THERMAL CHARACTERISATION OF THE UMBILICAL CORD AT BIRTH THROUGH NON INVASIVE METHODS

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ABSTRACT

There is growing evidence that infants benefit from receiving extra blood from the placenta at birth, some experts recommend delaying the cord clamping until the placental to infant blood transfusion is below a certain level. The aim of the present work is to add information to infer this moment. To accomplish this purpose a study case is analysed and presented. The studied period of time starts when the infant is delivered and finalizes with the clamping of the cord. Through thermography, the superficial temperature of the umbilical cord is obtained as experimental data. Anatomically, the umbilical cord is composed by two arteries and one vein surrounded by the Wharton's jelly, a conjunctive tissue that provides the cord with an elastic and cushion effect [1]. A two-dimensional model of a cross section of the mentioned tissue is developed using COMSOL [2] to solve the bio-heat equation. Certain parameters that characterize the model are undefined: physical properties of the Wharton's jelly, internal heat coefficients and the time when the blood flow stops, t^*. A sensitivity analysis is performed to identify which of these parameters have greater impact on the surface's temperature of the cord. The study suggests that k, ω and t^* are the more influential parameters and are then determined by calibrating the model in order to fit the infrared measured data. For this particular case it is possible to infer the moment when the blood flow inside the vessels of the cord present a change on its behaviour, being this value: $t^* = 255$ s.

NOMENCLATURE

ρ	[kg/m^3]	Density
c_p	[J/kg K]	Specific heat
T	[°C]	Temperature
t	[s]	Time
k	[W/mK]	Thermal conductivity
ρc_p	[J/m^{3}K]	Volumetric heat capacity
$\dot{q}$	[W/m^3]	Energy deposition rate
ω	[s^{-1}]	Local tissue-blood perfusion
h	[W/m^{2}K]	Thermal convection coefficient

Special characters

Δ	[m^{-1}]	Laplacian
∂	[-]	Partial derivative
$\sum$	[-]	Summatory
Re	[-]	Reynolds number
Gr	[-]	Grashof number
Pr	[-]	Prandtl number
Nu	[-]	Nusselt number
Le	[-]	Lewis number
Sh	[-]	Sherwood number
Sc	[-]	Schmidt number
t^*	[s]	time when the umbilical cord blood flux naturally stops

Subscripts

b	Blood
v	Vein
a	Artery
m	Metabolism
w	Wall
0	Ambient or reference

INTRODUCTION

Higher hemoglobin levels after birth, better neurodevelopment, an increase of the newborns blood volume by up to 30% and improved iron status at 4-6 months of age are benefits associated to delaying umbilical cord clamping (DCC) in full-term infants [3]. Despite being favourable, there is not a universally accepted definition of DCC. The aim of the present work is to add information to infer the moment when the placental to infant blood transfusion is below a certain level, and therefore the estimated time to clamp the cord. To accomplish this purpose a study case is analysed and presented.

Due to the nature of the problem only the umbilical cord superficial temperature will be used as experimental data, since it can be measured by non invasive methods. To do so, a heat transfer model of the umbilical cord the moment after the child is delivered is presented, which allows to relate the superficial umbilical cord temperature with the time-dependant flux of blood inside the cord. Previous works have focused on trying to understand the factors that influence the flow patterns inside the cord at birth, for instance first breaths and crying. But to our knowledge, there are neither experimental nor computational works that study the umbilical cord in this crucial moment in order to infer when the blood flux naturally stops.

A vaginal delivery at term was used as study case, were the cord was clamped 10 minutes after delivery. The non invasive method used in this project is thermography. An infrared FLIR camera was installed in the delivery room, that provided IR photos of the umbilical cord from the moment the infant was delivered until the cord was clamped. The umbilical cord is composed of two arteries and one vein protected by a mucous tissue named Wharton's jelly. In the present work a two-dimensional model of the cross section of the Wharton's jelly is developed using COMSOL [2] to solve the bio-heat equation. Some parameters and physical properties of the problem are undefined, one of which is the time when the blood flow stops, t^*. Then, a study of the influence of each parameter on the model solution is performed. Finally, the most sensible parameters are determined by calibrating the model in order to fit the measured data and obtain an estimation of t^*.

