the pool. Before delivery, the hemoglobin level of the pregnant woman is set in the measuring device. The quantification will be shown on a screen to the midwife.

Measurement method: Chemical added spectrophotometry. In the proposed method 'Chemical added spectrophotometry', a chemical will be added to the sample taken from the birth pool to convert the hemoglobin into different forms, after which they will be analyzed by spectrophotometry. It is not yet determined which specific approach is most suitable, as more research is needed for this. The cyanmethemoglobin method is used widely as a gold standard in determining the hemoglobin concentration in whole blood in scientific research [39]. Although the cyanmethemoglobin method can also be used for much lower concentrations of hemoglobin than present in whole blood, it must be noted that this method has added limitations in lower concentrations of hemoglobin as present in the birth pool [35]. The tetramethylbenzidine (TMB) method uses the addition of chromogens in deriving the concentration of hemoglobin in blood plasma, which may be more suitable for the low concentrations of hemoglobin. The advantage of this method compared to direct optical spectrophotometry is that by the addition of a chemical, the influence of disturbances and/or contamination of the birth pool can possibly be circumvented.

B. Measurement principles based on determination of non-hemoglobin blood components

1) Measurement principle: Measuring the concentration of a blood component in the pool without a pre-measurement of the concentration of that component in the blood of the pregnant woman: It is preferred that the concentration of the component in the blood does not need to be determined beforehand, as most pregnant woman are not willing to, will take time, and will lead to additional costs. Therefore, a component is aimed for that shows consistent concentrations in the blood of the pregnant woman between different individuals. Different laboratory reference value overviews are examined on many different components in blood. A range of 25% difference in upper and lower limit is set to obtain components in blood that are "stable" in their concentration among different patients. Although this constraint has some major limitations, it will be used to identify a general grasp of what components could potentially be used without measuring the concentration of that component before delivery. After investigating the laboratory reference values, only the following components fell into the range of 25%: calcium (9.0-10.5 mg/dl) ionized calcium (4.5-5.6 mg/dl) chloride (98-106 mEq/liter) sodium (136-145mEq/liter) [41]. Calcium has a presence in tap water varying from 1 to 135 mg/L with an average of 22 mg/L in the USA [42]. Chloride has an average presence of 150 mg/L in Dutch tap water and sodium 63 mg/L in tap water in Amsterdam [43] [44]. A large amount of tap water in the birth pool, combined with the presence of the mentioned components in amniotic fluid, urine, and feces, will make quantifying blood loss by measuring the concentration of these components impossible [45]. Therefore, it is concluded that a measurement principle based on a component in the blood can only be used whenever a blood sample is taken before the delivery to obtain an indication of the concentration of that component present in the pregnant woman.

2) Measurement principles based on other blood components inside the pool: Apart from hemoglobin, blood consists of many other components. The possibility of measuring ions has been shortly examined, and the presence of ions in tap water is likely to make an accurate measurement of ions due to blood in the birth pool impossible, yet more research is needed to confirm this. Due to a lack of time, the possible use of measuring other components next to hemoglobin and ions in the liquid in the pool to quantify the blood loss has not been examined.

XIII. RESULTS: MEASUREMENT PRINCIPLES THAT DO NOT FOCUS ON THE FLUID INSIDE THE BIRTH POOL

Some measurement methods outside of the system of interest were shortly examined for their use in reaching the objective of study.

1) Measurement method: filtration system: A possibility to quantify the amount of blood in the birth pool is to filter components of blood out of the bath, and consequently weigh or analyze them in an alternative way. By deriving beforehand the percentage weight or concentration of the measured component in the blood of the pregnant woman, the amount of blood loss could be computed. However, due to the large volume of the bath (600L), the throughput speed of the pump would need to be too large. In addition, the stakeholders indicated that the use of a pump is undesired, mainly due to infection risks, although no scientific evidence either supports or rejects this.

2) Measurement method: coagulation in pool: A theoretical possibility to quantify the amount of blood in the birth pool is to use a coagulant, which leads to full coagulation of all (red blood) cells, which could be manually extracted from the bath and consequently weighed. However, next to many other limitations, this approach will lead to health risks whenever the coagulant enters the body of the pregnant woman or child.

The following three techniques measure values or signs of the pregnant woman. However, such techniques are not used in conventional birth [46], indicating that they will not pose a solution.

3) Measurement method: hemoglobin levels pregnant woman: The calculated blood loss method works by measuring the hemoglobin or hematocrit level of the pregnant woman before and after the blood loss has occurred. However, the blood loss can only be determined at least two hours after the blood loss has stopped with this method [47]. An improved version of the calculated blood loss method suffers the same limitation [48].

4) Measurement method: vital signs pregnant woman: In conventional birth, systolic pressure and pulse rate alter due to severe hemorrhages. Blood loss may be over 1500ml or 2000ml before these measures will show [49].

5) Measurement method: vena cava: While the measurement of the diameter of the vena cava is widely used in emergency medicine to estimate the blood loss of a patient and is seen to be useful in quantifying blood loss for the period after delivery [50], the method is shown unsuitable to quantify the amount of blood loss accurately during delivery [51].

XIV. RESULTS: EVALUATION OF PROPOSED MEASUREMENT METHODS BY AN EVALUATION MATRIX

An evaluation matrix will be used in this chapter to compare the different proposed measurement methods. The evaluation factors explained in the chapter X will be used to rate the performance of the measurement methods in the evaluation matrix. Table V indicates how the evaluation factors are rated, and what performances lead to what rating. Further explanation of the table will be provided in the following section.

