Development of a Parameter Calculator in Cardiovascular Perfusion

BioMEP as a Tool for the Register of Physiological Parameters

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Abstract: Technology has played an increasingly important role in the health sector, with new devices allowing for better real-time monitoring of patients' biosignals. Among those, the ones developed with perfusion in mind are extremely useful, during cardiothoracic surgery, since they provide detailed information about the vital signs of the patient. However, doctors and technicians have often to calculate several physiological parameters, which help them make clinical decision during such surgical interventions. In this context, the authors present a software tool – BioMEP: *Perfusion Calculator Application*, built in a partnership between the Department of Cardiothoracic Surgery of Santa Marta Hospital and the Department of Physics of the Faculty of Sciences and Technology of the NOVA University of Lisbon, and which fulfils the needs of the surgical team. BioMEP - *Perfusion Calculator Application* is a safe, intuitive and user-friendly tool that incorporates and integrates department-specific perfusion parameters and calculations, in a single platform, and allows for higher intervention efficiency, while minimizing the errors of the required calculation, with the concomitant improvement in patient safety.

1 INTRODUCTION

Medicine is often an early adopter of new scientific and technological breakthroughs. Never like today, technology as had a higher impact in the healthcare sector. One of the most impressive of such advancements is the possibility to collect and store vast amounts data, as well as make them available to support real time decision making (Brettlecker et al., 2008). Critical to such progress are computer and mobile applications, which are becoming ubiquitous in all healthcare environments. Many reports state that those tools are helpful in the way they allow for better clinical decisions as well as improve patients' outcomes (Ventola, 2014).

Cardiovascular perfusion, as an important area in medical surgical care, is no exception to the stated above. That type of extracorporeal circulation procedure consists in replacing, temporarily, the pulmonary and heart functions, through specific circuits, techniques and medical equipment. In that process, patient's blood enters a mechanical system that filters, promotes its oxygenation and regulates its temperature (Gravlee et al., 2008). When arterialized, patient's blood returns to the systemic circulation, with the help of a pump that substitutes the heart. The extracorporeal circulation replaces the cardiopulmonary functions, while preserving the cellular integrity, as well as the structure, function and metabolism of the organs and systems of the patient, during complex cardiothoracic surgeries (Gravlee et al., 2008). There are, in current use, several free to use applications that assist perfusionists in their surgically demanding and complex tasks, (*cf*, i-Perfuse, 2014; i-Pump, 2013). They calculate certain physiological parameters; give cannula recommendations; allow users to take quizzes and present news with the latest information on the subject. Despite all these functionalities, both applications lack in the calculation of a great variety of physiological parameters, which are essential to perfusionists during surgeries. Those include:

- priming calculations
- heparin and protamine levels, at the different temperatures that the body is cooled
- post dilutional haematocrit levels

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These values are extremely important for the preservation of the integrity of the patients' body, in various cardiothoracic procedures, as they give invaluable insights and information to clinicians. Furthermore, no single calculator integrated all the information of relevance for such procedure. Practitioners were then left to employ a variety of non-communicating tools, which increased the possibility of information misuse.

For the aforementioned reasons, we developed a new application that calculates, automatically, all parameters deemed essential during surgery. Such clinical tool, presented in this manuscript, is called *BioMEP- Perfusion Calculator Application*.

2 APPLICATION REQUIREMENTS

BioMEP was developed in a close collaboration between physicians and perfusionists, from the Cardiothoracic Surgery Department of Hospital de Santa Marta partnership, and biomedical engineers, from the Physics Department of Faculdade de Ciências e Tecnologia of Universidade Nova de Lisboa.

The main goal of the proposed application is to calculate and integrate, automatically, biometric and physiological parameters of the patient, during cardiothoracic surgery. Together with clinicians and surgeons, and after evaluating the most commonly used perfusion applications, the following list of requirements were drawn for *BioMEP:*

- be user-friendly
- be in digital format
- divided in blocks – each one dedicated to a specific topic
- allow the user to insert new data
- calculate, automatically, various biometrics and physiological parameters
- provide relevant data reports

BioMEP was developed using the programming language MATLAB's R2012b (MathWorks ©). The content was designed keeping in mind the definition of what parameters were worth calculating and what formulas they required. All calculations of the various physiological parameters, such as heparin and protamine levels were assessed through literature (Gravlee et al., 2008). The entire set of algorithms was simplified, so that the application would run faster, and present an easy-to-use interface, while allowing the access to programming code, if one needed to construct other specific functions, for any given parameter. There is no need for the user to see all the moving information in the application. Yet there is great value in the complete interaction between the various elements of the application. Hence all functions interacted internally with each other, to register the values inserted by the clinicians, and to calculate and show the needed parameters.

