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THE VACUUM EXTRACTION FORCE VECTORS ANALYSIS

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ANALIZA VEKTORSKIH SILA KOD VAKUM EKSTRACIJE PLODA

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ABSTRACT
The vaginal delivery operations, the vacuum and forceps, are commonly used in certain situations in delivery rooms. Every obstretician is facing challenges and controversies when deciding which type of assisted vaginal operational to choose.
The aim of this work is to analyze vacuum force vectors by new measurement device. Physical models, metrical system and experimental research of the process of fetus head extraction by vacuum implementation were successfully conducted in collaboration with the Faculty of Mechanical Engineering in Kragujevac, Terotechnology Institute.
We reached the conclusion that it is contradictory to try vacuum delivery if the head is not visible in the introitus of vagina. Achieving the correct cup placement should be result of proper indication as well as proper physician education. The vacuum force must be increased in one step to proper power level of 80 N (0,8 bar, 600 mmHg), traction should take maximum one minute. Failure of vacuum extraction is indication for Cesarean Section, not for forceps delivery, unless the failure occurs in the introitus. Avoiding complicated vacuum extraction and prolonged traction, timely cup detachment can prevent infant head, brain and soft tissue injuries.
Key words: vacuum extraction, obstetrical, biomechanics

SAŽETAK
Vaginalne akušerske operacije, vakuum i forceps ekstrakcija, su uobičajeni metodi koji se koriste u indikovanim slučajevima u akušerskim salama. Kontraverze i izazovi sa kojim se suočavaju akušeri pre donošenja odluke koji vrstu akušerke operaije da izvedu su stalni.
Cilj ovog rada je da analizira vektore sila koje se javljaju kod vakuum ekstarkcije ploda. Fizički model, merni sistem i eksperimentalno istraživanje u procesu vakuum ekstrakcije glave ploda su postavljeni i uspešno izvedeni u saradnji sa Institutom za Terotehnologiju, Mašinskog fakulteta, Univerziteta u Kragujevcu.
Zaključili smo da je kontraindikovano da se pristupi vakuum ekstrakciji ukoliko glava nije u introitusu vagine. Sila vakuuma bi trebalo da se postigne u jednom koraku do pravilne sile od 80 kPa (0,8 bar, 600 mm Hg), ekstrakcija bi trebalo da traje do 1 minuta. Neuspeh u ekstrakciji vakuuma je indikacija za izvođenje Carskog reza, plasiranje forcepsa dolazi u obzir samo ako se radi o izalznom vakuumu. Izbegavanje komplikovanih plasiranja vakuuma, produžena trakcija glave i po završetku ekstrakcije, skidanje kalote vakuuma, da bi se sprečila povreda poglavine i mekih tkiva porođajnog kanala, predstavlja osnovne uslove uspešno izvedenog zahvata.
Ključne reči: vakum ekstrakcija, obstetrička, biomehanika

INTRODUCTION
One of the major risk factors for maternal as well as fetal morbidity and mortality associated with operative vaginal delivery was controversial for decades. Many Ob/Gyn societies (RCOG, ACOG ...) published clinical guidelines for use of these instruments, considering cost/effectiveness, merits, indications and unnecessary complications. The Royal College of Obstreticians and Gynecologists concluded that: „Obstetricians should be competent, and confident, in the use of both vacuum and forceps," (1-3) but „in view of the reduction of maternal injuries the vacuum should be considered to be the instrument of first choice." (4-6)
Shoulder dystocia was lower among women with a forceps delivery and both vaginal laceration and third-and fourth degree perineal lacerations were higher than with vacuum. A vacuum-assisted vaginal delivery was still associated with higher rates of 5-minute Apgar scores less than 7, cephalohaemathoma, admission to the NICE, and neonatal jaundice (7- 9). The Cochrane meta-analysis (10) of randomized trials of the forceps vs. vacuum concluded that vacuum was:

- More likely to fail delivery
- Associated with lower Cesarean Section rate
- Less likely to cause serious maternal genital tract injury, less immediate and late pain
- Associated with less regional and general anesthesia
- More cephalohaemathomas and retinal hemorrhagies
- Was not associated with significant differences in neonatal mortality

