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Interface pressure monitoring for a secured instrumented childbirth

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***Abstract*—Complications in forceps deliveries are rare but their consequences might be dramatics. This situation could be avoided if the obstetrician knows the information concerning symmetry of the obstetrical forceps position on the fetal head and the related interface pressure. Indeed, forceps delivery is an emergency gesture which is normally not expected. Our purpose is to determinate relevant parameters for a fast decision-making without any danger for the fetus.**

We have developed a new interface pressure measurement system in order to study pressure distribution of human body whatever its support (forceps, chair, bed…). This method has been adapted to measure the interface pressure between the fetal head and the forceps. This new system also provides information of forceps position symmetries.

The aims of this system are: first, to prevent instrumented delivery accidents. Secondly, to provide a safe training of forceps technique.

This paper presents results about experiments performed on phantoms of fetal head. Different forceps positions on phantom have been tested according to the classification of forceps application as per A.C.O.G 1981 (revised in 1991). These experiments have lead to the definition of relevant parameters in order to help the physician to validate the forceps positions before extraction.

I. INTRODUCTION

Instrumental deliveries are necessary in many obstetrical conditions but it can induce maternal and fetal complications. In developed countries, instrumental deliveries account around 10 % of all deliveries [1], [2]. Mother's tissues injuries or fetal injuries might be associated with the incorrect forceps positioning. Using instrumented forceps, physician doesn't have information about how pressure is applied on fetal head. Moreover, he can't check the forceps position. The physician loose two main sensory modalities: vision and touch-sensing.

Soft living tissues have non-linear mechanical properties making conventional rigid sensors non suitable for interface pressure measurement.

We have developed an interface pressure mapping system intended to measure interface pressure between living tissues and an object (forceps, chair, bed…) [3]. This method has been adapted to measure the interface pressure between the fetal head and the forceps in a project called "FORSAFE" [4].

The physician can be always informed about the pressure distribution applied on fetal head and the forceps position. This smart system provides information for early diagnosis and decisional purposes. Relevant parameters are provided to evaluate forceps positioning. Thus, if this positioning reminds dangerous, a warning signal is transmitted to the obstetrician.

The aim of the intelligent forceps "FORSAFE" is to secure the childbirth. It is also designed to train future obstetricians to the forceps application's techniques. In this case, the intelligent forceps are used in association with our functional childbirth simulator [5] to learn the best way to position the obstetrical forceps.

II. INTERFACE PRESSURE MEASUREMENT: STATE OF THE ART

The interface is a surface of separation between two materials. The pressure is a normal force that acts on the surface element. Pressure is defined as the ratio between the force modulus and the surface. The interface pressure (IP) is the pressure that results from the application of those opposite forces on the separation's surface.

Interface pressure measurement is mainly achieved through three sensors families: electronic transducers, pneumatic transducers and electropneumatic transducers.

For example, Tekscan (Boston, MA, USA) supplies the "Flexiforce" sensor based on a pressure-sensitive ink. Novel, Xsensor Technology Corporation and Pressure Profile Systems are capacitive sensors suppliers.

About electropneumatic transducers, Bader [6] applied this principle to develop the Talley Pressure Monitor.

There are few systems dedicated to measure the interface pressure between forceps and the fetal head. Toward 1960, some researchers worked on the traction effort values and on the pressure values of compression exerted on the fetal head during a forceps delivery. According to the study of Wylie [7], the traction effort measured with a dynamometer, can reach 300N without causing accidents. This result is debatable since no indications on how pressure distributed on the skull is given.

In 1966, Kelly performed a pressure study on an instrumented forceps by placing strain gages on the blade of the forceps [8]. However, rigid sensors are not suitable for this measurement because the fetal head is constituted by soft matter with non linear characteristics.

These systems do not perform forces or symmetry analysis and do not allow the appreciation of the contact surface flexibility.

III. MATERIALS AND METHOD

A. Design constraints related to forceps technique application.

The forceps is generally used during the final stage of the childbirth. Forceps are placed in the absence of uterine contractions which occur every 2 minutes. This time range corresponds when the physician should perform the interface pressure measurement.

