ORIGINAL ARTICLE

Changes in attenuation characteristics of axial system of pregnant drivers detected by the TVS method

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Abstract

OBJECTIVES: During a longer car drive there are changes in rheological properties of driver's or passenger's connective tissues taking place as a consequence of monotonous and vibration load. These changes show more among the pregnant drivers, whose motion system is under heavier demands due to pregnancy. To asses these changes we have used the TVS (transfer vibration through the spine) method.

METHODS: The TVS is based on application of γ excitation pulses with half-length 5 ms and then harmonic excitation continuously periodically changing from 5 Hz to 160 Hz on C7 and L5 vertebrae. This wave is transferred along the axial system and the acceleration of all the spinous tips of the vertebrae, along which the waves spread between C7 and S1, is detected by accelerometric sensors. The measurement was carried out on three drivers before and after a 4-hours driving. The same measurements of wave transfer along the spine with just one pregnant woman were carried out in th 16^{th}, 26^{th} and 32^{nd} week of pregnancy. Consequently we constructed a simplified model of the spine in order to analyze gathered data by discovering elementary properties of the measured system.

RESULTS: After both vibration and physical load there is a more significant dampening of the spinal tissues apparent, i.e. lower acceleration amplitude and the tissues resonance frequency also shifts towards the lower frequencies. On the other hand after long lasting relaxation on a bed an opposite tendency showed, the acceleration amplitude was higher, tissues were relaxed and dampening was lower. The same tendency manifested among the pregnant women. The influence of progressing pregnancy on the spinal segment transfer function showed through a shifting of peaks above 20Hz. Their size also changes monotonously. An absorption area moves towards higher frequencies, rigidity of axial system connections grows.

CONCLUSION: The results say that drivers, including pregnant women, show changes in mechanical properties of examined tissues before and after vibration or other type of load. Or conversely before and after relaxation on a bed. Results of this work will be further analyzed, verified and evaluation procedures will be improved. We expect to find dependencies between excitation and resonance frequencies during the transfer via the axial system, the rheological properties of the axial system components and the physical nature of the load of the axial system. They are then going to be applicable for the prevention of injuries of the axial system, physiotherapy practices in the rehabilitation of post-operative conditions, the dosage of training loads of athletes, in determining the effects of job stress regimes and their prevention.

INTRODUCTION

Many shape and tissue changes as well as changes of rheological properties especially in the abdomen and uterus, but also in other parts of the body, occur as a result of pregnancy among pregnant women. Partial load of the spine changes along with pelvis position, some postural muscle groups develop and woman's body weight increases. As a result of these changes greater demands on the musculoskeletal system of a pregnant woman arise. The consequences of static monotonous and vibration loading show when driving in the car. To demonstrate the mechanical (or rheological) changes in connective tissues as a result of vibration and monotonous loading among pregnant drivers we used the TVS method Marsik (2011). Same measurements took place also among nonpregnant subjects and their characteristics were compared.

Discussions in the literature regarding the characteristics and parameters of a pregnant body relates particularly to enlarging the lumbar lordosis and weight gain in pregnancy and their effect on low back pain in pregnancy. There are several methods for measurement of biomechanical properties of cartilage (intervertebral discs) on macroscopic scale. Knowledge of parameters yielded from this method seems to be crucial for construction of artificial tissue (Varga *et al.* 2007).

Fast (1987) interviewed 200 women from 24 to 36 hours after birth. The questionnaire contained 34 items relating to personal data, the presence and manifestation of low back pain, the interviewed were asked to mark the painful areas on the anatomical diagram. Patients were not examined. 56% (112) patients complained of back pain, while 44% (88) did not suffer from back pain during pregnancy.

Although Fast did not measure change of lumbar lordosis during pregnancy, he considers that quickly developed lordotic posture in pregnancy changes the load distribution in motion segment and therefore places increased demands on trunk muscles. Stretched abdominal muscles and shortened back muscles are in a mechanical disadvantage and are unable to withstand the demands that are placed on them due to postural changes and the increased load. Another factor which according to Fast (1987) may contribute to back pain is the ligaments relaxation and tension in the SI. The relaxation of ligaments during pregnancy is caused by the secretion of the hormone relaxin. It is engaged in the remodeling of collagen in target tissues, which includes the symphysis. The hormone changes rheological properties of the pelvis due to the presence of the growing fetus and future delivery. Fibrous and hyaline cartilage are the parts of intervertebral discs and play an important role in their biomechanical properties (Filova *et al.* 2008).

