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Possibilities of objective identification of meniscoids in joint blocks of the axial system, by MRI and Transfer Vibration through the Spine

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Abstract

OBJECTIVE: The aim of the study was to identify the meniscoids of the cervical spine using in-vivo MRI imaging and to determine their potential role in the development of functional joint blocks of the axial system (AS). Another objective was to find out how the articular blocks affect the rheological properties of the spine by the Transfer Vibration through the Spine (TVS) method.

METHOD: In this study were used methods TVS and MRI. The study was conducted on a research file of 12 subjects and was conceived as a pilot one.

RESULTS: It has been shown that the MRI method, in appropriate circumstances, enables the detection of changes in the size and shape of meniscoids in-vivo. On the basis of the investigations carried out, it can be assumed that several mechanisms are involved in the formation of functional joint blocks, and are not primarily caused by the incarceration of meniscoidal tissue. Using the TVS method, it has also been found that a functional articular blockade affects the rheological properties of the axial system, specifically reducing the damping capabilities of the particular spine segment.

CONCLUSION: In the follow-up studies, it will be necessary to verify the theoretical interpretations on a larger statistical set.

INTRODUCTION

The functional joint block is a common clinical term that denotes joint dysfunction, which need not be accompanied by a structural disturbance. In the second half of the 20th century, the foundations for its comprehension were laid down by the description of joint meniscoids (Tondury 1948; Emminger 1967; Kos & Wolf 1972) and barriers (Kimberly 1980). From a phenomenological point of view, a functional joint block is defined as a "joint play" limitation. Thus, it can be looked at as a limitation of passive movement in the joint (in the sense of the shifting, rotation or distraction of the joint surfaces) upon reaching the physiological barrier of the respective articulation.

From the pathophysiological point of view, the functional joint block is a reversible state. It is manifested by muscular hypertonia, the trigger points in its surroundings, furthermore by pain and the reflex chaining of disorders affecting the surrounding soft tissues and internal organs (Lewit 1968). If the blockade occurs on the spine, it will cause hypomobility in the segment. However, because of the compensatory hypermobility of the axial system segments above and below the blockade, the overall motion of the spine need not be limited. In a chronic blockade, we can also observe the structural changes of the spine as a reaction to long-lasting changes in the muscle tension and surrounding tissues (Kříž & Majerová 2009). Malátová and others carried out a study with the help of an instrument called a muscle dynamometer, which enables detailed information about muscle activity in the deep stabilisation spinal system (Malátová *et al.* 2007; Malátová *et al.* 2008). The joint blocks can be successfully treated with so-called manual therapy using mobilization and manipulation techniques.

The pathogenesis of the formation of functional articular blocks of the axial system has not yet been satisfactorily explained. Lewit (2003) demonstrated through an experiment, conducted in patients with narcosis, that its entity is of a mechanical nature. One of the possible causes of a blockade may be so-called meniscoids. Their existence is demonstrated by anatomical studies of the intervertebral joints of the spine (Kos & Wolf 1972; Kos *et al.* 2002; Engel & Bogduk 1982; Webb *et al.* 2011a; Webb *et al.* 2011b; Yu *et al.* 1987). According to the meniscoid entrapment theory (Digiovanna 2005), the apex of these fibrous folds can get wedged between articular surfaces and stuck there (Kos *et al.* 2002).

From the available studies, the meniscoids are known to be articular capsule and synovial membranes protrusions. The meniscoids are established early in the fetal period and are found in all the intervertebral joints of the spine (Schmincke & Santo 1932; Kos & Wolf 1975). They help with the joint stability and the decomposition of pressures acting in the joint by balancing the incongruence of the joint surfaces. They lubricate the articular cartilage by the secretion and reabsorption of the synovial fluid. The shape, size, and location of the meniscoids are considerably individual. Engel and Bogduk (1982) categorized them histologically into three types: fat pads, fibro-adipose meniscoids and capsular rims.