A. Method of rating of evaluation factors

Table V shows an overview of the methods and criteria for rating the evaluation factors. The evaluation factors can be rated as no limitation, moderate limitation, severe limitation, or impossibility for practical use (requirement unmet). Evaluation factors that need no further explanation apart from the table on how they are rated will be omitted in the following explanation.

Accuracy will be derived by experimental results and rated in the mean average deviation of the desired result. *Reliability* will be determined by experiments, however, a clear value has yet not been determined for evaluation. *Ease of use* and *Disturbance to pregnant woman* indication will be provided by the stakeholders. Reluctancy in practical use means that while midwives and pregnant women might dislike the use of the measurement method, it is estimated that less than 30% will quit using the measurement method due to its ease of use or disturbance to the pregnant woman. *Continuity of measurement* is achieved when a device computes a continuous quantification, and this quantification can be logged, such that the dynamics of blood loss can be tracked. A moderate limitation is considered when the device can output a value within intervals of 60 seconds, or when the method quantifies blood loss continuously, yet a midwife needs to score the result. In *objectivity of the measurement* the influence of different midwives in scoring the quantification is used. When a measurement method loses significant accuracy and reliability due to the personal interpretation of the midwife, it is considered a severe limitation.

B. The evaluation matrix

The evaluation matrix shown in figure 10 will be used to compare the proposed measurement methods. The proposed measurement methods are rated using the methodology of table V. The evaluation matrix computes a weighted score, in which accuracy and reliability are a factor of three more important. The lowest score yields the best performance of a measurement method based on the evaluation matrix. The weight importance is assigned as reliability and accuracy are crucial factors for the measurement method. No further differentiation is made in other factors, as the importance of these factors have not been quantified.

C. Explanation on ratings evaluation factors in evaluation matrix

In most cases, the rating of an evaluation factor is unambiguous. However, for the following evaluation factors, more explanation is provided. *Accuracy and reliability* is estimated based on comparative studies. However, large differences between the equally ranked methods may still occur. For *disturbance to pregnant woman* the hemoglobin-based measurement methods are rated a moderate limitation, as a pre-measurement of the hemoglobin level is necessary, which is undesired by most women opting for water birth. For no excessive water movement, it is hypothesized that less water movement is necessary for the color card and colorimetric approach, as a larger volume of fluid is examined by the methods. However, this has not been verified in an experiment yet. In *objectivity of measurement*, the proposed measurement methods based on visual estimation are not objective. However, due to the aid in visual estimation, these methods will be less susceptible to differences in interpretation between midwives. For *delay*, the chemical added spectrophotometry method has a dashed severe limitation rating. The measurement method 'Filtration system' will have no practical use due to the time necessary to filter all the fluid in the pool. However, the rating could also be considered unpractical for use, as the delay for most forms of chemical added spectrophotometry will exceed five minutes. For *prone to contamination*, the spectrophotometric methods and the 'AVE, lights in pool' are estimated to have no significant limitation, as specific wavelengths can be chosen that are not affected by contamination. 'Coagulation in pool' has no practical use due to *disturbance to pregnant woman*, as it will pose health threats.