3 IMPLEMENTATION

The built application is divided in six fundamental blocks, which interact internally between each other, each of them dedicated to a specific topic, calculating automatically several parameters using the empirical expressions found in the literature (Gravlee et al., 2008). The six blocks are:

- Biometric Data
- Priming
- Blood flow
- Heparin and protamine doses
- Modified ultrafiltration
- Post-dilution haematocrit

In the biometrics block (figure 1), the clinician can insert the biometric data, such as: the identification number, the age, the gender, the weight and the height of the patient as the correspondent fields for these parameters are available for the user to insert and modify if needed. The body surface area is automatically calculated:

$$Body\ surface = \sqrt{\frac{Weight \times Height}{3600}}$$

In the priming block (figure 2) the user should decide the priming type (hematic/non-hematic) and should type the values of the priming polyelectrolyte solution in ml and the priming Heparin dose in UI. If the priming type was chosen, Packed Red Blood Cells (PRBC), the Fresh Frozen Plasma (FFP) and the Calcium Gluconate values in ml should be also inserted manually. The outputs that are automatically computed are:

Mannitol (20%) = 2.5 × $Weight$

$NaHCO_3$ = 1× $Weight$, if the ratio (ml/kg) = 1 was chosen

$NaHCO_3$ = 0.5× $Weight$, if the ratio (ml/kg) = 0.5 was chosen

Mannitol dose for rewarming = 1.5× $Weight$

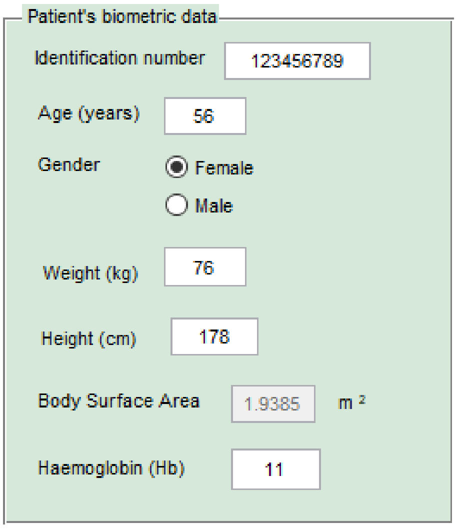

Figure 1: Interface block with the biometric data.

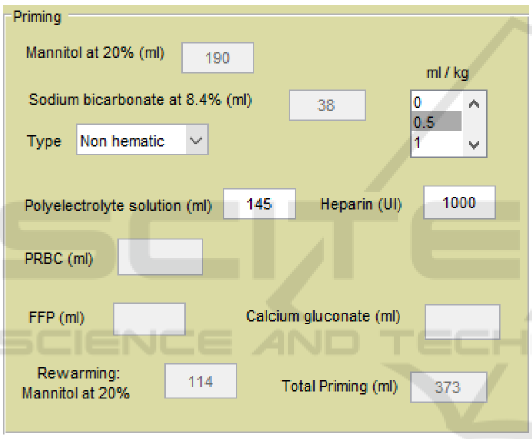

Figure 2: Interface block concerning priming data.

Total Priming Volume, which is the sum of all other parameters of priming block, but the mannitol at 20% and the heparin.

In the blood flow block (figure 3), when a specific temperature is selected, the blood flow value at the corresponding temperature is displayed.

The empirical expressions used in the application are:

$$Flow\ (37°C) = Body\ surface\ \times\ 2.6$$

$$Flow\ (30°C) = \ 3/4\ Flow\ (37°C)$$

$$Flow\ (25°C) = \ 3/4\ Flow\ (30°C)$$

$$Flow(20°C) = \ 3/4\ Flow\ (25°C)$$

$$Flow\ (18ºC) = \frac{Flow(20ºC) - Flow(15ºC)}{5} \times 3 + Flow(15ºC)$$

$$Flow(15°C) = 3/4\ Flow(18°C)$$

This information is particularly important, since some parameters as the blood flow of the patient depend crucially on the temperature at which the body was cooled (Gravlee et al., 2008).

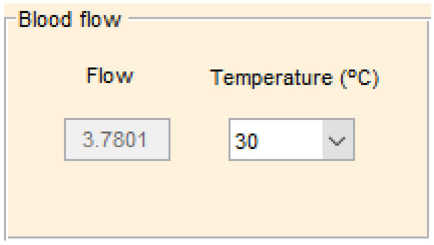

Figure 3: Interface block related to blood flow.