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If the measure is correct, he uses the contraction forces of the mother for the extraction.

During the contractions, the average pressure exerted on the fetus varies with the time. Initially, the pressure is about 56mmHg when dilatation is about 3cm. Then it increases until 73mmHg at the expulsion moment. Both the abdominal push and the traction actions double the pressures values. Consequently, the pressure values rise about 130mmHg. This pressure also depends on the forceps localization on the fetal head. In this context, the effective interface pressure measurement range is fixed from 0 to 160mmHg. This range is enough to detect the high pressure areas. The measurement precision must be approximately 10mmHg. It is sufficient for a fast diagnosis in this emergency situation.

B. Method of interface pressure measurement

The fetal head consists of soft matter with nonlinear characteristics; living tissues are composed of skin, subcutaneous tissue, blood vessels, bone… All these elements have very different mechanical behavior one from each other. For example, skin (epidermis and dermis) is assumed to have hyperelastic and viscoelastic behavior [9]. For these reasons, the IP measurement cannot be carried out with traditional sensors. It requires specific design rules: interface pressure evaluation between soft living tissues and any support has to consider the human environment specificity, it requires interaction between the tissue and the sensor, but should modify the less possible, measured phenomenon.

Our device is constituted by numerous cells, connected together. Cells are inflated and deflated periodically using two pumps and the same air supply. Electrical contacts are fixed in the cell inner surface. When the local pressure inside the cell, is just higher than external interface pressure, electrical contact is disrupted and an external pressure sensor connected to the pneumatic circuit records the corresponding pressure which correspond to the interface pressure.

C. Forceps probe

The probe (fig 1) is a combination of three parts: the envelope, the movable electrode and fixed electrode. The envelope is rubber or PVC made. The material used must be as thin as possible, flexible and biocompatible. The envelope must be hermetically sealed. It is fixed on one side of the blade and on the other side it is physically in contact with the fetal head (fig 2).

The movable electrode is designed to limit copper breakdown from micro-displacements. The electrode design represents little waves sequence to increase flexibility. This electrode is connected to the ground voltage. The fixed electrode is a combination of 16 wires connected to each multiplexer input. The electrodes tracks are engraved with a Protomat M60®, from LPKF. The electric tracks which form the contacts matrix are made in a flexible Copper-Kapton sheet. The thicknesses of this film are respectively 50µm for the fixed electrode and 75µm for the mobile electrode. Copper thickness is 35µm.

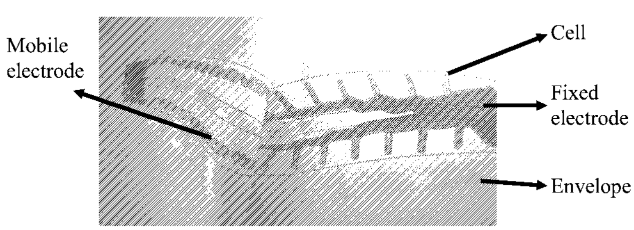

Fig. 1. Forceps sensor realization – Stage of probe sealing

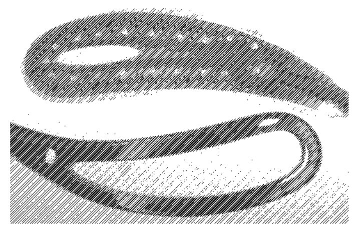

Fig. 2. Interface pressure sensor with visible electrodes ready for positioning on the forceps blades

D. User's interface

The system allows real time pressure measurement. The visualization of the pressure mapping helps the obstetrician to evaluate the positioning of the blades. The pressure mapping is constituted by the representation of each sensor cell by points of colors (fig 3). The aims are to locate quickly the soft and hard points of pressure and also to check the forceps positioning symmetry.

The data processing indicates the pressure in 4 levels (4 colors), sufficient for the doctor to establish a fast diagnosis:

-The cells with low pressure values or not in contact with the fetal head are represented in blue.