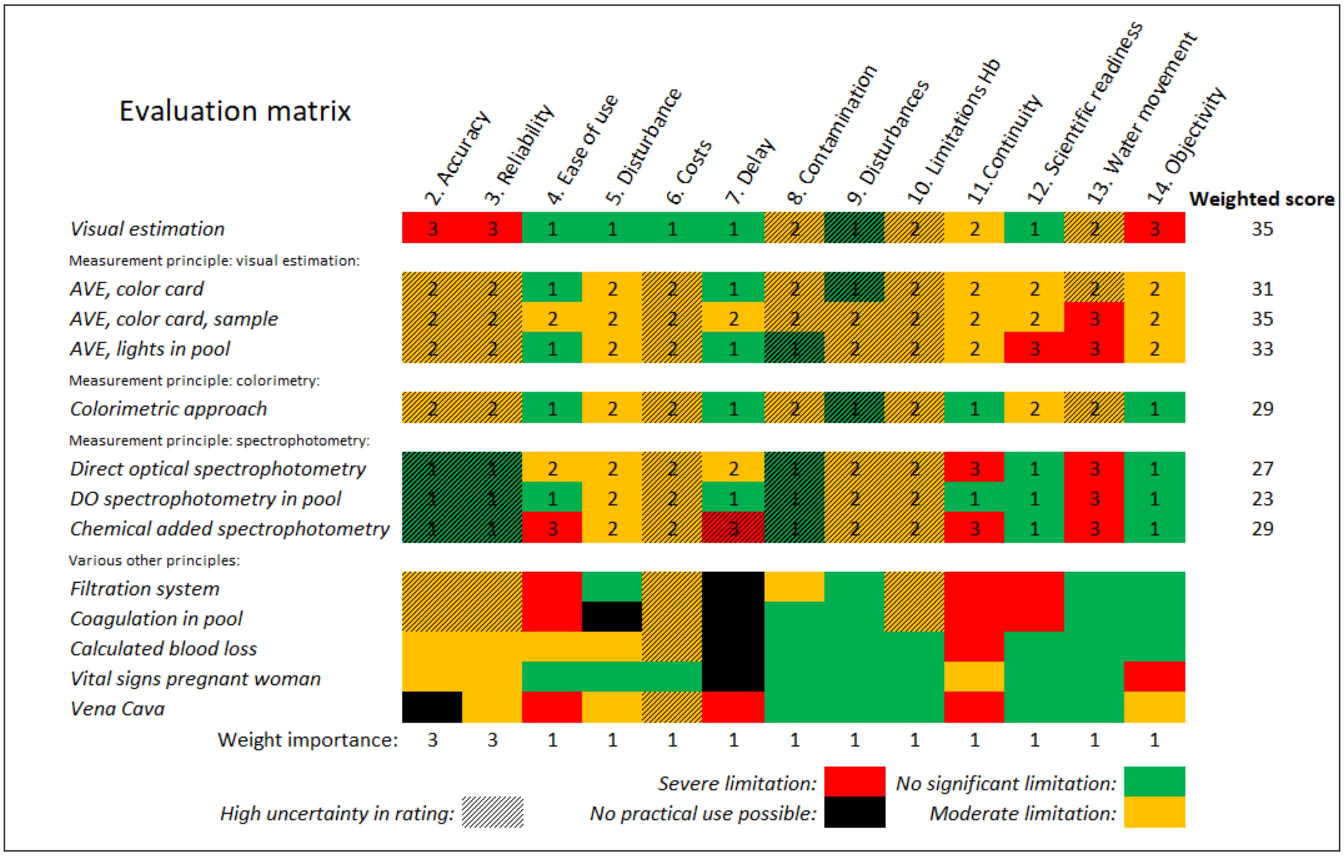
D. Results from evaluation matrix

The weighted score will be used to evaluate the proposed measurement methods. In table VI the results based on the matrix are ranked. The measurement method 'DO spectrophotometry in pool' shows the highest performance. The currently used measurement method 'Visual estimation' shows the worst performance together with 'AVE, color card, sample'. Five methods have seen a score for no practical use.

Evaluation factor	Way of rating	No limitation	Moderate limitation	Severe limitation	Impossible
2. Accuracy	Experiment	$\leq 15\%$	15%-30%	30-40%	$\geq 40\%$
3. Reliability	Experiment	Unknown	Unknown	Unknown	Unknown
4. Ease of use	Stakeholders	No limitation	Reluctancy in practical use	More than 30% not use	No practical use
5. Disturbance	Stakeholders	No limitation	Reluctancy in practical use	More than 30% not use	No practical use
6. Costs	Calculation	Unknown	Unknown	Unknown	Unknown
7. Delay	Measurement	$\leq 30sec$	30 - 180 sec	180-300 sec	$\geq 300sec$
8. Contamination	Experiment	No influence	Max 10% error	10-25% error	Unusable
9. Disturbances	Experiment	No influence	Max 10% error	10-25% error	Unusable
10. Limitations Hb	Literature research and experiment	No influence	Max 10% error	10-25% error	Unusable
11. Continuity	Nature of method	Continuous value	$\leq 60secorpossibilitycontinuous$	Discontinuous	n.a.
12. Scientific readiness	Literature research	Fully described	Comparable method described	Undescribed	n.a.
13. Water movement	Experiment / nature of method	No water movement	Movement as in experiment	Excessive water movement	n.a.
14. Objectivity	Nature of method	Quantified by device	Minor differences in scoring	Large differences scoring	n.a.

TABLE V

THIS TABLE SHOWS HOW THE EVALUATION FACTORS OF THE MEASUREMENT METHODS WILL BE RATED IN THE EVALUATION MATRIX. THE EVALUATION FACTORS IN COLUMN ONE HAVE EQUAL NUMBERING AS USED IN THE PREVIOUS CHAPTERS. THE SECOND COLUMN INDICATES THE METHOD OF RATING. THE FINAL FOUR COLUMNS SHOW THE CRITERIA FOR NO SIGNIFICANT LIMITATION, MODERATE LIMITATION, SEVERE LIMITATION, AND NO POSSIBILITY FOR PRACTICAL USE.



