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Mechanical reaction of the frontal abdominal wall to the impact load during gravidity

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Abstract

THE AIM OF THE STUDY: Selected parameters of mechanical characteristics of the gravid abdomen under impact load. **TYPE OF THE STUDY:** Experimental biomechanical study carried out in a human in vivo.

METHOD: Damped vibration of the gravid abdomen was detected after a defined impact load using speed cinematographic recording of 103 pictures/sec. A women in 32nd week of gestation, performing toe stand and fall down to the heel, the drop was 0.08 m. The recording was digitalized and the values mathematically analysed. The method used was PAM (polynomial approximation method) of approximation of discrete coordinates. The umbilikus' trajectory in reaction to the impact load was described analytically and interpreted graphically. Parameters of abdomen vibration were detected in horizontal profile by tensometric belt. Impact in interaction of soles with the underlay was detected with the help of tensometric platform Kistler. Ultimate strength point of myometrium was set by tearing experiment in 12 samples.

RESULTS: Calculation of characteristics of damped, aperiodic vibration of hydroviscous elastic system as the outside behaviour of the gravid abdomen. Parameters in vertical direction of umbilicus: impulse in abdominal area – 2,72 Ns, T-period – 0.1299 s, amplitude – 0,009 m, frequency – 7,7 Hz, functional damping – from –6 to +12 Nsm^{-1}. In horizontal direction: frequency 5,4 Hz, damping 123 Nsm^{-1}. Impact in soles' sphere 40 Ns with maximum value 1511 N, which represents level 2,2 G. Ultimate strength point of myometrium is 0,1 – 1,1 MPa.

CONCLUSION: The results show one of the possible critical, risky frequencies of the gravid abdomen, that is, in this concrete case, the frequency of the vibrating system of cca 7,7 Hz in vertical direction and cca 5,4 Hz horizontally. This implies that e.g. this frequency is dangerous (possible abruptio placentae) and is necessary to be avoided e.g. when travelling by means of public transportation. The applied analytic methods and presented parameters will be used for e.g. modelling the examined gravid system under impact load of a general character – locomotion, work-load, car accidents, etc.

INVITED RESEARCH PAPER

Introduction

Gravidity represents system *sui generis*. Vibrations of a body and specially abdomen laparoseismicities are an everyday matter, they happen permanently. Oscillations are started as a result of present impulses. They are caused by inner factors – breathing waves, abdominal aorta, intestinal peristalsis, using abdominal press while pushing, coughing, sneezing, foetus movements in gravidity, uterus topic changes during contractions in childbirth. Outer factors – they impact with different power, in different direction during any motion, while walking, hopping, during coitus, during vibrations in the means of transportation and vibrations at work etc.

Apart from everyday impulses impact loads in traumatism play a special role. Impact load – abdominal vibrations (gravid uterus and topically related organs – GUTO) may as a consequence reach utero-placental connection itself. Practically the most significant role in various mechanical impact loads on gravid abdomen play traumatisms generally, especially in transport accidents, which is a serious world problem [1–6], and others.

During all given regimes vibrations take place that set abdomen, enlarged by pregnant uterus, vibrating. Uterus itself reaches high above naval at the end of gravidity, it is fixed backwards by sacral-uterus ligaments which form in the area of L4–L5 gravid retro-uterus space which is being used at the start of lower hollow vein syndrome and aorta-concave compression during childbirth [7]. Uterus oscillates as an upturned pendulum, in front it leans on muscles of frontal abdominal wall that absorbs vibrations.

The whole body reacts as an integral whole, every participating item, bones, ligaments, muscles, myometrium, connective tissue, membrane bag, amniotic fluid, placenta – is given mechanically different parameters of rigidity, stiffness, elasticity, density, damping. Tissue instability under impact is different, with supra-threshold impulses defects of its structures may appear which will call out chain of following reactions.

Within the frame of general problems of hydro-viscose vibrations and elastic systems we were solving the range of these vibrations and their consequences from the point of view of the followed complex damping [8, 9]. Abdomen enlarged by gravid uterus is a very complicated system from mechanical point of view. Uterus itself is fixed backwards by sacral-uterus ligaments which forms specific gravid retro-uterus space supported by frontal abdominal wall muscles. Uterus contains amniotic fluid, foetus and placenta, when each of these subsystems (i.e. placenta, amniotic fluid and abdominal muscles and individual tissues) have different mechanical qualities – elasticity, rigidity, stiffness, damping [2] etc.