-The cells with pressures values below the half maximal pressure (Pmax/2) are represented in green.

-The cells with pressures values beyond the half maximal pressure (Pmax/2) are represented in yellow. This locates the places with high pressures.

-The cells with pressures values beyond the maximal pressure (Pmax) are represented in red. This locates the places with very high pressures.

A visualization of the pressure measured on each cell is also available in histogram form [4].

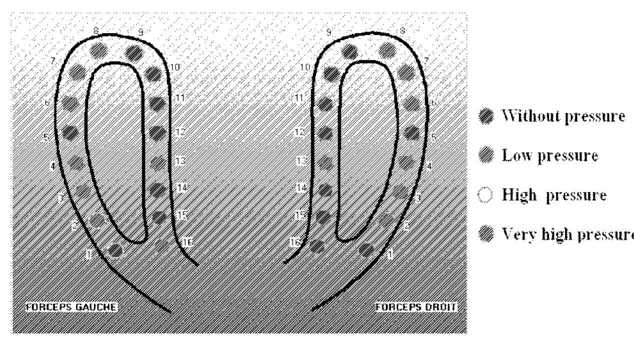

Fig. 3. User's interface of IP measurement system. Pressure is represented in 4 levels. Each cell or contact is represented by a point of color.

IV. CALIBRATION EXPERIMENTS

In order to calibrate the IP sensor, we have designed a phantom reproducing dry hydrostatic pressure. For the first experiments,

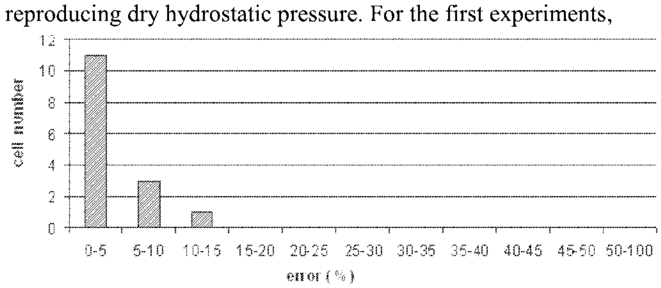

Fig. 4. Sensor characterization when the probe is laid flat. 11 cells have an error less than 5%.

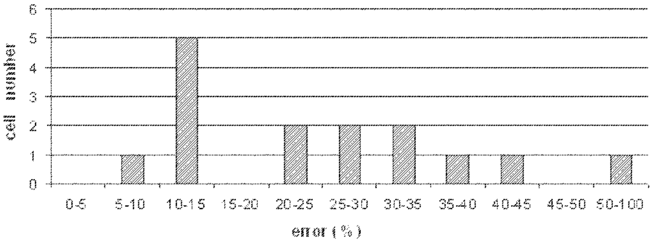

Fig. 5. Sensor characterization when the probe is positioned on the blade. Initially sensor performance is reduced. Most of the cells have a large error.

the sensor is laid flat. Results are reported for 15 cells on the right probe, one cell is defective. The results of this sensor are very promising (fig 4); only 1 cell out of 15 presents more than 10% of error.

For the second characterization, the sensor is positioned on its blades. The flexible sensor takes the blade's shape. The dry hydrostatic pressure simulator is applied. The sensor performance is reduced (fig 5). The weak radius curvature is enough to deteriorate its performances. We verify that this sensor is sensitive to the geometrical variations. A data-processing correction is necessary to get the initial precision.

Computer correction

A calibration cell by cell is performed. For each cell, we trace the transfer function, which is the pressure measured according to the real pressure. The correction function, which linearizes each cells behavior, is calculated. This procedure is completed for the 32 cells. Difference between a line ideal function and the correction function is the error delivered by the sensor.

It is interesting to note the sensor curve influences on the measurement error. Thee first degree coefficients shows that the cells on the blade center (from 4 to 6 and from 10 to 13) have a coefficient more raised (fig 6). There is a close connection between the curvature radius and the measurement error.