Evaluation matrix

	2. Accuracy	3. Reliability	4. Ease of use	5. Disturbance	6. Costs	7. Delay	8. Contamination	9. Disturbances	10. Limitations Hb	11. Continuity	12. Scientific readiness	13. Water movement	14. Objectivity	Weighted score
Visual estimation	🟥 3	🟥 3	🟩 1	🟩 1	🟩 1	🟩 1	🟨▨ 2	🟩▨ 1	🟨▨ 2	🟨 2	🟩 1	🟨▨ 2	🟥 3	35
Measurement principle: visual estimation:														
AVE, color card	🟨▨ 2	🟨▨ 2	🟩 1	🟨 2	🟨▨ 2	🟩 1	🟨▨ 2	🟩▨ 1	🟨▨ 2	🟨 2	🟨 2	🟨▨ 2	🟨 2	31
AVE, color card, sample	🟨▨ 2	🟨▨ 2	🟨 2	🟨 2	🟨▨ 2	🟨 2	🟨▨ 2	🟨▨ 2	🟨▨ 2	🟨 2	🟨 2	🟥 3	🟨 2	35
AVE, lights in pool	🟨▨ 2	🟨▨ 2	🟩 1	🟨 2	🟨▨ 2	🟩 1	🟩▨ 1	🟨▨ 2	🟨▨ 2	🟨 2	🟥 3	🟥 3	🟨 2	33
Measurement principle: colorimetry:														
Colorimetric approach	🟨▨ 2	🟨▨ 2	🟩 1	🟨 2	🟨▨ 2	🟩 1	🟨▨ 2	🟩▨ 1	🟨▨ 2	🟩 1	🟨 2	🟨▨ 2	🟩 1	29
Measurement principle: spectrophotometry:														
Direct optical spectrophotometry	🟩▨ 1	🟩▨ 1	🟨 2	🟨 2	🟨▨ 2	🟨 2	🟩▨ 1	🟨▨ 2	🟨▨ 2	🟥 3	🟩 1	🟥 3	🟩 1	27
DO spectrophotometry in pool	🟩▨ 1	🟩▨ 1	🟩 1	🟨 2	🟨▨ 2	🟩 1	🟩▨ 1	🟨▨ 2	🟨▨ 2	🟩 1	🟩 1	🟥 3	🟩 1	23
Chemical added spectrophotometry	🟩▨ 1	🟩▨ 1	🟥 3	🟨 2	🟨▨ 2	🟥▨ 3	🟩▨ 1	🟨▨ 2	🟨▨ 2	🟥 3	🟩 1	🟥 3	🟩 1	29
Various other principles:														
Filtration system	🟨▨	🟨▨	🟥	🟩	🟨▨	⬛	🟨	🟩	🟨▨	🟥	🟥	🟩	🟩	
Coagulation in pool	🟨▨	🟨▨	🟥	⬛	🟨▨	⬛	🟩	🟩	🟨▨	🟥	🟥	🟩	🟩	
Calculated blood loss	🟨	🟨	🟨	🟨	🟨▨	⬛	🟩	🟩	🟩	🟥	🟩	🟩	🟩	
Vital signs pregnant woman	🟨	🟨	🟩	🟩	🟩	⬛	🟩	🟩	🟩	🟨	🟩	🟩	🟥	
Vena Cava	⬛	🟨	🟥	🟨	🟨▨	🟥	🟩	🟩	🟩	🟥	🟩	🟩	🟨	
Weight importance:	3	3	1	1	1	1	1	1	1	1	1	1	1	

Severe limitation: 🟥 *No significant limitation:* 🟩

High uncertainty in rating: ▨ *No practical use possible:* ⬛ *Moderate limitation:* 🟨

Fig. 10. This figure shows the evaluation matrix. The legend shows the meaning of the different colors used. Dashed lines are used to indicate the rating of the evaluation factor has high uncertainty and is based on the estimation of the author. The values inside the boxes are used for the quantification of the performance of the measurement methods. Results are shown on the right side. The weighted score shows the summation of the rating of all the different evaluation factors multiplied by their weight importance, which is shown below in the figure. The lowest score means the best performance. Quantification of measurement methods containing an unmet requirement is omitted, as these methods find no practical use.

Measurement method	Performance weighted score
DO spectrophotometry in pool	23
Direct optical spectrophotometry	27
Colorimetric approach	29
Chemical added spectrophotometry	29
AVE, color card	31
AVE, lights in pool	33
Visual estimation	35
AVE, color card, sample	35

TABLE VI

THIS TABLE SHOWS THE PERFORMANCE OF THE MEASUREMENT METHODS IN ORDER.

XV. RESULTS: VALIDATION OF THE PROPOSED MEASUREMENT METHOD

As all methods base their measurement on the quantity of hemoglobin in the birth pool, it will first be explained why it is valid to measure the hemoglobin concentration of the birth pool to obtain a quantification of blood loss. The measurement methods all use a measurement of the hemoglobin level of the pregnant woman, which can be done accurately [52]. As the optical properties of whole blood are dominated by hemoglobin, the optical properties of the liquid in the pool will change due to an increase in hemoglobin concentration. The limitations applicable to a measurement based on hemoglobin have been explained in this research and will be quantified in further research. Hemoglobin is also the main component targeted in other blood loss quantification techniques [53].

Validation of 'DO spectrophotometry in pool'
As the measurement method DO spectrophotometry in pool has shown the highest performance in the evaluation matrix, the validation of this measurement method will be explained. The use of hemoglobin measurement has been shown valid in quantifying blood loss in water birth in the previous paragraph. Multiple studies have validated different forms of direct optical spectrophotometry in deriving the hemoglobin concentration in a liquid [16]. As submersible UV-vis spectrometers can provide reliable results [54], no difference is obtained compared to regular direct optical spectrophotometry.

Validation by experiment. Two experiments will be proposed that can validate a measurement method in practice, a simulated and a real-life reference method.

Simulated method. All measurement methods can when fully developed, be (additionally) validated by simulating a birth pool environment and adding known quantities of blood. An anticoagulant must be used to prevent clotting in tubing used for blood extraction, though this will not influence the optical properties of the hemoglobin in the pool. The developed measurement methods can be used to quantify the blood in the pool, and the results can consequently be compared with the known quantity (and hemoglobin level) of added blood.

Real life reference method. The following reference method could be used to validate the proposed measurement methods in real life: the concentration of dissolved hemoglobin in the birth pool can be determined using multiple (chemical added) spectrophotometric assays after excessive stirring. The average outcome of the spectrophotometric assays can be taken as the result. The blood clots can be extracted from the pool and by use of a chemical added spectrophotometry method, e.g. the alkaline hematin method [55], the hemoglobin concentration of the blood clots can be determined. By adding the quantities of the hemoglobin dissolved in the fluid and present in the blood clots, the total blood loss can be quantified. The results of this reference method can then be compared with the results of a developed measurement method.