Considering serious neonatal and maternal complications with the incorrect or inappropriate use of a vacuum device, the need for appropriate training in the correct use of this equipment came out as very important.
Attempts have been made to identify the predisposing factors associated with the adverse outcomes, and several changes have been made to the basic instrument, designed to facilitate its use and reduce the rate of complications.
The basic premise of any vacuum device is that a suction cup, of silastic or metal construction, is connected, via tubing, to a vacuum source. Either directly, though the tubing, or via a connecting „chain," traction can then be applied to the presenting part, the vertex, to expedite delivery (11, 12).
For successful use of the vacuum, determination of the flexion point is vital. This is located, in an average term infant, on the sagital suture 3 cm anterior to the posterior fontanelle, and thus 6 cm posterior to the anterior fontanelle.
The center of the cup should be placed directly over this, as failure to adequately position the cup can lead to a

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progressive deflexion of the fetal head during traction, and failure to deliver the baby (10, 13, 14).

However, not all vacuum cup designs allow easy positioning over the flexion point, especially when the fetal head adopts an occipito-posterior or lateral position. This problem is frequently followed by the presence of asynclitism or deflexions. This the vacuum must be applied in the midpelvic or higher position, with cepahlopelvic disproportion, or before full dilatation of the cervix the soft cups instead of rigid must be used (10, 15).

Passage of the fetal head through the birth canal is the result of the sum of forces between exerted powers which must be greater than resisting forces of the pelvis. Exerted forces could be enhanced by propulsion (stronger uterine contractions or maternal expulsions) or by applying traction to delivery object (head) by the vacuum or the forceps. Resisting forces could be shrunk by decreasing the size of the pelvic canal. Well trained practioner must consider all this information in very short time and make the best decision. The number and duration of the vacuum extraction is proportional to the efficiency, primarily as it could be to delivery of fetal head. Force strength on the fetal head during vacuum is calculated between 8 and 15 kg. (10, 16, 17).

Discussing about fetal effects of the vacuum extraction, we concluded that variety of the factors produce fetal head harm, ranging from cosmetic effects (chignon, cup discoloration) to clinically significant injuries (subaponeurotic and intracranial hemorrhage and skull fracture). Our aim was to create a model that can assume force vectors for the vacuum of vaginal operation, predicting potential obstetrician risks.

MATERIAL AND METHODS

MODELING THE BIOPHYSICS OF HEAD EXTRACTION PROCESS BY EMPLOYING VACUUM

With in-vivo medical research a certain amount of risk is inevitably to be incorporated into the process. The current approach applied in the research is primarily based on modelling and the application of contemporary metrical methods and calculation with the aim of defining the principal law of the process development.

Following the forgone conclusion, the fundament in the verification of the biophysical process of fetus head extraction is related to defining the following:

- anthropometrical model matching epicranium and model head,
- instrument contact zone and fetus epicranium model,
- biophysical properties taking part in the head extraction process (forces, stress and motion),
- physical model of the head and fetus epicranium and metrical system bu means of which an obstetrician is to monitor, in a sophisticated fashion in real time, the variations in the biophysical properties of the modeling process of fetus head extraction and
- experimental research

ANTHROPOMETRICAL MODEL OF EPICRANIUM AND FETUS HEAD

The previous research into the biophysical nature of the fetal vacuum extraction process at the Clinical Center in Kragujevac, Obstetrics and Gynecology Clinic and Faculty of Mechanical Engineering in Kragujevac, Terotechnology Institute was performed on a representative measurement sample with characteristic anthropometric parameters of fetal epicranium. The properties measured are shown in figure 1, and numerical values in table 1.

Figure 1. Defining fetal epicranium anthropometrical features (Rfr-frontal radius, Rpp-anterior transversal parietal radius, Rzp-posterior transversal radius, Rup-longitudinal parietal radius).

Table 1. The values of estimated parameters.