Berg (1988) obtained 862 completed questionnaires. 79 of these 862 pregnant women (9%) were monitored and treated by orthopedic surgeons because of severe pain. SI dysfunction was found by orthopedic surgeons in two thirds of women with severe back pain. Symphysiolysis was significantly more frequent among women with SI joint dysfunction than among women without back pain, which supports previous assumptions that hormonal effects are an important cause of pelvic instability. Berg also assumes that pregnancy is the etiological factor for the development of disc protrusion in the lumbar spine.

Increased relaxation of peripheral joints in pregnancy, which he assumes to lead to larger prolongability of collagen was proven by Östgaard (1993). Östgaard was examining some simple biomechanical factors specific to pregnancy among 855 women, monitored their progress and assessed their impact on back pain during pregnancy. Furthermore, some parameters were recorded at birth, which relate to the flexibility of collagen tissues. Complaints of pain collected via a questionnaire during pregnancy were correlated with large sagittal ($r=0.15$, $p<0.01$), transverse ($r=0.13$, $p<0.01$) and abdominal dimensions and great lumbar lordosis ($r=0.11$, $p<0.01$). The results also show that lumbar lordosis was the only parameter which did not significantly change between 12th and 36th week and the resulting correlations were weak. That concludes that women with normally greater lumbar lordosis are more likely to be prone to back pain during pregnancy. Östgaard assumed that the change in peripheral joints freedom will reflect the increased relaxation of spinal joints, which is present among all pregnant women as a necessary preparation for delivery. Freedom of peripheral joints (detected by laximeter on the 4^{th} finger using force of 1.7 N) was significantly changed during pregnancy, particularly between 12^{th} and 20^{th} week. However, the increase in the relaxation of peripheral joints during pregnancy was not uniform for all pregnant women and occurred primarily among first-time mothers. The results also show that the increased relaxation of joints does not return to a completely original condition after delivery. Increased collagen prolong ability caused by hormone relaxin and estrogen generally affects the ability of collagen tissue, which includes ligaments and intervertebral discs of the spine, to resist prolongation during pregnancy. The composite scaffold based on collagen/hyaluronate/fibrin showed biomechanical properties similar to hyaline cartilage and intervertebral disc (Filova *et al.* 2008).

Work of Yung-Hui Lee (1999) confirmed the changes in posture of the pregnant in sitting position. The increasing volume of the abdomen requires the bigger upper body forward inclination and an increased extension of the hip. To reduce the load in the back the most fitting was the seat pitch increased by ten degrees. Similar changes of posture while working in a sitting position are confirmed by Nicholls (1992).

On the other hand, an article by Gilleard (2002) did not show any changes in the upper body posture among pregnant women. The study included 9 pregnant women and 12 nonpregnant women as control group. The pregnant group was tested at 18 weeks, 24 weeks, 32 weeks, 38 weeks of pregnancy and then 8 weeks after delivery. The control group was tested at the beginning, re-tested after 16 weeks and 32 weeks.

200 women were interviewed at work (Nicholls 1992) during the 3rd trimester of the first pregnancy and fifty of them also for the second time – 4 months after delivery. The questionnaire covered 46 common tasks, their comparison and evaluation of the degree of difficulty of their performance before and after delivery. Additional information concerned factors affecting the individual activities, such as discomfort and fatigue. Data were analyzed to identify activities that were affected by pregnancy the most and the least.

Twenty activities were considerably difficult. Concerning the car 70% of subjects had a problem with clumsiness while getting out of the car, while bending, turning and lifting the body against gravity.

Cheng (2006) tried using the questionnaires to identify the major components and influencing factors in the difficult tasks performed by pregnant women employed in education, health and services. Subjects were working women in the 20th and 34th week of pregnancy, which also filled in a specially prepared questionnaire in the 20th and 34th week. In this questionnaire (Task Description Questionnaire) 44 subjects described 105 problematic tasks which subjects had difficulties performing. The recorded tasks were divided into 9 categories according to biomechanical and ergonomic point of view.