XVI. DISCUSSION

A. Limitations to hemoglobin measurement

Multiple measurement methods have been proposed and evaluated. All methods that show practical use are based on the optical properties of hemoglobin in the liquid of the birth pool. Therefore, the limitations that hold to measuring the optical properties of hemoglobin will apply to all measurement methods. Multiple limitations are yet unknown in how much they limit the use of optical properties in the birth pool: the prevalence of different forms of hemoglobin in the birth pool due to decay and oxygenation, the rate of hemolysis, the effect of lysed red blood cells on optical properties, the hemoglobin concentration of blood clots and the effect of contamination on optical properties. Also, an effective stirring technique must first be obtained. Therefore, it cannot be concluded whether the proposed measurement methods will be of use in practice. However, the proposed measurement methods can be discussed on their advantages and disadvantages, assuming they will not be hindered significantly by the previously mentioned limitations.

B. Experiment pigment in pool

Another limitation, apart from the limitations due to hemoglobin measurement in the birth pool, to the measurement methods is the spreading of hemoglobin in the pool. As the hemoglobin will most likely be dissolved in the pool, the results of the experiment conducted can be discussed here and extrapolated to hemoglobin in the birth pool. Based on the results of the experiment, it can be concluded that with the movement of water applied by the stakeholder, the spreading of the pigment is inadequate after 210 seconds, and significantly more time is needed for homogeneous spreading. When excessive stirring is applied for fifteen seconds, the results show homogeneous spreading. Therefore, it is concluded that more stirring is needed than what has been applied by the stakeholder to obtain reliable results. It is speculated that the measurement methods 'AVE, color card' and 'Colorimetric approach' will need less stirring than the other proposed methods, as the measurements will be performed over a larger volume. However, it is unknown whether this is valid and how much stirring would yield a reliable result for these methods.

C. Comparison of measurement methods

In comparing the measurement methods, difficulties arise due to the unknowns in the rating of the following evaluation factors: the accuracy, reliability, costs, proneness to contamination and disturbances, limitations of hemoglobin measurement, and no excessive movement necessary are (partly) estimated and are not yet quantified, while they will have a significant impact on the performance of the measurement methods.

Uncertainty and predictions in accuracy and reliability Especially the rating of the evaluation factors accuracy and reliability are important to discuss as they have the most influence on the performance of the measurement methods, while their rating is uncertain. Four methods have the same estimated rating of a moderate limitation, yet large differences in accuracy and reliability may be seen in practice. The prediction of these large differences is based on the study of [33] indicating high accuracy in a comparable colorimetric approach, and based on the study of [56] which indicates acceptable, yet limited accuracy of the color scale method of the WHO which is comparable to the 'AVE, color card, sample' method. The 'AVE, color card' approach is expected to be even less accurate and reliable than the 'AVE, color card, sample' approach due to the maximization of absorption in the birth pool of certain wavelengths. The three spectrophotometric methods could show differences in accuracy and reliability as well, although more similar performance is expected based on [35]. In general, the weighted scores show a preference for the three spectrophotometric methods, which is mainly caused by better performance on accuracy and reliability. However, as explained, these advantages are uncertain, and equal ratings might show significant differences in practice.

DO spectrophotometry in pool as the best measurement method. The weighted scores of the evaluation matrix show a clear preference for the measurement method 'DO spectrophotometry in pool'. However, many evaluation factors are rated with uncertainty. In practice, e.g. the colorimetric approach might be quite similar in accuracy and reliability, while providing significant advantages in costs and proneness to disturbances, leading it to be superior in performance compared to 'DO spectrophotometry in pool'. Furthermore, in 'DO spectrophotometry in pool', a severe limitation is seen in 'no excessive water movement necessary' for this method. As previously mentioned, further research is needed to indicate whether this limitation will make practical use of this method possible or not.

If excessive water movement is not a possibility in practice, then the measurement methods 'Aided visual estimation, color card' and 'Colorimetric approach' will remain the only options in quantifying blood loss in a birth pool environment, after it is indeed verified that no excessive water movement is necessary for these methods. Comparing these two methods based on the evaluation matrix, the colorimetric approach shows better performance based on the weighted score. Differences are only present in the objectivity and continuity of measurement, in favor of the colorimetric approach. In addition, as previously mentioned, it is argued that the accuracy and reliability of the colorimetric approach might outperform the 'aided visual estimation, color card' method.

XVII. CONCLUSION

Higher accuracy and reliability are desired in quantifying blood loss in water birth in comparison with currently used visual estimation. The measurement method 'DO spectrophotometry in pool' is the most promising. However, for practical use, the limitations on hemoglobin measurement must be further researched on their severity, and a method must be obtained that yields sufficient stirring in the birth pool. If no such method can be obtained, the colorimetric approach seems to be the most promising method.

XVIII. FURTHER RESEARCH

As all proposed measurement methods are based on the measurement of hemoglobin, the following limitations must be researched before the proposed measurement methods can be developed:

- The effect of various contamination on the optical properties of the liquid.
- An adequate stirring technique that does not disturb the pregnant woman severely.
- The concentration and total quantity of hemoglobin in blood clots formed in a birth pool environment.

Other limitations of which their characteristics are not yet fully understood can be experimented on as well, which would yield a more accurate and reliable measurement method, being:

- The effect of lysed red blood cells on optical properties in a birth pool environment.
- The concentration of oxyhemoglobin and deoxyhemoglobin over time in a birth pool setting (oxygenation).
- The prevalence of other forms of hemoglobin due to decay in a birth pool environment.
- The rate of hemolysis in a birth pool environment.