Baby No	Frontal portion		Parietal portion	
	Rfr (mm)	Rpp (mm)	Rup (mm)	Rzp (mm)
1.	44.3	73.5	44.3	48
2.	47	50	51	50
3.	47.5	73	48	48
4.	-	-	44.5	49.5
5.	-	-	51	50.5
6.	-	42	46	44.5
7.	-	51	50.5	45
8.	-	-	52.5	50.5
9.	49.5	50	49.5	49
10.	50	49	50	50
11.	47	50	47	46.5
12.	50.5	46	50.5	46
13.	50.5	50.5	50.5	50
14.	51	53.5	51	46
15.	49.5	47	49.5	47.5
16.	-	49.5	59	43
17	64	44.5	64	45.5
18.	-	49.5	55	49.5
19.	46	51.5	46	46.5
20.	48.5	46	48.5	44
Medium value	49.6	51.5	50.6	47.5

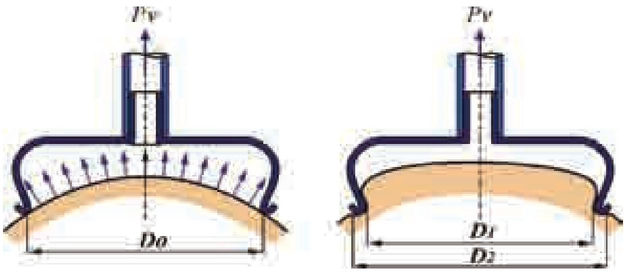
From the results displayed in table 1 it can be concluded that fetus head is subject to modelling within the sphere with diameter of 100 mm.

VACUUM DEVICE CALOTTE AND FETUS EPICRANIUM CONTACT ZONE

Basic geometrical features defining vacuum device calotte and fetus epicranium contact zone relates to calotte diameters (D1 and D2) – figure 2 and figure 3.

Figure 2. Vacuum cup (rigid).

Fetal vacuum extraction device produces Pv (vacuum) sub-pressure transferred onto fetus epicranium by means of a plastic hose via vacuum device tube (figure 2.). A chamber of reduced pressure (vacuum) is formed between the inner surface of the vacuum device calotte and fetus epicranium. In the initial stage of vacuum formation the contact diameter as Do and with the increase in the subpressure, the contact between the vacuum device calotte and epicranium is realized along the circular ring defined by D1 and D2 diameters - figure 3 (b).

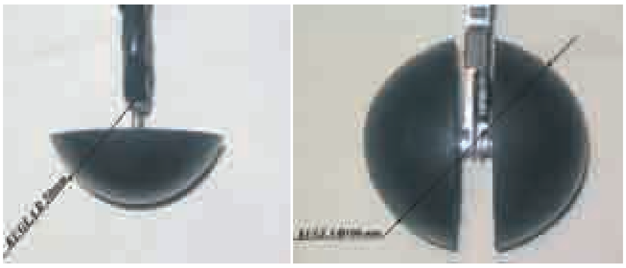


a) b)

Figure 3. Contact stages: a) initial stage in contact formation, b) deformed fetus epicranium in vacuum formation.

PHYSICAL MODELS AND METRICAL SYSTEM

Considering previously defined anthropometrical epicranium model, head model (diameter sphere 100 mm) and biophysical properties which determine vacuum and forceps fetus head extraction, physical models of head (a) and epicranium (b) have been designed (figure 4.)



a) b)

Figure 4. Physical models of the head (a) and epicranium (b)

These models were specially molded and made of soft rubber, which by its physical characteristics corresponds to mechanical characteristics of the fetus epicranium.

As displayed in figure 4, the first physical model (a) consist of two hemispheres between which metrical providers are installed according to figure 9 of the normal Fn and tractional F force in forceps application.

Metrical system employed had very good characteristics, as it in real time monitors the forces characteristic for the contact zone in a higly sophisticated way.

In other words, as an obstetrican simulates fetus head extraction by means of external forces developed in actual process, thus the providers register the forces relevant in the contact zone, while the data obtained via two-channel amplifier and A/D converter along with the application of an adequate acquisition software are transmitted over to database in NOTEBOOK computer. The real force values in the process of simulating head extraction are monitored. The components of the metrical system as well as their connection with the head models, are displayed in figure 5 and figure 6.