In the process of our work we asked a following question: *What is the basic characteristics of abdominal vibrations after defined load.* Its answer is a prerequisite for further solution of problems connected with loading the pregnant women in current and extreme loads.

Method

For non-contact, non-invasive data recording of abdominal vibrations we used a method of speed cinematographic recording from lateral side projection in frequency 103 pictures/ sec. Further we used tensometric belt that outlined abdomen in the biggest diameter and registered frequency changes in impact load. Both measurement systems were electronically synchronized and analysed separately. The third used synchronized method was dynamographic reaction recording of the underlay with the help of Kistler platform with possibility of 3D reaction power recording during interaction of soles and underlay.

The examined pregnant woman in the 32^{nd} week was at first standing calmly on toes and then fell on extended legs by orders. The height of this "fall" was 0,08 m fig.1.

The first analysis was made from recorded vibrations of a pregnant abdomen taken in reference as umbilicus. Weights of all topically appropriate organs having substantial connection to vibrating pregnant abdomen refer to it. The umbilicus' trajectory was added to the solution. Wakening impulse with short lasting where shape of impulse course could be neglected, had theoretical value 6.4 Ns max. Weight of vibrating abdomen was calculated by uterus with amniotic egg and topically appropriate organs at m = 5.l. kg. The model was considered as a complex of material point placed with the help of a spring and shock absorber in all three directions of the system of coordinates. Solution of dynamic qualities was made for vertical direction. Absorbing characteristics were shown this way. Discrete points of umbilicus y-coordinate were at first approximated by polynomial approximation method. From thus treated trajectory function course speed courses were analytically described – fig.2. – and acceleration. After setting appropriate values frequencies were counted, stiffness and proportionate damping of the vibrating point. Similarly vibrating parameters of gravid abdomen in horizontal plane were gained with the help of tensometric belt. Basic wakening parameters were detected by tensometric platform Kistler. Ultimate strength point of myometrium was set experimentally with twelve samples of transverse, lengthways and oblique sections.

Results

Cinematographic method

Umbilicus kinematics was being solved. Wakening impulse with short length of lasting, with possibility of neglecting the shape of impulse course and theoretical value max. 6,4 Ns. Weight of vibrating abdomen was m = 5,l kg. .

Four models were constructed for cinematic data. These models were made more and more precise and gradually represented models accepting more qualities of organisms *in vivo*. Gradually systems with free subcritical vibration of damped complex (pregnant abdomen) were modelled with one free grade. Further models then accept more the solution of characteristics of strongly damped, aperiodic, overcritical damped vibration of gravid uterus and topically appropriate organs as a whole. Further model is represented by the model of supracritical constant damping. The last model, the results of which we are presenting is represented by the model of vibrating complex with damping parameter depending on actively changing damping (nonmonotonous functional dependence, Fig. 2.) – which is biological reality of alive vibrating system of gravid uterus and topically appropriate organs.

They are active changes of also biological parameters of appropriate tissues that may be actively corrected depending on for instance, perception and estimatation of the following situation under impact load of a body in interaction with surroundings. The result of this model of a following movement is a complex of directing equations like this:

$$m\ddot{x}+b(b_0+b_1\dot{x}+b_2\dot{x}^2+...+b_k\dot{x}^k)\dot{x}+kx=0$$

The unknown is stiffness k and the second unknown is a constant b by which polynom of damping (depending on speed) is multiplied. The solution leads to pregiven complex of linear equations with two unknowns.