The data-processing correction improves considerably the sensor behavior. At the end of the calibration the sensor has its initial properties (fig 7).

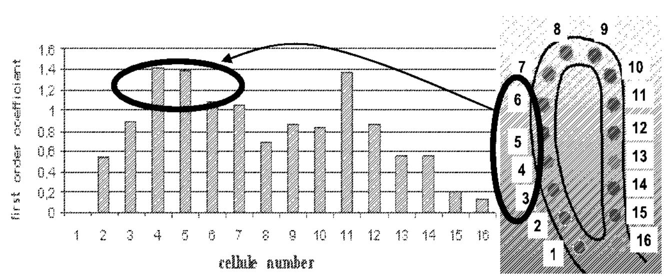

Fig. 6. First degree correction coefficients for each cell. The error is maximal near larger curvature radius.

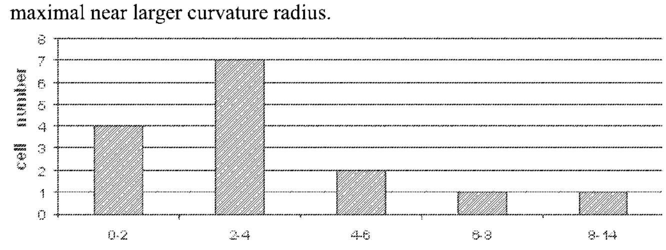

Fig. 7. Sensor characterization after computer correction. 11 cells have an error less than 4%.

V. Results and discussion

The method below is aimed to build a reliable base of relevant parameters to provide to the obstetrician a decision-making aid. The interface pressure cartography is a considerable advanced but it is suitable to define safety parameters compatible with a fast visual diagnosis. These parameters are based on the concept of pressure symmetry and maximum pressure.

Our system allows discriminate 4 cases, the weight for each case are: Blue =0; Green = 1; Yellow = 2; Red=3. For example the weight of cellule number 2 is Cleft2=3 if it is located in the left blade and its color representation is Red.

A. Parameters of symmetries

On the basis that an optimal forceps position must respect all symmetries and should not have excessive points of pressure, we can define relevant parameters according to these symmetries (fig 8), in order to provide to the obstetrician an effective help with the diagnosis. If the position of the forceps is not optimized, a warning message is displayed on the PC screen by the user's interface.

1) The parameter H

This parameter characterizes the horizontal asymmetry (H). It is particularly relevant to know the total forceps depression.
It is calculated through 4 parameters:

$$H = |(h1+h2)-(h3+h4)| \quad \text{with} \quad Hmax = 48.$$

$$h1 = \sum_{i=1}^{4} C_{left}i + \sum_{i=13}^{16} C_{left}i \;; \qquad h2 = \sum_{i=1}^{4} C_{right}i + \sum_{i=13}^{16} C_{right}i$$

$$h3 = \sum_{i=5}^{12} C_{left}i \;; \qquad h4 = \sum_{i=5}^{12} C_{right}i$$

2) The parameter H'

This parameter characterizes the horizontal pressure of each blade (H1 and H2). It is particularly relevant to know the each forceps depression difference.

$$H' = |h1 - h3| + |h2 - h4| \text{ with } H'max = 48.$$

3) The parameter V

This parameter characterizes the vertical asymmetry (V). It is particularly relevant to know the pressure difference between each blade of the forceps. It is calculated through 4 parameters:

$$V = |(v1+v2) - (v3+v4)| \quad \text{with} \quad Vmax = 48$$

$$v1 = \sum_{i=1}^{8} C_{rigth}i \;; v2 = \sum_{i=9}^{16} C_{right}i \;; v3 = \sum_{i=1}^{8} C_{left}i \;; v4 = \sum_{i=9}^{16} C_{left}i$$

4) The parameter V'

This parameter characterizes the vertical pressures asymmetry on each blade. This parameter is particularly relevant to know the pressure difference of each forceps edge.