From our perspective is important that the uncomfortable position was the second most important influencing factor in difficult tasks in the 20th week of pregnancy. In the 34th week the uncomfortable position ranked the first. This is important from the perspective of long-term monotonous load such as when driving a car, where the pregnant has no possibility to change the position and the seat ergonomics is adjusted to the average driver and not the pregnant woman. In contrast, vibrations ranked the last place among both groups (20^{th} and 34^{th} week).

Muscle strength parameters in pregnant women may possibly be influenced by several factors such as regular exercise or supplementation. Pregnant are advised to supply extra-doses of float and B12 vitamin as a congenital defects prevention e.g. neural tube defects. These vitamins have been shown to affect a skeletal muscle metabolism showing some pro-anabolic properties (Navrátil 2001; Petr 2011).

MODELING OF VIBRATORY LOAD AMONG PREGNANT DRIVERS

Pope (1998) deals with the effect of vertical and horizontal vibrations on pregnant women in his study. A previously used electrical simulation and experimental verification of the developed mechanical model had been used for this study. The human body (see Figure 1) was modeled by a mechanical model subjected to vibrations coming from:

a. the steering wheel or
b. from the seat or
c. both – from the steering wheel and the seat

From the results of previous studies (Pope 1992, 1990, Wilder 1985) is clear that the worst effect comes from the combination of vertical and anteroposterior movements. Vibrations are the worst if their frequency range is between 1 and 15 Hz, the human spine resonates around 4–5 Hz in the longitudinal bending mode.

From the results of a study by Pope (1998) is clear that with increasing degree of pregnancy the effect increases of the various parts of the body to "energy gain" G varies by the type of vibration (horizontal or vertical) and the input source of vibration (steering wheel, seat, or both). This can be explained by the progressing pregnancy the abdominal momentum greatly increases, while for the other parts it remains only slightly elevated. Therefore, the abdomen acts as a damper for some vibrations, which in turn reduces the effect of vibrations on other body parts.

G is defined as the ratio Fo / Fi.
Fo – output power,
Fi – input power.

Gain is positive if the ratio is greater than one and negative if it is less than one.

This work is unique because it is the only one dedicated to vibrations effects on the pregnant. The disadvantage of this work is that a previously developed electrical simulation of the mechanical model has been used. This represents a kind of simplification, for example, a chest is very simplified whose stiffness varies with each inhalation and exhalation. For the pelvis the biomechanical (rheological) properties of the abdomen, uterus and ligaments holding the uterus are changing with each week of pregnancy. A vaguely defined torso is also in the picture, apart from which there is the chest, diaphragm and uterus in the picture.

METHODS

Use of vibration transfer as a detection method for rheological changes to the system after monotonous and vibration load

In our experiment we used vibration transfer via an axial system as a method of detecting changes in rheological properties of axial system due to vibration and monotonous loading during long sitting in the car. Vehicle driving is probably the most frequent operator movement in society where errors can result in serious social, medical and economic consequences (Jelen 2011).

The detection of vibrational excitation transfer via the axial system was performed using TVS method (transfer vibration through spine) on three non-pregnant drivers before and after the four-hour car journey. The same measuring of the change of waves transfer via the spine was performed with a pregnant driver in the 16th, 22nd and 26th week of pregnancy.

The TVS method is based on applying excitation δ pulses of 5ms half-width and then harmonic excitation continuously periodically changing from 5 Hz to 160 Hz on C7 and L5 vertebrae. This wave is transferred along the axial system and the acceleration of all the spinous tips of the vertebrae, along which the waves spread between C7 and S1, is detected by accelerometric sensors.

In the detection of spinal response to the input excitation it is assumed that the wave transmission rate and attenuation are associated with parameters of the tissue which spreads the waves. The changes in mechanical properties of tissues can be re-characterized from the waves propagation velocity.

The measurement is carried out on a composite bed, which is damping vibrations of all excited frequencies. The measured subject lies facing the ground. Muscles are willingly as relaxed as possible. Breathing is spontaneous.