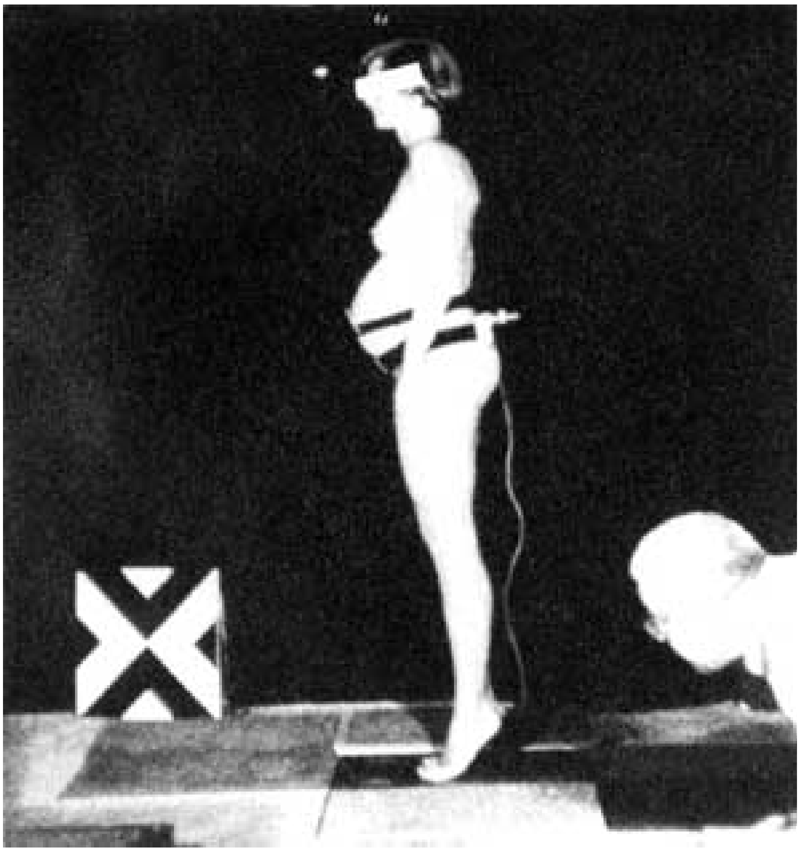
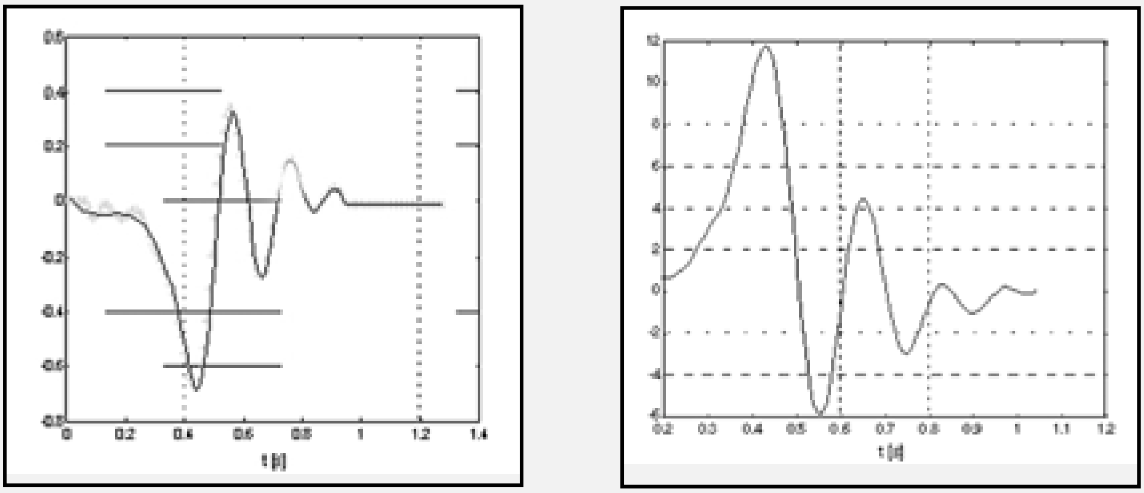


Fig. 1. Experimental surroundings. Synchronized methods cinematographic, tensiometric and dynamographic.

Fig. 2. Speed and damping in model M3B for moving body GUTO m = 5.1 kg for data from film recording.



First derivation of a trajectory-speed, after modification: PAM – v [ms $^{-1}$]

The course of active damping: active damping: – b [Nsm^{-1}]

Model M3B with active damping. Its course is approximated by polynom of 30.grade-similarly to the course of speed.

Stiffness of the complex:	k = 302,4	Nm^{-1}:	
Absorption of the complex:	b = –6 to 12	Nsm^{-1}	– **functional dependence** (the sign means direction of damping)
Frequency of the complex itself:	Ω = 7,7	Hz.	