Fat pads are typical for atlanto-occipital joints, their wide bases are attached to the joint capsule and the free rounded edges projecting towards the centre of the joint. They consist primarily of adipose tissue, loose connective tissue and blood vessels. Fibro-adipose meniscoids occur most frequently throughout the cervical spine. The wider base passes into a thin free apex which extends between the articular facets and is freely mobile over the articular cartilages. The core of the base consists predominantly of adipose tissue infiltrated with the collagen fibers from the joint capsule. Sometimes, adipose tissue can be lacking and the base is formed by collagen fibres and blood vessels. The apical region and free border of the meniscoids are made up of collagen. Capsular rims are wedge-shaped structures around the marginal parts of the joint (Mercer & Bogduk 1993).

Meniscoids are innervated by small diameter nerves immunoreactive for neuropeptides which are involved in the transmission of pain. The apical part is collagenous and is not innervated (Inami *et al.* 2001). The presence of meniscoids is not sex-dependent and decreases with increasing age (Fletcher *et al.* 1990). With an incipient ankylosis, the meniscoids disintegrate and disappear (Kos *et al.* 2002).

An important fact for the *in vivo*-study is that meniscoids can be shown by the MRI method (Friedrich *et al.* 2007 and 2008). However, due to their size, these formations are at the very distinctive limit of the method. The mechanical properties of the axial system as a whole can be objectively assessed by the method of Transfer Vibration through the Spine (Panská *et al.* 2016).

Based on the meniscoid entrapment theory that has been conceived from the above findings, the following questions arise:

- Is it possible to detect the changes in the size and shape of meniscoids *in vivo* by using the MRI method, before and after the treatment of the functional joint block of the axial system using manual therapy.
- Does the manual therapy of the functional joint block of axial system have effects on its mechanical properties?

In connection with the research questions, the following main objective of the work was set: To find the possibilities of the objective identification of the cervical spine meniscoids and to determine their role in the pathogenesis of AS joint blocks. Furthermore, to find out how the joint block affects the AS rheological properties.

METHODS

The study is conceived as a pilot one. In view of the identified research questions, its design was divided into two separate parts. At first, attention was paid to the morphological nature of the problem (MRI method), then to the mechanical properties of the axial system (TVS method).

MRI method

Meniscoids and their shape changes were first investigated on anatomical preparations and their presence, size, shape and location in the intervertebral joints of the cervical spine were verified. The meniscoids found were evaluated in two ways. First, by the orthogonal view of the upper and lower facet, and also, in the sagittal section through the intervertebral joints of the cervical spine (Figure 1).

The follow-up MRI imaging of joints was performed at the Na Homolce radiodiagnostic department using