All four above-mentioned limitations will affect the optical properties of the liquid in the pool due to blood. However, without understanding the underlying dynamics of these four limitations, the optical properties can also be derived experimentally by obtaining the absorption spectra of blood added to a birth pool environment over time.

The following questions need to be answered to make a better choice on the most suitable measurement method.

- Is excessive water movement a possibility in practice?
- Do 'AVE, color card' and 'Colorimetric approach' indeed need less water movement and would this amount of water movement be possible in practice?

- How do the measurement methods compare in the evaluation matrix after further research on the ratings of evaluation factors with high uncertainty?
- What is a better quantification of the relative importance of the evaluation factors?

Methods based on the measurement of a different component of blood than hemoglobin can be investigated in further research if the limitations entailed in hemoglobin measurement are too significant.

REFERENCES

[1] G. Ramanathan and S. Arulkumaran, “Postpartum hemorrhage,” *Journal of Obstetrics and Gynaecology Canada*, vol. 28, no. 11, pp. 967–973, 2006, FIGO Kuala Lumpur 2006.

[2] S. L. Clark, “Obstetric hemorrhage,” English, *Seminars in Perinatology*, vol. 40, no. 2, pp. 109–111, Mar. 2016, Place: Philadelphia Publisher: W B Saunders Co-Elsevier Inc WOS:000371557000007.

[3] K. Wisner, “Measuring Blood Loss in Obstetric Hemorrhage,” English, *Mcn-the American Journal of Maternal-Child Nursing*, vol. 45, no. 3, pp. 184–184, Jun. 2020, Place: Philadelphia Publisher: Lippincott Williams & Wilkins WOS:000618801800008.

[4] E. R. Cluett, E. Burns, and A. Cuthbert, “Immersion in water during labour and birth,” English, *Cochrane Database of Systematic Reviews*, no. 5, p. CD000111, 2018, Place: Hoboken Publisher: Wiley WOS:000433887900040.

[5] E. Neiman, E. Austin, A. Tan, C. M. Anderson, and E. Chipps, “Outcomes of waterbirth in a us hospital-based midwifery practice: A retrospective cohort study of water immersion during labor and birth,” English, *JOURNAL OF MIDWIFERY & WOMENS HEALTH*, vol. 65, no. 2, pp. 216–223, Mar. 2020.

[6] D. Garland, *Revisiting waterbirth : an attitude to care / Dianne Garland.* eng, Second edition. London: Palgrave, 2017.

[7] E. Burns, L. Hunter, Z. Rodd, M. MacLeod, and L. Smith, “Developing and evaluating an online learning tool to improve midwives’ accuracy of visual estimation of blood loss during waterbirth: An experimental study,” English, *Midwifery*, vol. 68, pp. 65–73, Jan. 2019, Place: Oxford Publisher: Elsevier Sci Ltd WOS:000450307700009.

[8] A. Kolbasov, P. M. Comiskey, R. P. Sahu, *et al.*, “Blood rheology in shear and uniaxial elongation,” English, *RHEOLOGICA ACTA*, vol. 55, no. 11-12, pp. 901–908, Dec. 2016.

[9] NVOG, *NVOG-richtlijn Hemorrhagia postpartum (HPP)*, Jun. 2015.

[10] A. Lathrop, C. F. Bonsack, and D. M. Haas, “Women’s experiences with water birth: A matched groups prospective study,” en, *Birth*, vol. 45, no. 4, pp. 416–423, Dec. 2018.

[11] M. Meinke, G. Müller, J. Helfmann, and M. Friebel, “Optical properties of platelets and blood plasma and their influence on the optical behavior of whole blood in the visible to near infrared wavelength range,” eng, *Journal of Biomedical Optics*, vol. 12, no. 1, p. 014 024, Feb. 2007.

[12] N. Bosschaart, G. J. Edelman, M. C. G. Aalders, T. G. van Leeuwen, and D. J. Faber, “A literature review and novel theoretical approach on the optical properties of whole blood,” *Lasers in Medical Science*, vol. 29, no. 2, pp. 453–479, 2014.

[13] A. Taylor, “High-Altitude Illnesses: Physiology, Risk Factors, Prevention, and Treatment,” *Rambam Maimonides medical journal*, vol. 2, e0022, Jan. 2011.

[14] D. B. Morrison and A. Hisey, “THE PREPARATION OF HEMOGLOBIN IN A DRY AND ACTIVE STATE,” en, *Journal of Biological Chemistry*, vol. 117, no. 2, pp. 693–706, Feb. 1937.

[15] Kadry, Sleem, and Samad, “Hemoglobin levels in pregnant women and its outcomes,” English, *Biometrics & Biostatistics International Journal*, vol. Volume 7, no. Issue 4, Aug. 2018, Publisher: MedCrave Publishing.

[16] E. C. Calvaresi, S. L. La’ulu, T. M. Snow, T. R. Allison, and J. R. Genzen, “Plasma hemoglobin: A method comparison of six assays for hemoglobin and hemolysis index measurement,” en, *International Journal of Laboratory Hematology*, vol. 43, no. 5, pp. 1145–1153, 2021, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/ijlh.13457.

[17] L. N. M. Duyens, “The flattering of the absorption spectrum of suspensions, as compared to that of solutions,” en, *Biochimica et Biophysica Acta*, vol. 19, pp. 1–12, Jan. 1956.