These assumptions were incorporated into a simplified model of the spine, which was compiled in order to analyze the measured data by specifying basic properties of the measured system. Based on measured data (input excitation and its detected response on the spinous tips of the vertebrae) and geometrical dimensions of the spine (height and radius of the intervertebral discs) can we evaluate the overall change in viscoelastic parameters of the spine before and after vibration or another spine loading. From the detected response (ratio of excitation amplitudes and the amplitude of the relevant vertebrae) and phase shift of the excitation signal on successive vertebrae the relations can be found between the overall elastic model of the spine and its viscosity. We developed the two significantly differed methods for the processing of data obtained by this method of measurement.

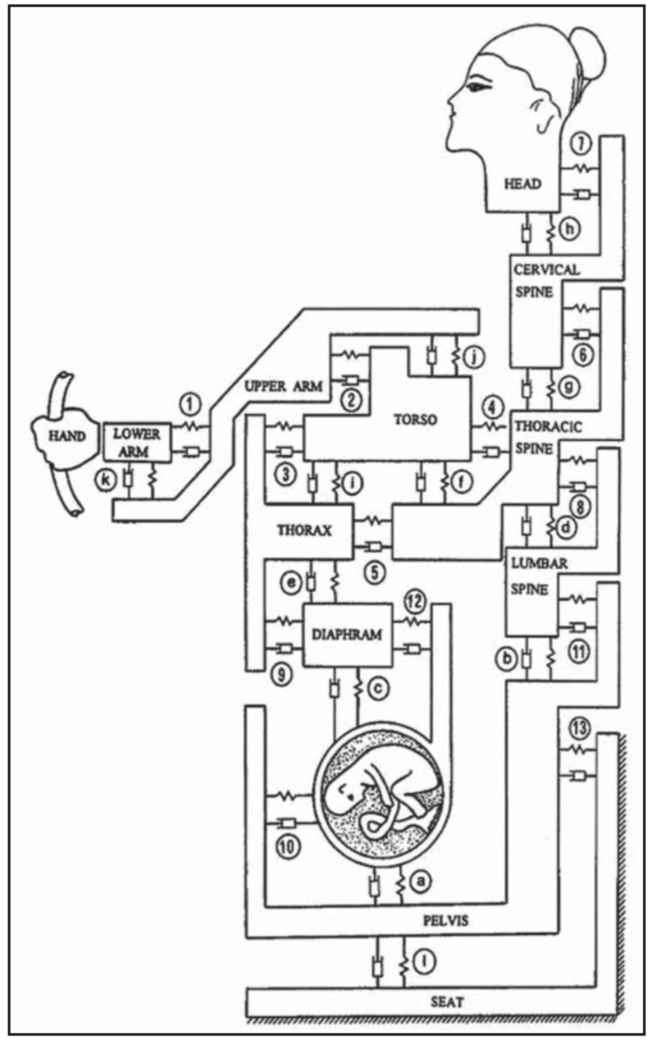

Fig. 1. In this model of Pope (1998) the mass of these segments was considered (L. A. - distal part of the upper limb, U. A. - proximal part of the upper limb, C. S. - cervical spine, H - head, T - torso, Th - chest, D - diaphragm, A - abdomen, T. S. - thoracic spine, L. S. - lumbar spine, P - pelvis). The system of flexible connections (spring-mass-damper) was represented by elastic constants of connective tissue between the individual segments. Mechanical parameters of individual body segments were taken from previous research. Mechanical models were simulated by corresponding electrical models based on direct analogy between the force and electric tension.

One way to analyze the measured data lies in the use of mentioned model and fitting the model parameters, i.e. attenuation and stiffness of individual model links, to the measured data. See, e.g. Machac (2011).

The second, principally different data evaluation procedure is to show the transfer functions of individual vertebrae. That we can show as an amplitude ratio and phase difference between excitation and excited signal for each excitation frequency. If we assume that the vibrations are transmitted only between the individual vertebrae in a row (which is a very good assumption for higher frequencies), we can the signal which is measured on the preceding vertebrae as the excitation signal. In this work we chose this procedure.

Fig. 2. Excitation of mechanical vibration at the C7; accelerometers picked up acceleration on all the other spinous tips in caudal direction.