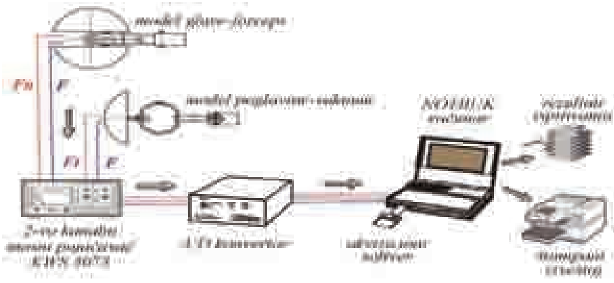


Figure 5. Metrical system scheme for model of head extraction by forceps and vacuum.

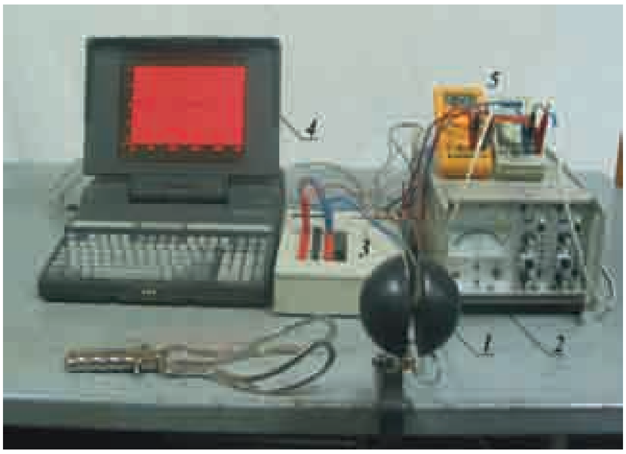


Figure 6. Metrical system for model examination of fetus head extraction by vacuum.

1) Head model, 2) Two-channel bridge-mode voltage signal amplifier (KWS 3073 – HOTTINGER, 3) BALDWIN MESSTECHNIK), 4) A/D-analog-to-digital converter ED 2000, 5) NOTEBOOK computer TOSHIBA T5200/100 and

Digital metrical instrument for the adjustment of the primary zero force value works on both channels (Fn and F).

All providers are designed according to the measurement stripes and Winston bridge principles. In that way, the impact of the physical force is transffered onto sensors and subsequently converted into electrical (voltage) signal, whose value is proportional to the property measured. Such providers enabled (as previously stated) the process of monitoring relevant forces in fetus head extraction modelling, which was conducted in a sophisticated fashion and placed in real time. Physical models, metrical system and experimental research of the process of fetus head extraction by vacuum were successfully conducted in collaboration with the Faculty of Mechanical Engineering in Kragujevac, Terotechnology Institute.

INSTRUMENT AND HEAD MODEL CONTACT ZONE

While analyzing the instrument and head model contact zone, the starting point is the analysis of the actual fetus head extraction process - figure 7.

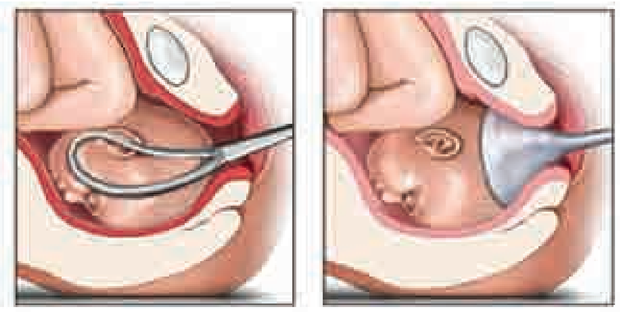


Figure 7. Forceps and fetus head contact (a), epicranium and vacuum device calotte contact (b).

In the comparative analysis of forces in the process of fetus head extraction by means of forceps or vacuum employment, all the peculiarities are to be examined and taken into consideration, primarily those related to the nature of contact and instrument and head model contact zone. With vacuum extraction process, the position of vacuum device callote on epicranium is a partially visible zone, whereas that is not the case with forceps application. Given the existing differences between the way in which the force is applied and the position of the instrument employment, there are divergences in the size of the contact zone, and in the load within the contact zone.