Tensometric method

At first stiffness of the measuring belt was set with the help of dependence of deformation on extending strength to 0,37 Nmm^{-1}. From the recording of measurement on tensometric belt Myodat fig.3. parameters of damped vibrations GUTO were counted in horizontal plate.

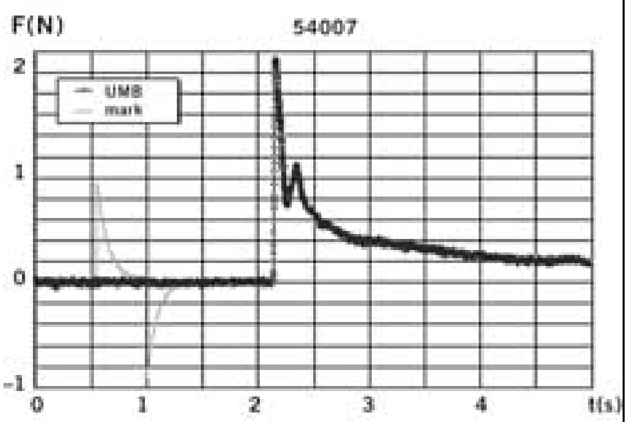


Fig. 3. Laparoseismographic recording of vibrations GUTO.

Reaction of an underlay on tensometric platform Kistler

The recording of the course of vertical interaction strength between underlay and a sole of a gravid woman is on fig. 4.

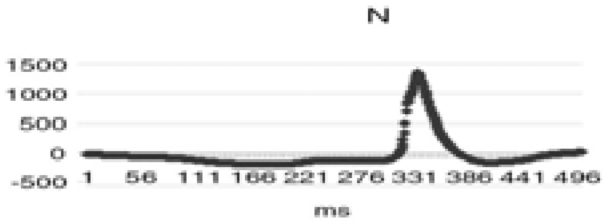


Fig. 4. Impact fall on the heels – reaction F_Z [N].

Frequency Ω, damping ξ and stiffness k of the system are derived from the relations for harmonically damped motion. Basic equation of this motion is:

$$y(x)=v_0 \cdot e^{-\xi \cdot x} \cdot \sin \bar{x}$$

Parameters of the harmonic damped motion are:
T ... time of one period (we read from recording)
v_0, v_1 ... following amplitudes of motion (we read from recording)

Frequency Ω resp. coefficient of damping ξ derived from relations:

$$\Omega = \frac{1}{T}, \qquad \nu_1 = \nu_0 \cdot e^{-\xi \cdot T}, \qquad \xi = -\frac{1}{T} \cdot \ln \frac{\nu_1}{\nu_0}$$

Stiffness of the system k is then:

$$\Omega_B = \sqrt{\frac{k_B}{m_B}} \Rightarrow k_B = \Omega_B^2 \cdot m_B \qquad \text{... for abdomen}$$

$$\Omega_C = \sqrt{\frac{k_C}{m_C}} \Rightarrow k_C = \Omega_C^2 \cdot m_C \qquad \text{... for soles}$$

The described state may be schematically represented by fig. 5.

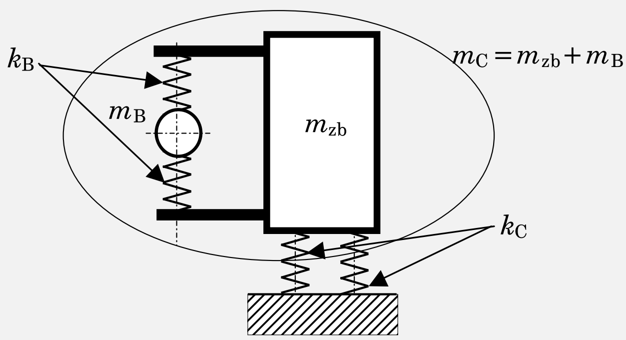


Fig. 5. Stiffness of system abdomen and rest of body.

k_b ... stiffness of abdomen
k_c ... stiffness of system
m_b ... mass of abdomen
m_{zb} ... mass of rest of system
m_c ... mass of system

Frequences, dampings and stiffneses are in the table 1.

Table 1. Characteristics of the system.