In heparin/protamine doses blocks, (figure 4) heparin and protamine doses and the maximum value of heparin that can be administrated (Heparine 500 UI/kg) are calculated automatically with the input of patient's weight:

$$\text{Heparin dose (300 UI/kg)} = Weight \times 300$$
$$\text{Heparin dose (400 UI/kg)} = Weight \times 400$$
$$\text{Protamine dose (3 mg/kg)} = Weight \times 3$$
$$\text{Protamine dose (4 mg/kg)} = Weight \times 4$$

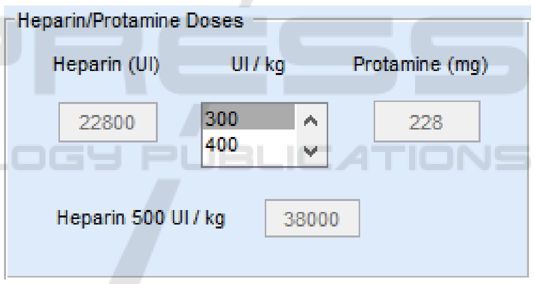

Figure 4: The heparin/protamine doses block.

There are further two blocks in which the modified ultrafiltration volume (ml), the initial haematocrit (%) and post-dilution haematocrit (%) were calculated, given the anaesthesia fluids volume (ml) (figure 5):

$$Modified\ ultrafiltration\ (adult) = 545 \times\ Body\ surface$$
$$Modified\ ultrafiltration\ (pediatric) = 700 \times Body\ surface$$

$$Initial\ Haematocrit = 3 \times basal\ hemoglobin$$

The percentage of the post-dilution haematocrit is then calculated by:

$$Hct = Hct\ pt\ \times \frac{BV_{pt}}{TPV},$$

where: *Hct pt* is the initial haematocrit of the patient; BV_{pt} is his blood volume; and *TPV* is the total priming volume.

In summary, the heparin and protamine doses, priming parameters, dilutional haematocrit and modified ultrafiltration volume are automatically calculated and displayed in the corresponding fields, remaining unavailable for the user to modify, since they are generated by the software.

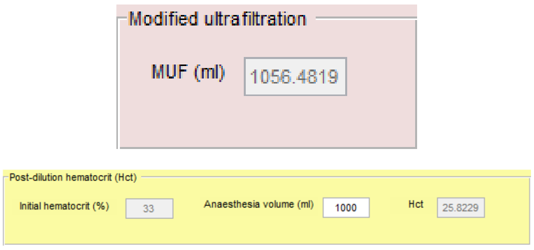

Figure 5: The interface blocks concerning modified ultrafiltration and post-dilution haematocrit.

BioMEP – Perfusion Calculator Application is also prepared for input errors of the user, rejecting data inserted that is not expected by the application (letters, characters, and so on). In this case, no calculations involved the wrong parameter are performed by the software, leaving the values to zero. The clinician can correct in real time those parameters inserted and the calculations are then correctly performed.

If the health care professional wishes to add the application data to the perfusion report at the end of the procedure, a print option is also available. When closing the application, all generated data is deleted to make sure that all the values of the current patient do not get mixed with the parameters of the next subject.

4 DISCUSSION

In the current manuscript we have proposed a new application, *BioMEP*, which can be applied in the field of cardiovascular perfusion and cardiothoracic surgery (both adult and pediatric procedures). Before the advent of technology, such as the one presented here, professionals had to calculate all relevant biometric and physiological values by hand. In a Hospital specialised in cardiothoracic interventions, such as Hospital de Santa Marta, four cardiothoracic surgeries are performed, in average, each day, which totals over 1000 such surgeries every year. Any help reducing the workload of the highly specialised personnel present in a surgical scenario has a very high potential impact.

In addition, *BioMEP* allows for higher efficiency in handling data, and a concomitant reduction in potential sources of mistake, since data transport between calculations is done automatically.

After some trials, the *BioMEP* has been deemed a useful, safe, user-friendly and intuitive tool. It is currently in test use at the Department of Cardiothoracic Surgery, with very positive feedback from surgeons' teams.

Although fully functioning, the natural evolutional step for the proposed application interface, presented in this manuscript, is to export the current computer-based tool to a more useful smartphone platform., Because of the modularity of the application, we may envision other improvements in the future, such as to include the calculation of new physiological parameters that may add further information to surgery procedures.

The *BioMEP* is an innovative application, very well received by the cardiothoracic surgery community, which is showing very promising practical applicability levels. It shows to be reliable, easy to use, and capable of combining multiple anatomical and physiological calculations. New developments may include the calculation of further parameters, provide cannula recommendations, as well as perfusion guidelines.

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