BIOPHYSICAL PROPERTIES DEFINING FETUS HEAD EXTRACTION PROCESS

During fetus extraction from birth canal by either forceps or vacuum method (both imply a procedure of a coercive nature), external physical properties also take part in the process. Force of varying direction, due to the anatomical form of birth canal, is of vitali mportance for the fetus head passage through birth canal. Thus, the dominant biophysical properties occurring in the process of fetus head extraction could be designated as the following:

- force
- stress and
- motion

BIOPHYSICAL PROPERTIES IN FETUS HEAD VACUUM EXTRACTION PROCESS

In the process of fetal vacuum extraction, the only function of the vacuum is to fix vacuum device calotte, and enable the exterior Fu force to be transffered onto the fetus epicranium - figure 8. The obstetrician transfers the overall Fu force by means of R handle (figure 8 onto vacuum device calotte at point A). The force obscures the (alfa) angle with N normal on epicranium in the zone of vacuum device calotte placement. The overall external Fu force is comprised of two components, normal F and tangential Ft component on the contact surface of vacuum device calotte and epicranium. N and T axes in figure 8 intersect in fetus head rotational center. Normal F component acts along the calotte axis and represents a tractional force. Ft tangential force influences the rotational Mo instance (flexion).

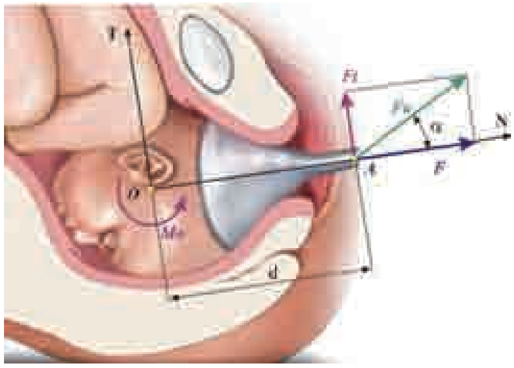


Figure 8. Forces and instances in the fetal vacuum extraction process.

The fetal vacuum extraction device produces Pv subpressure (vacuum) which is further transffered on fetal epicranium through a plastic hose via vacuum device calotte. The chamber of reduced pressure is formed between the interior surface of vacuum device calotte and fetus epicranium. This suggests that it is only the normal force which is formed on fetus epicranium within the vacuum zone. The resulting Fn normal force, acting on fetus epicranium, depends upon the level of Pv subpressure, as well as on the characteristic vacuum device calotte D1 diameter (figure 9):

$$Fn = Pv.\ Av$$

$$Av = D1\ n/4$$

Epicranium suction occurs as a consequence of forgoing resulting force. The epicranium of the fetus behaves as quasi plastic substance and, after birth, deformity is evident. The epicranium suction into the calotte of the vacuum device and the extent of quasi plastic deformity depend exclusively on the vacuum level and properties, of the epicranium tissue.

The semicircular form of the calotte vacuum device acts by means of Fk force in the contact zone on fetus epicranium. If there is no external force, the Fu force is approximately of the same intensity as the Fn force, it is just of the opposite direction in relation to the latter:

$$Fk = Fn$$

The surface of the contact between the callote of the vacuum device and fetus epicranium is of a relatively low degree. The surface is of an approximate circulare shape defined by D2 and D1 diameters as demonstrated in figure 9. The surface of the contact is to be calculated by following formula:

Ak = (D2 – D1) n/4

When the surface of the Ak contact is established, it is possible to calculate the stress, the pressure in the contact zone of the calotte semicircle in vacuum and fetus epicranium:

Pk = Fk/Ak

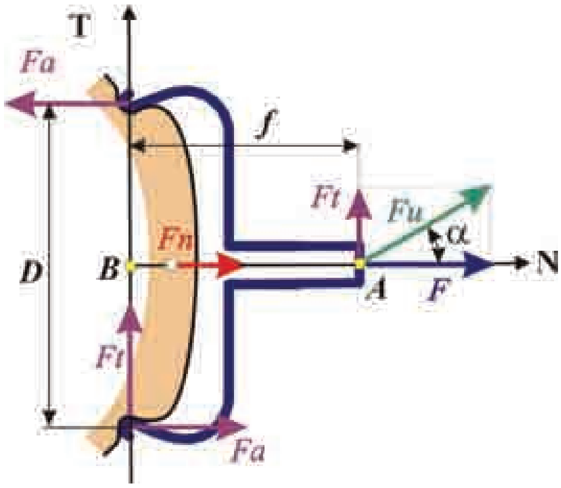


Figure 9. Characteristic diameters of the calotte and fetus epicranium contact zone.

Henceforth, we are to conclude that there are two zones of dissimilar stress in the process of interaction between vacuum device calotte and fetus epicranium, one of them being the zone of dilatation and the other of pressure - figure 10. The fetus epicranium dilatation zone is much greater than that of pressure.

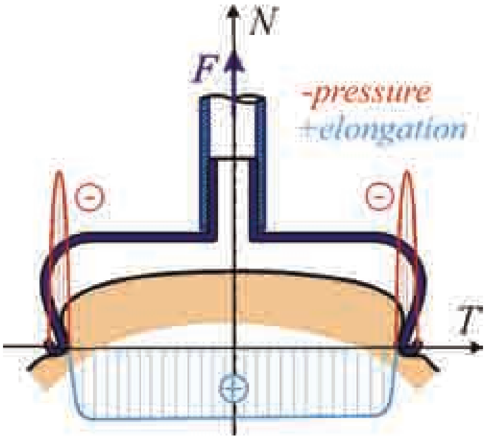


Figure10. Stress zone prior to angular tractions.

The stress demonstrated in figure 10 occurs in the process of fetal vacuum extraction when the operational vacuum is achieved without any angular traction, without F normal component of the external Fu force. When these angular tractions commence, there is a decrease in the Fk force in the calotte contact zone. The latter could be demonstrated by the following equation:

Fk = Fn – F = Fn – Fu. cos alfa?

When the normal component of F force approaches the resulting Fn normal force (occurring due to the vacuum process upon fetus epicranium), the impact of the Fk force ceases to have its effect, and the latter equals to zero. This is the critical stage in the process of fetal vacuum extraction, since the calotte of the vacuum apparatus is detached in relation to the epicranium and the vacuum ceases to have its effect, the vacuum „slips off".

When analyzing the process of fetus head vacuum extraction from the aspect of the biophysical nature of the process itself, the following conclusions are to be derived. Maximum force and stress property in the contact zone depend upon the vacuum level. In this case, unlike with forceps, vacuum displays a feature of limiting effect, it represents a „safeguard", avoiding fetus epicranium overload. Subjectiv self-control on the part of obstetrician, is necessary to prevent slippage of the so that vacuum device calotte, which may happen when external forces (as previously stated) are greater than the force of the grasp resulting from the vacuum impact upon fetus epicranium. If the latter is considered in the light of the fact that the implementation of the vacuum device calotte takes place in a partially visible zone, the probability of risk and undesirable fetus epicranium deformity is considerably decreased.

RESULTS

As previously stated, the process of head extraction by vacuum implementation highly depend on the vacuum regulatory system. Only the results relevant from the aspect of comparative analysis of the process and fetus head extraction by forceps and vacuum are presented.

In the model testing conducted in mutual collaboration of the Faculty of Mechanical Engineering in Kragujevac, Terotechnology Institute and Clinical Center in Kragujevac, Obstetrics and Gynecology Clinic, the principal physical values of the head extraction process employing vacuum were established. This primarily refers to:

- computer maximum value of normal F force (figure 9),
- maximum F force value without tractional motion measured on head model,
- medium value of normal F force in the course of tractional motion,
- overall external Fu force transffered on the vacuum device calotte and
- stress within characteristic contact zones

The research was conducted with vacuum device calotte employed at Clinical Center in Kragujevac, Obstetrics and Gynecology Clinic. Calotte diameter defining the vacuum zone is presented in figure 11.