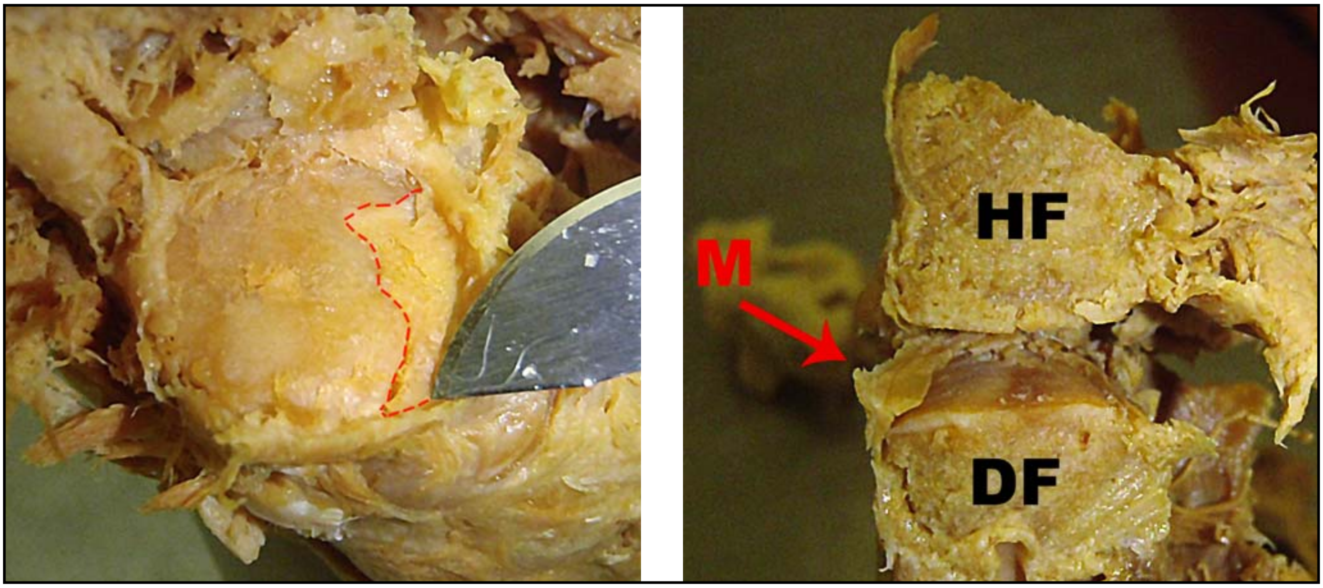

Fig. 1. a) Orthogonal view of the articular face of segment C3/4; **b)** In a sagittal section, meniscoids marked in red.

the Siemens Skyra (3T) apparatus. The examination of the meniscoids was focused on a cervical spine section. A high-density segment (32 channel) head coil was used, which also covered the atlanto-occipital junction. The initial investigations were conducted on anatomical preparations of two heads with the cervical spine. The in-vivo examination of the cervical spine was performed on ten subjects. The first three subjects were examined to determine the appropriate MRI setting and the in-vivo identification of meniscoids.

For the seven additional subjects, positively evaluated for the presence of functional joint blocks, the manipulation of cervical spine (from the head joints to the C/Th junction) was applied after the initial MRI examination. This was followed by the checking examinations. Using the sagittal sections, we evaluated the changes in the positions and shapes of the meniscoidal tissue.

At this point, it is worth mentioning that the visibility of the meniscoids depends heavily on the technical parameters of the device (the magnetic field strength, the pulse sequence selected, etc.), the properties of the segment under consideration (size, location, height, etc.) and last but not least on the motion of the person under investigation and other artifacts (breathing, pulsation) arising during the examination. The display of anatomical preparations was not limited by examination time and the artifacts associated with physiological movement. In this way, it was possible to test different MRI sequences (proton density, T1 and T2 weighted). For the linked up methodological (Nm=3) and comparative (Nc=7) investigations, the sequence *de3d* was selected. The sequence was set up with isotropic resolution, which enables reconstruction in any plane. Moreover, this sequence provided best contrast for imaging the meniscoids. The detection of MRI images on a given device with the mentioned sequence takes 6:53 minutes. This allows a full view of meniscoids, when using the localizer sequences, under 9 minutes. The time is extended by automatic auxiliary measurements of the inhomogeneity of the magnetic field with the instrument. The resolution of the sequence is $0.7 \times 0.7 \times 0.7$ mm. The acquisition is done in two parallel volumes (slabs), which are in distance of 20% of these volumes. In the direction of phase coding, the 100% oversampling is proven. In the Z-axis (i.e., cranio-caudial), the oversampling of 25% will do. There, 48 layers with a thickness of 0.67 mm, a repetition time of 15.58 ms, an echo time of 5.06 ms and a flip angle of 20 degrees are scanned.

In the strong 3T field, especially in devices with a wider 70 cm gantry, significant geometrical distortions may be present. Therefore we elected to apply K-space based correction (Siemens function) to improve the preciseness of evaluation of small meniscoids.

TVS method

The Transfer Vibration through the Spine (TVS) method is based on the ability of substances (tissues) to transfer their external force through their structure. If the exciting force is the pulse character, the pressure waves propagate through the affected tissue. They generate corresponding changes in the density of mechanical energy (Maršík & Dvořák 1998). This mechanical energy is, due to the viscoelastic properties of the tissue, partially absorbed in the form of elastic deformation and partially damped down (dissipated) by their viscosity. In addition, the velocity of the pulse wave transfer and its amplitude decrease are related to the parameters of the tissue, through which the wave passes (Kloučková *et al.* 2011).