	Parameters	No. 54007
STRIP	Ω_B [s^{-1}]	5,417
	ξ_B [s^{-1}]	12,069
	k_B [Nm^{-1}]	146,7
PLAT FORM	Ω_C [s^{-1}]	6,289
	ξ_C [s^{-1}]	15,073
	k_C [Nm^{-1}]	2729,3

Damping was set at values:
b_b = 123,1 Nsm^{-1} – tangent damping,
b_c = 314502 Nsm^{-1} – transversal damping

By comparison of signals on the desk in peace state and during fall we get overloading that starts in the area of soles at the moment of the fall from the known height (about 80 mm).

$$\frac{s_{drop}}{s_{still}} = \frac{1374}{616} = 2,23$$

In the sphere of dynamographic data – KISTLER platform – parameters for basic impact wakening of the whole gravid body system during interaction with the underlay, simulating impact similar to sliding on the stairs.

Table 2. Samples of myometrium strips used in the tear-test.

Sample no.	cross-section dimension	resultant force	ultimate strength	ultimate strength – average [MPa]	
characteristics	[mm]	F [N]	ν [MPa]	each type of section	all sections
1. cross-section	11 x 3	36	**1,0909 max**		
2. cross-section	15 x 5	30	0,4000		
3. cross-section	10 x 2	14	0,7000	**0,6243**	
4. cross-section	13 x 9	34	0,3063		
5. bevel section	16 x 9	32	0,2222		
6. bevel section	15 x 5	24	0,3200		**0,3334**
7. bevel section	16 x10	20	0,1250	**0,2114**	
8. bevel section	16 x 7	20	0,1785		
9. longitudinal section	15 x 4	16	0,2666		
10. longitudinal section	17 x 8	20	0,1470		
11. longitudinal section	15 x 8	12	**0,1000 min**	**0,1645**	
12. longitudinal section	16 x 5	13	0,1444		

ν – ultimate strength [MPa]
F – specimen limit strength [N]

Basic values of maximum deceleration of the simulated fall down to the heels from a stair step reach the level of 2.2G (1511 N) and impulse of 40 Ns with the time period of 60 ms.

Strength of Myometrium

The prerequisite for a detailed simulation of the impact load upon myometrium is awareness of its basic characteristics. 12 myometrium samples were used in the tear-test to obtain the strength characteristics, see table 2 above.

The tear-test outcomes imply that in the samples tested:

- the ultimate strength ranges between 0,1–1,1 MPa,
- cross-section of samples exhibits strength 4 times higher than in longitudinal section,
- the average value of the ultimate strength in the samples tested is 0,333 MPa,

Discussion

Vibration of the gravid abdomen results from the gravid woman's movements (physical activities), shocks or other mechanical interactions with the environment, in all possible directions. In the upright position, the abdomen, cambering forward, is in constant mechanical contact with other objects, which causes increased risk of mechanical exertion, which may affect the pregnancy. Unfortunately, when testing and analysing the impact, the analysis cannot be applied to animals, as the erect position associated with a specific position of the uterus can be found only in humans [10]. The experiment should represent a common type of impact corresponding to a probability of everyday risk gravid women are exposed to. The experiment simulated walking down the stairs and household jobs. This relatively small impact provides information, which can be used in modelling a threshold-exceeding impact. The experimental structure of the impact upon GUTO – simulated by falling on the heels after standing on tiptoe – shows that hard and soft tissues are affected in the upward direction.

Reaction of the pad the woman stands on, exhibited an impact of 40 Ns impulse and exciting impulse of 6,4 Ns in the abdominal area. In cranial transmission of the exciting impulse, the impulse is damped. Decreasing the exciting impulse results from gradual damping of all lower body segments – the ankle, knee and hip joint, sacroiliac connection and individual vertebras with all components. The damping is supported by flexibility of bones, joints, joint cartilage, fascia, inter-vertebral disc etc.

The uterus in its caudal part is fixed by sacrouterine ligaments and follows the downward movement. The cranial part of the uterus, which is not fixed in this way, displays greater vibration, hitting the flexible abdominal walls. The impact of the inertial motion of spleen, liver and intestines including the content, affects the associated ligaments in a similar way.

This factor is also important when considering a biological aspect of the parameters measured: frequency Ω describes resonant frequency of the uterus system and its attachment to os sacrum. Rigidity k – rigidity of all absorptive attachments of the uterus, k_b – damping effect of topically relevant organs on the uterus' movement particularly represented by the whole frontal abdominal wall in the vertical direction.