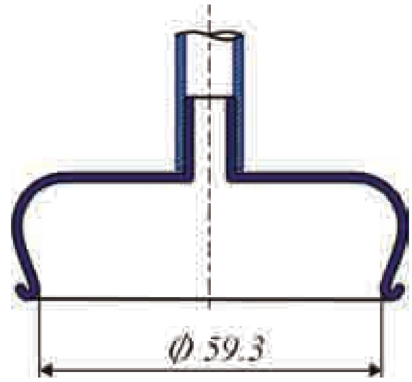


Figure 11. Calotte diameter defining the vacuum zone.

Based on the measurement of the vacuum device calotte surface, the shift in vacuum level and measuring performed on the model, table 2 was established. Maximum force measuring was performed while pulling vacuum device calotte, after previously adjusting the vacuum level.

Table 2.

Pv (bar) Vacuum level	F (daN) Calculated maximum normale force value	F (daN) Maximum normal force value without tractional motion measured on the model
0.70	19.3	16.7
0.75	20.7	17.5
0.80	22.1	18.4
0.85	23.5	19.3
0.90	24.9	20.6
0.95	26.2	22.5

Medium normal F force with tractional motion in progress is defined by greater pressure of the experimental process, the tractional motion with 0.8 bar vacuum. This vacuum level is quite common in the process of fetus head extraction. As with forceps, fetus head motion in the extraction process by vacuum is primarily determined by the anatomical from of birth canal. The coercive conditions occur due to Ft and F forces (figure 9). Forces and the instance in the process of vacuum fetal extraction active on vacuum device calotte and on the fetus epicranium. By means of the R handle motion (figure 2 - Vacuum device calotte) following the desired direction, the corresponding rotation, that is to say translatory motion-fetus head traction, is also provided. Tractional force is simulated as shown in figure 12.

The diagram of the F normal force shift in particular stages of the simulated process of fetus head extraction is displeyed in figure 13.

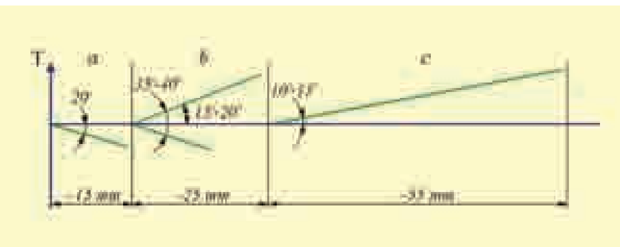


Figure12. Tractions in certain stages of fetus head extraction.

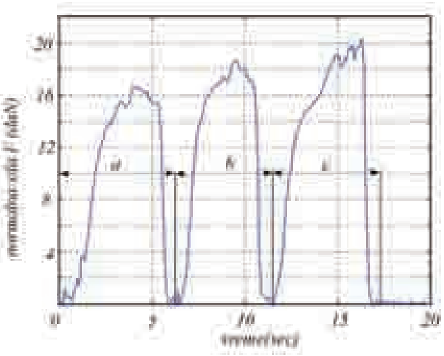


Figure 13. Normal force shift with certain tractions.

DISCUSSION

When perceived from the aspect of biophysical properties, vacuum extraction is an entirely defined process (10). The load and stress are limited by the vacuum level, unlike the process of forceps extraction in which the latter is mostly determined by the subjective estimate on the part of the obstetrician and his working experience.

In conclusion, we found that the maternal and fetal stress is determined by vacuum level. Achieving that goal is less demanding than placement of forceps spoons, therefore considerable easy to use. But we must be aware of other challenges due to vacuum mechanism. According to our conclusions there are:

- Not to attempt vacuum delivery if the head is not visble in the introitus of vagina
- Achieving correct cup placement should be result of proper indication as well as proper physician education.
- The vacuum force must be increased in one step to establish proper power level of 80 kPa (0,8 bar, 600 mmHg), traction should take maximum one minute.
- Failure of vacuum extraction is indication for Cesarian Section, not for forceps delivery, unless the failure occurs in the introitus.
- Avoiding difficult vacuum extraction, prolonged traction and immediately cup detachment can prevent infant head, brain and soft tissue injuries.

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