[18] P. Naccache and R. I. Sha’afi, “Patterns of nonelectrolyte permeability in human red blood cell membrane,” eng, *The Journal of General Physiology*, vol. 62, no. 6, pp. 714–736, Dec. 1973.

[19] L. K. Goodhead and F. M. MacMillan, “Measuring osmosis and hemolysis of red blood cells,” *Advances in Physiology Education*, vol. 41, no. 2, pp. 298–305, Jun. 2017, Publisher: American Physiological Society.

[20] S. P. Akeson and H. C. Mel, “Osmotic hemolysis and fragility. A new model based on membrane disruption, and a potential clinical test,” eng, *Biochimica Et Biophysica Acta*, vol. 718, no. 2, pp. 201–211, Oct. 1982.

[21] C. N. Barry, “Water births. Could saline in the pool reduce the potential hazards?” eng, *BMJ (Clinical research ed.)*, vol. 310, no. 6994, p. 1602, Jun. 1995.

[22] C. Huang, S. Wang, and P. Tsui, “In vitro study on assessment of blood coagulation and clot formation using doppler ultrasound,” English, *JAPANESE JOURNAL OF APPLIED PHYSICS PART 1-REGULAR PAPERS BRIEF COMMUNICATIONS & REVIEW PAPERS*, vol. 44, no. 12, pp. 8727–8732, Dec. 2005.

[23] E. Mihalko and A. C. Brown, “Clot structure and implications for bleeding and thrombosis,” English, *SEMINARS IN THROMBOSIS AND HEMOSTASIS*, vol. 46, no. 1, pp. 96–104, Feb. 2020.

[24] Y. Ding, M. Abbasi, Y. Liu, *et al.*, “In vitro study of blood clot identification and composition assessment by different magnetic resonance sequences,” English, *CUREUS*, vol. 13, no. 7, Jul. 2021.

[25] H. M. F. Al Kadri, B. K. Al Anazi, and H. M. Tamim, “Visual estimation versus gravimetric measurement of postpartum blood loss: A prospective cohort study,” English, *ARCHIVES OF GYNECOLOGY AND OBSTETRICS*, vol. 283, no. 6, pp. 1207–1213, Jun. 2011.

[26] N. Makhubo, J. D. Makin, and S. Adam, “Use of a visual aid to improve estimation of blood loss in obstetrics,” English, *SAJOG-SOUTH AFRICAN JOURNAL OF OBSTETRICS AND GYNAECOLOGY*, vol. 24, no. 1, pp. 18–21, May 2018.

[27] J. de Rigal, M.-L. Abella, F. Giron, L. Caisey, and M. A. Lefebvre, “Development and validation of a new skin color chart((r)),” English, *SKIN RESEARCH AND TECHNOLOGY*, vol. 13, no. 1, pp. 101–109, Feb. 2007.

[28] L. ARMSTRONG, C. MARESH, J. CASTELLANI, *et al.*, “Urinary indexes of hydration status,” English, *INTERNATIONAL JOURNAL OF SPORT NUTRITION*, vol. 4, no. 3, pp. 265–279, Sep. 1994.

[29] A. Singh, S. Murki, D. Sharma, V. Vardhelli, S. Subramanian, and A. Mekarthi, “Development and evaluation of a novel method “bilirubin color card” for screening of treatable jaundice in neonates: Prospective comparative diagnostic study,” *The Journal of Maternal-Fetal & Neonatal Medicine*, vol. 0, no. 0, pp. 1–4, Mar. 2022, Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/14767058.2022.2056442.

[30] C. F. Ingram and S. M. Lewis, “Clinical use of WHO haemoglobin colour scale: Validation and critique,” English, *Journal of Clinical Pathology*, vol. 53, no. 12, pp. 933–937, Dec. 2000, Place: London Publisher: Bmj Publishing Group WOS:000165766400011.

[31] P. García, S. Ibáñez-Calero, and R. Escalera, “Degradation of synthetic organic dyes in solution by ferrate – hypochlorite or calcium hypochlorite degradación de tintes sintéticos orgánicos en solución por ferrato-hipoclorito o hipoclorito de calcio,” *INVESTIGACION DESARROLLO*, vol. 1, pp. 43–53, Jul. 2017.

[32] J. Palmer, *Estimating Blood Loss in an Inflatable Birth Pool*, en-AU, Jul. 2020.

[33] L. Gerdessen, P. Meybohm, S. Choorapoikayil, *et al.*, “Comparison of common perioperative blood loss estimation techniques: A systematic review and meta-analysis,” English, *Journal of Clinical Monitoring and Computing*, vol. 35, no. 2, pp. 245–258, Apr. 2021, Place: Heidelberg Publisher: Springer Heidelberg WOS:000561278300001.

[34] G. Konig, J. H. Waters, E. Hsieh, *et al.*, “In Vitro Evaluation of a Novel Image Processing Device to Estimate Surgical Blood Loss in Suction Canisters,” en-US, *Anesthesia & Analgesia*, vol. 126, no. 2, pp. 621–628, Feb. 2018.

[35] R. A. Malinauskas, “Plasma Hemoglobin Measurement Techniques for the In Vitro Evaluation of Blood Damage Caused by Medical Devices,” en, *Artificial Organs*, vol. 21, no. 12, pp. 1255–1267, 1997, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1525-1594.1997.tb00486.x.

[36] C. M. Cripps, “Rapid method for the estimation of plasma haemoglobin levels.,” en, *Journal of Clinical Pathology*, vol. 21, no. 1, pp. 110–112, Jan. 1968, Publisher: BMJ Publishing Group Section: Research Article.