In the following sections the data acquisition procedure is described, the numerical model and it sensitivity analysis is presented and the calibration of their parameters is explained. Finally, some conclusions and comments about future work are drawn.

DATA ACQUISITION AND PROCESSING

The method used to determine the umbilical cord's superficial temperature in the desired time interval is infrared photography. The commercially available infrared camera (FLIR T440, FLIR Inc, USA) with a resolution of 320 x 240 pixels and thermal sensitivity of 0.045 °C, is installed in the delivery room. The objective is to collect information of the superficial temperature of the umbilical cord from the moment the infant is delivered until the cord is clamped. Consent to register this moment is obtained from the mother prior to labour. The camera's parameters are set as shown in Table 1, and the picture frequency used was 15 s.

Emissivity	0.95
Reflected apparent temperature	20°C
Atmospheric temperature	25°C
Relative humidity	50%

Table 1: Set camera parameters.

The case of study is a vaginal delivery at term, were the infant is placed on the mothers chest directly after birth and the cord was not clamped until 10 minutes after delivery. As an example, one IR image is shown in Figure 1.

As a result, a photo sequence is obtained and processed with a Matlab script combined with FLIR Atlas SDK for Matlab (discontinued software), which enables to extract the temperature of every pixel in the picture. Three manually selected points are tracked through the pictures in order to obtain the surface's temperature as a function of time. This information is later used to calibrate the model, preforming several simulations varying the uncertain physical parameters.

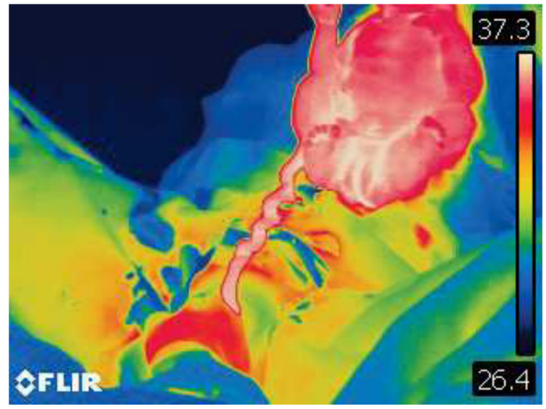

Figure 1: Thermography example of the study case. Scale in (°C).

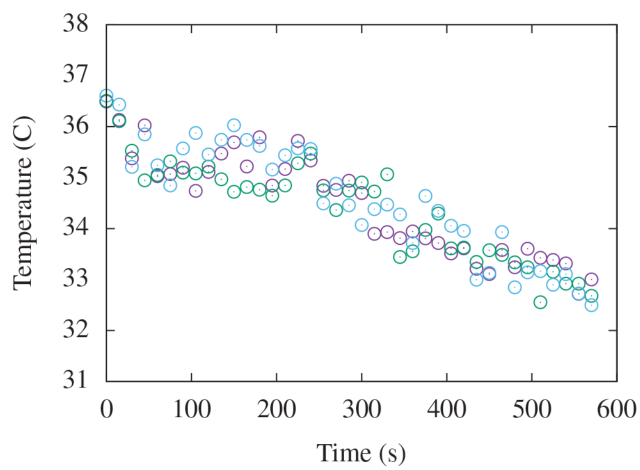

Figure 2: Surface temperature of the umbilical cord from IR images.

NUMERICAL MODEL

The two-dimensional model of the cross section of the Wharton's jelly is preformed using COMSOL [2] to solve the bio-heat equation using finite element methods. The solved equation, first introduced by Pennes, combines Fourier's law of heat conduction and the effect of the heat exchange between blood flow and solid tissues. It can be written as [4]:

$$\rho c_P \frac{\partial T}{\partial t} = k\Delta T + q_p + q_m - \rho_b \omega c_b (T - T_b) \quad (1)$$

where T is the local tissue temperature, T_b is the blood temperature, c_b is the blood specific heat, c_p is the specific heat of the Wharton's jelly, ω is the local tissue-blood perfusion rate, k is the WJ thermal conductivity, ρ is the Wharton's jelly density, ρ_b is the blood density, q_p is the energy deposition rate and q_m is the metabolism, both assumed zero for this model.

The geometry for this model is defined from average parameters obtained from literature [5], being 0.35 cm and 0.2 cm the