As shown in Panská *et al.* (2016), it is possible, by the excitation of vibrations on the selected vertebra of the spinal system and by detecting their attenuation on other spinal segments, to assign objective mechanical parameters to the parts of the axial system under investigation (the modulus of elasticity and the dynamic viscosity). Specifically, for the viscosity μ [Pa.s] of the examined tissue, the relationship applies:

$$\mu = b \cdot f(\rho, \omega_r, \lambda) .$$

Thus, the viscosity of the respective segment of the axial system can be determined from the product of the value of the attenuation coefficient b [] and the function f that is partly dependent on the density ρ [kg.m^{-3}] of the tissue explored and partly on the resonance frequency ω_r [s^{-1}] of the standing wave of the wavelength λ [m]. The natural attenuation coefficient can be estimated from the approximation of the acceleration of the individual oscillating vertebrae (y-axis) at their distance (position) from the excitation source (x-axis) by the function:

$$y = Ae^{-bx} .$$

It follows from the above that, when the resonance frequency ω_r or the attenuation coefficient of the axial system segment monitored are changed, its viscosity changes as well (see Panská *et al.* 2016). These two selected descriptors of mechanical properties of tissues will be given attention to in the results section of the text.

In the experiment, two persons (N_{TVS}=2) with functional joint blocks diagnosed in the cervical spine (subject No.1 in the region $C_{3\text{-}5}$, subject No.2 in the region $C_{2\text{-}4}$) were examined. The vibration by excitation took place on the processus spinosus vertebra C_7. The transmission trough the axial system was scanned with the accelerometers located on the processus spinosus of the vertebrae C_6, C_5, C_4, C_3, C_2 and the occiput (Figure 2).

In order to avoid adaptive changes due to the neuromotoric reactions of the body to the mechanical load of the spine (van Dieen *et al.* 2003), periodic rising and falling frequencies from 5 to 180 Hz were applied and vice versa. The entire recording cycle lasted 3 × 3 minutes, i.e., there were 3 pairs of rising and decreasing sequences of excitation frequencies recorded.

As in the first case, the treatments of the cervical spine (from the head joints to the C/Th junction) were applied after the initial examination. A follow-up examination and evaluation of changes in the damping properties of AS was followed.

All the results of AS responses to mechanical excitation were processed, evaluated and graphically interpreted using an especially developed software.

RESULTS

MRI method

For all the persons under investigation (N_m=3, N_c=7), the presence of large wedge-shaped meniscoids was detected in the segment C1/C2, both from the dorsal and ventral joint parts. They equalize the convexly shaped articulation facies between the atlas and axis. For this segment, there is also a typical thicker layer of cartilage covering the articular joint facies and the hyperintense signal likely indicating the presence of a greater amount of synovial fluid in the joint cavity. In the other segments, smaller meniscoids were found, irregularly extending only from the dorsal or ventral side, or bilaterally. The decreasing signal intensity in the caudal direction and the movement artifacts of the investigated persons are the reason for reduced sharpness in the image in the lower parts of the cervical spine. No other patterns in the location and shape of the meniscoids in the lower segments were found.

In the scope of methodical examinations (N_m=3), a long thin tongue-like meniscoid was found in the C0/C1 segment, with its base on the dorsal side of the joint, which extended deep into the articular cavity (Figure 3). A similar finding was published in Friedrich (2008) and marked the state as an entrapment

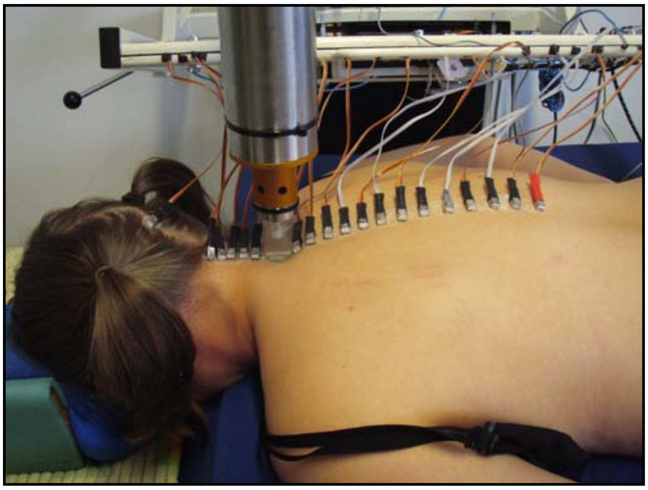

Fig. 2. Examination of the rheological properties of the cervical spine using the TVS apparatus.