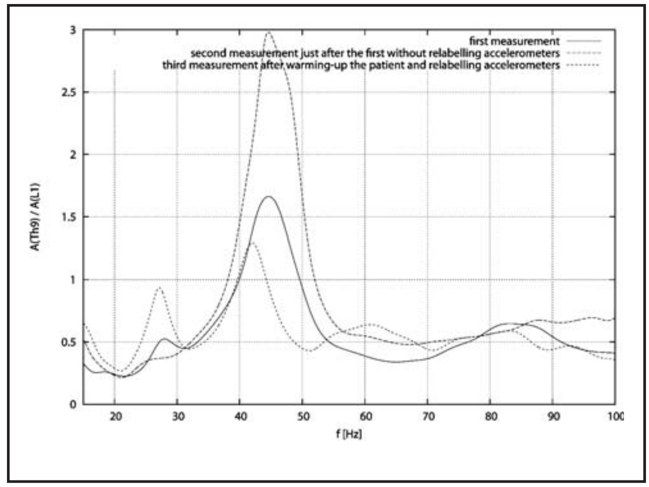

Fig. 3. Excitation of C7. TVS method measurement, changes of the subject (man) after a long relaxation without removing the accelerometers or on the contrary – after physical load – running up stairs – the third measurement – with re-attached accelerometers.

<u>Measurement procedure</u>

We scanned the sagittal oscillations of spinous tips of the spine of person lying on the vibration damping composite layer – see Figure 2. During this scan the C7 vertebrae were gradually vibration ally excited through the gauge and accelerometers picked up acceleration on all the other spinous tips in caudal direction.

Because of the results verification was the procedure repeated, but in the opposite direction. Excitation took place at the L5 and the accelerometers picked up the response on the spinous tips cranially. Each subject was tested in a series of these TVS examinations, between which the subject was exposed to physical load by driving the car.

<u>Evaluation</u>

As an example of the results we chose a sample of vibrations transfer between the L5 vertebra and middle thoracic vertebra Th7 (see Figure 5). These results remain valid between other pairs of vertebrae though, as shown in the following examples (see Figures 3, 4). The theory shows that for transfer of higher frequency vibrations only materials with high stiffness and low attenuation are suitable. Experience shows that even frequencies above 15 Hz are already dominantly transmitted primarily via the spine itself and its close surroundings, while the surrounding muscle tissue and ribs have primarily no significant influence on the transmission of vibrations with these frequencies – the spine vibrations are not transferred through them. Their effect is above all secondary, because they are keeping the spine in a state that is characteristic for the transfer.

RESULTS

The results of the analyzed data show the changes in mechanical properties of tissues of the axial system before and after load. After both either physical (walk-

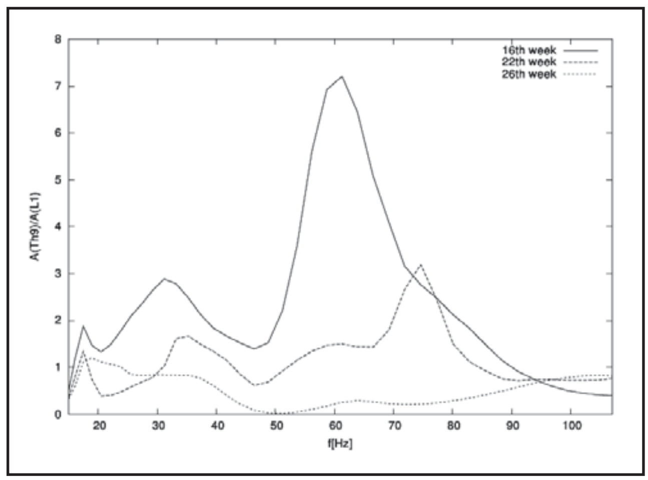

Fig. 4. Excitation of C7. Transfer of vibrations between Th9 and L1 changes significantly during pregnancy. Measurements were carried out in 16th, 22nd and 26th week of pregnancy.