[37] M. Harboe, “A Method for Determination of Hemoglobin in Plasma by Near-Ultraviolet Spectrophotometry,” *Scandinavian Journal of Clinical and Laboratory Investigation*, vol. 11, no. 1, pp. 66–70, Jan. 1959, Publisher: Taylor & Francis _eprint: https://doi.org/10.3109/00365515909060410.

[38] H.-J. Chung, J.-W. Chung, J. Yi, *et al.*, “Automation of Harboe method for the measurement of plasma free hemoglobin,” en, *Journal of Clinical Laboratory Analysis*, vol. 34, no. 6, e23242, 2020, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/jcla.23242.

[39] P. Bhaskaram, N. Balakrishna, K. V. Radhakrishna, and K. Krishnaswamy, “Validation of hemoglobin estimation using Hemocue,” eng, *Indian Journal of Pediatrics*, vol. 70, no. 1, pp. 25–28, Jan. 2003.

[40] F. Hofstaedter, T. Ertl, G. Langergraber, W. Lettl, and A. Weingartner, “On-line nitrate monitoring in sewers using UV/VIS spectroscopy,” Jan. 2003.

[41] A. Kratz, “Normal Reference Laboratory Values,” en, *The New England Journal of Medicine*, p. 16, 2004.

[42] S. Morr, E. Cuartas, B. Alwattar, and J. M. Lane, “How Much Calcium Is in Your Drinking Water? A Survey of Calcium Concentrations in Bottled and Tap Water and Their Significance for Medical Treatment and Drug Administration,” *HSS Journal*, vol. 2, no. 2, pp. 130–135, Sep. 2006.

[43] Rijksoverheid, *Handleiding Chloridenormering Drinkwater(bronnen)*, nl, Last Modified: 2019-07-23.

[44] Waternet, *Kwaliteit van drinkwater*, nl.

[45] C. Rose, A. Parker, B. Jefferson, and E. Cartmell, “The Characterization of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology,” *Critical Reviews in Environmental Science and Technology*, vol. 45, pp. 00–00, Feb. 2015.

[46] M. N. Schorn, “Measurement of Blood Loss: Review of the Literature,” en, *Journal of Midwifery & Women’s Health*, vol. 55, no. 1, pp. 20–27, Jan. 2010.

[47] K. T. Gabel and T. A. Weeber, “Measuring and Communicating Blood Loss During Obstetric Hemorrhage,” en, *Journal of Obstetric, Gynecologic &*

Neonatal Nursing, vol. 41, no. 4, pp. 551–558, Jul. 2012.

[48] S. Jaramillo, M. Montane-Muntane, P. L. Gambus, D. Capitan, R. Navarro-Ripoll, and A. Blasi, "Perioperative blood loss: Estimation of blood volume loss or haemoglobin mass loss?" *Blood Transfusion*, vol. 18, no. 1, pp. 20–29, Jan. 2020.

[49] M. Natrella, E. Di Naro, M. Loverro, *et al.*, "The more you lose the more you miss: Accuracy of postpartum blood loss visual estimation. A systematic review of the literature," *The Journal of Maternal-Fetal & Neonatal Medicine*, vol. 31, no. 1, pp. 106–115, Jan. 2018, Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/14767058.2016.1274302.

[50] T. Oba, M. Koyano, J. Hasegawa, *et al.*, "The inferior vena cava diameter is a useful ultrasound finding for predicting postpartum blood loss," English, *JOURNAL OF MATERNAL-FETAL & NEONATAL MEDICINE*, vol. 32, no. 19, pp. 3251–3254, Oct. 2019.

[51] M. Massalha, R. Faranish, S. Romano, and R. Salim, "Decreased inferior vena cava diameter as an early marker in postpartum hemorrhage," English, *ULTRASOUND IN OBSTETRICS & GYNECOLOGY*, vol. 59, no. 2, pp. 234–240, Feb. 2022.

[52] K. Yadav, S. Kant, G. Ramaswamy, *et al.*, "Validation of Point of Care Hemoglobin Estimation Among Pregnant Women Using Digital Hemoglobinometers (HemoCue 301 and HemoCue 201+) as Compared with Auto-Analyzer," English, *Indian Journal of Hematology and Blood Transfusion*, vol. 36, no. 2, pp. 342–348, Apr. 2020, Place: New Delhi Publisher: Springer India WOS:000488908200001.

[53] J. L. Magnay, S. O'Brien, C. Gerlinger, and C. Seitz, "A systematic review of methods to measure menstrual blood loss," English, *BMC WOMENS HEALTH*, vol. 18, Aug. 2018.

[54] L. Qing-bo, W. Yuan, C. Hou-xin, F. Hao, and L. Jia-ye, "Quantitative analysis of toc in water quality based on uv-vis spectroscopy," Chinese, *SPECTROSCOPY AND SPECTRAL ANALYSIS*, vol. 42, no. 2, pp. 376–380, Feb. 2022.

[55] E. J. King, "Alkaline Haematin Method for Haemoglobin Determination," *British Medical Journal*, vol. 2, no. 4521, pp. 349–350, Aug. 1947.

[56] H. Anand, R. Mir, and R. Saxena, "Hemoglobin color scale a diagnostic dilemma," English, *Indian Journal of Pathology and Microbiology*, vol. 52, no. 3, pp. 360–362, Sep. 2009, Place: Mumbai Publisher: Wolters Kluwer Medknow Publications WOS:000269448800015.