The frequency of the gravid uterus and topically relevant organs in the frontal plane of vibration is app. 8 Hz. It implies high sensitivity to resonance especially for this frequency. **The resonant zone is considered one of the high-risk zones for the foetus.** Mechanical vibration of low frequency, related to associated organs, may result in separation of them, which may cause e.g. abruptio placentae. It may often occur despite the fact there was no direct impact on the gravid uterus. The vibration may lead to separation of the amnion in the lower segment and cause amniotic fluid outflow. It may also lead to premature contractions, which usually follow the Hamilton's touch. The vibration may induce entero-uterine reflexes, leading to uterine contractions. The system's vibration may also cause transmission of foetal blood cells into the blood circulation of the gravid woman. Critical exciting frequency may occur when travelling by means of transportation etc.

The vibration frequency of GUTO varies in the inter- and intra-individual aspect. It has to be taken into account that a simple mechanical interpretation may lead to inappropriate simplification, as the functional unit observed in the response (GUTO) is composed of various tissue types. In inter-individual characteristics differences in the composition of topical tissues and organs are relevant, as well as the actual state of muscle tonus and active changes in muscle contractions. Some of the characteristic points, as it is present in intra-individual assessments, may be changed by voluntary and involuntary mechanisms during the course of impact load. It concerns one of the very important characteristics of the biological system – adaptation. The adaptation also involves improvements of mechanical characteristics of tissues (e.g. muscle tissues – increase in the resulting muscle strength, ligament bone and other tissue characteristics, etc.) as a response to the load. It also involves various types of reflexes – their changes, anticipation of expected interactive situations, changes in reological characteristics of tissues, biochemical and bioelectrical changes, etc. In other word anisotropic structures of biological materials do return back to the initial state after they have been unloaded, which means there is no unique reference system describing stress-deformation relation.

Frequency reflects also other quantities – stiffness k and the weight of the uterus with the foetus m. This implies that with *changes in the weight of the uterus and its mechanical characteristics, e.g. in multiple pregnancy, the frequency of the whole system will change.*

Conclusion

As seen from the biomechanical viewpoint, this is a pilot study, introducing new approaches (biomedical engineering) to obstetrics, which have been neglected. This approach objectivizes, makes precise and enhances theoretical knowledge necessary for preventive care in pregnancy. The practical outcomes can be noted in obstetric implications, work and leisure activities and in transportation traumatology.

The parameters obtained contribute to the modelling of load in pregnancy, which will be further described in our following studies.

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REFERENCES

1 Ali J,Yeo A, Gana TJ, McLellan BA. Predictors of fetal mortality in pregnant traumapatients. J Trauma 1997; **42**:782–5.

2 Pearlman MD. Automobile crash simulation with the first pregnant crash test dummy. Am J Obstet Gynecol 1996; **175**:977–81.

3 Pearlman MD. Motor vehicle crashes, pregnancy loss and preterm labor. J Gynecol Obstet 1994; **57**:127–132.

4 Schneider H. Trauma und Schwangerschaft. Arch Gynecol Obstet 1993; **253**:suppl.4–14.

5 Siegel JH, Mason-Gonzales S, et al. Causes and costs of injuries in multiple trauma patients requiring extrication from motor vehicle crashes. J Traum 1993; **35**,920–31.

6 Wallace C. General practitioners knowledge of and attitudes to the use of seat bealt pregnancy. Ir Med J 1997; **90**,63–64.

7 Kerr MG. The mechanical effects of the gravid uterus in late pregnancy. J Obstet Gynec 1965; **72**:513–529.

8 Jelen K, Otahal S, Dolezal A. Mechanic behaviour of a pregnant uterus under impact load. Abstracts of XVII th Congress of ISB; 1999 Aug 8–13; Calgary, Canada. Calgary: 1999; pp. 806.

9 Jelen K, Otahal S, Dolezal A, Reznicek J, Turkova Z, Vilimek M. Vibration frequency of the gravid uterus and topically related organs.Proceedings of 40th international conference experimental stress analysis; 2002 Jun 3–6; Prague, Czech Republic. Prague: Czech Technical University in Prague Faculty of Mechanical Engineering Prague; 2002; 125–139.

10 Crosby YWM, Snyder RG, Snow CC, Hanson PG. Impact injuries in pregnancy. Am J Obstet Gynec 1971; **284**:100-108.