$$V' = |v1 - v2| + |v3 - v4| \text{ with } V'max = 48.$$

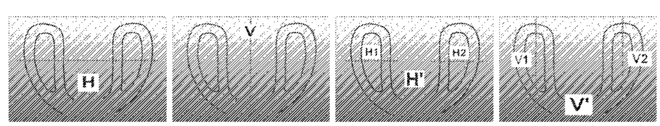

Fig. 8. Parameters H, H', V, V' according to four symmetries H1, H2, V1, V2

B. Experiments on phantom

First experiments are conducted on phantoms (fetal head from Denoyer Geppert). They are exploratory and confirm the feasibility of the interface pressure flexible sensor. The fetal head model is used to simulate potential dangerous positions of the forceps during delivery.

According to the classification of forceps application [10], three forceps positions have been tested.

1) Good position

For this test, the fetal head is positioned a priori in an optimal way to maximize contact surfaces between fetal head and the blades and to minimize the excessive pressure applied by the forceps. The results point out that measured pressures on the head are equitably distributed on blades. All symmetries: H=4, H'=4, V=4,V'=2, are respected because all parameters have been minimized. The total pressure is not excessive. In this case, the obstetrician can continue his gesture.

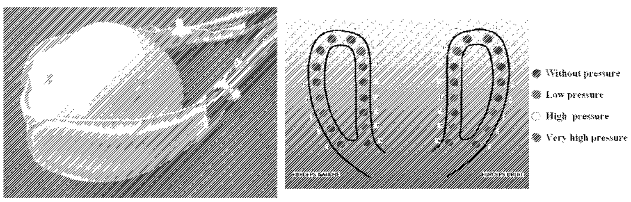

Fig. 9. Good positioning and the result in the user's interface

2) Bad position 1

In this case, the forceps presents a position error. Only the blades end cells are in contact with the physical model. This is illustrated in the radio (fig 10) which indicated a double depressed fracture of the skull. There is a distribution error of the efforts on the horizontal axis. The system detects this error through the high values of the parameters H=18 and H'=18. In this case the obstetrician must reexamine the forceps position.

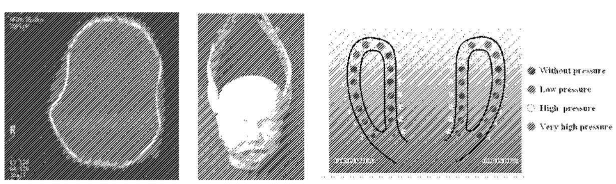

Fig. 10. Depressed fracture of the skull due to the bad forceps position (radio). The system detect this result in the user's interface

3) Bad position 2

In this case, the forceps presents another position error. The system detects this error through the high values of the parameters V= 16, H=18, H'=18. There is a distribution error of the efforts on the horizontal and vertical axis. In this case the obstetrician must reexamine the forceps position.

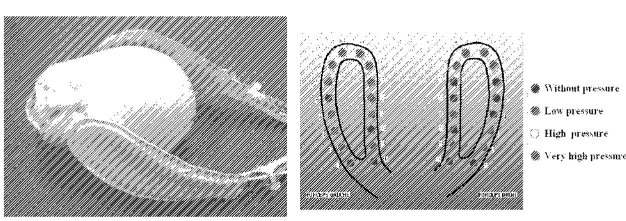

Fig. 11. Bad forceps positioning and the result in user's interface

VI. Conclusion

Forceps delivery has still got a place in modern obstetrical practice and should be considered in certain cases.

The main purpose of project FORSAFE is to give to the obstetrician the forceps positioning information in real time. It also allows the future obstetricians training. In fact, the direct visualization of good or bad forceps positioning leads the immediate gesture correction.

Relevant parameters are determinate to check the symmetries (H, H', V, V') and to maximize the contact surface of the fetal head with the blades in order to decrease the applied pressure.

The next stage is the prototype validation with the expert obstetricians in hospitals and with the childbirth simulator.

This technique of interface pressure measurement has many applications fields. It can be applied in robotics to perform the prehension of non-rigid or fragile objects.

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