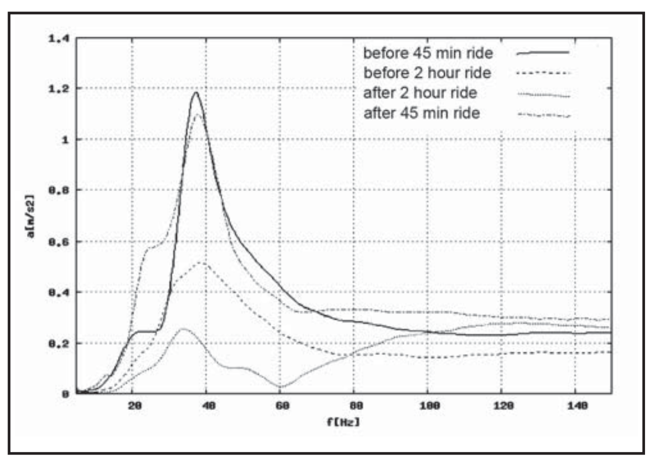

Fig. 5. Excitation on L5. Transfer of vibrations from L5 to Th7 for pregnant woman driver twice before driving and after driving.

ing under load, going up stairs) or vibration (driving in a car) loading a greater dampening effect spinal tissue is shown, i.e. the lower acceleration amplitude and resonance frequency of the tissues moves to lower frequencies (see Figure 3). In the 22 Hz area is the bending mode of section Th9–L1 3 times higher, the signal amplifies between Th9 and L1, the section does not dampen. By contrast, in the area of even multiple – twice the frequency of 22 Hz at 44 Hz, the vibration transmission is minimal, dampening is large. The same tendency occurs among pregnant women drivers (see Figure 5).

Conversely, after two consecutively repeated measurements (first and second measurement) by TVS method for the same driver, when he was lying relaxed for 1.5 hours during the measurement, the opposite trend showed – i.e. acceleration amplitude was higher, tissues were relaxed and the dampening was lower (see Figure 3).

In Figure 4 we can see a typical effect of progressing pregnancy on the transfer of the spinal segment. Virtually all peaks are moving over 20 Hz. Their size is also changing monotonously. Area of absorption is shifting towards higher frequencies, the stiffness of links of axial system is increasing.

After ride, like among the non-pregnant drivers, there is greater dampening and lower acceleration amplitude and resonance frequency is shifting to lower values.

CONCLUSIONS

The current works show that the vibration and monotonous load affects the state of the axial system, particularly of soft tissues, ligaments and intervertebral plates, but also carries on bone tissue. The human body is influenced mainly by low frequency vibrations that occur during monotonous loading in the car. To evaluate the transfer of vibrations through the human body both experimental measurements and modeling are being used, which leads to considerable simplification of the composition of individual body segments. In our work we used transfer of vibrations via the axial system as a method of detecting changes in its mechanical properties after repetitive vibration load in a car or after physical activity or conversely after a long relaxation of pregnant and non-pregnant subjects. For example, after 1.5 h of rest the dampening of the reference section of the spine L1–Th7 almost doubled for the driver. The results show that the axial system vibration transfer varies depending on the mechanical properties of the section, through which vibrations travel, among both pregnant and non-pregnant subjects. The results show that the drivers including pregnant women show a change in mechanical properties of examined tissues before and after vibration and other type of load, or vice versa, before and after long relaxing on the bed. For example for pregnant woman driver does the resonance zone of Th9–L1 segment shift from the value 38 Hz before driving to 34 Hz after 2 hour drive and the damping decreases by about 55%. Ongoing pregnancy has a significant influence on the position of the resonance peaks of individual spinal segments. Along with the pregnancy duration the dampening increases between 16th and 22nd week by about 60% and the resonance band is shifted from 60 Hz to 80 Hz in this period. Generally the stiffness of the reference section increases with the square of the frequency shift.

Results of this work will be further analyzed, verified and evaluation procedures will be improved. We expect to find dependencies between excitation and resonance frequencies during the transfer via the axial system, the rheological properties of the axial system components and the physical nature of the load of the axial system. They are then going to be applicable for the prevention of injuries of the axial system, physiotherapy practices in the rehabilitation of post-operative conditions, the dosage of training loads of athletes, in determining the effects of job stress regimes and their prevention.

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