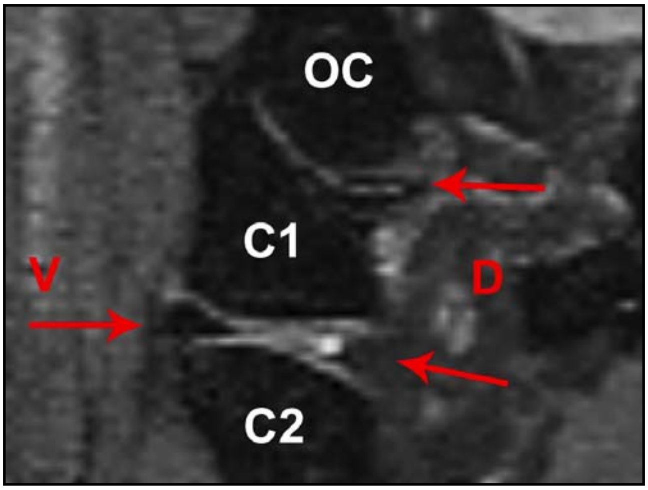

Fig. 3. Sagittal MRI section of the C0/C1 a C1/C2 segments. Meniscoids are shown with red arrows from the ventral (V) and dorsal (D) sides.

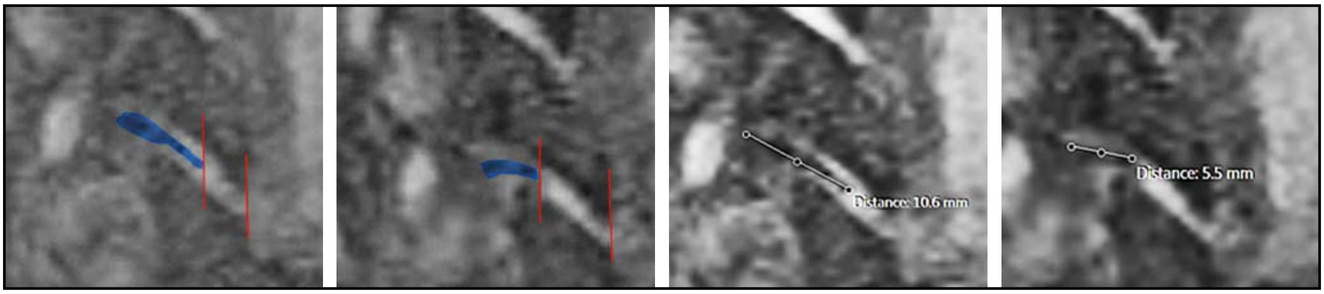

Fig. 4. The resulting shift of the meniscoid ventrally placed in the C6 /7 segment. Left before and right after the handling treatment application. The meniscoidal tissue is stained with blue color. In the space between the red lines, the residual volume (or its projection, respectively) of the joint cavity, caused by the slip of the meniscoid, is indicated. The scale is shown in the next figures.

Tab. 1. Changes in monitored rheological parameters before and after manipulation treatment.

Subject	**Before**		**After**	
	band ω_r^i (Hz)	**b ()**	**band ω_r^i (Hz)**	**b ()**
no. 1	110–150	0.28	40–160	0.39
no. 2	60–90, 130–170	0.20	50–175	0.47

Legend: Band ω_r^i – the frequency band range, where the resonance frequency ω_r^i occurs, b – the attenuation coefficient.

(see above). In this case, we did not apply manipulation treatment and check-ups, and therefore we cannot objectively claim it to be a trapped meniscoid. The MRI method was used inter alia by Masopust *et al.* To investigate the influence of perioperative Epidural Steroid application on the development of Epidural fibrosis (Haeckel & Masopust 2009).

In the case of comparative examinations ($N_c=7$) before and after manipulatory treatment, any differences in the storage, change in shape or size of meniscoids tissue were sought. As mentioned above, all seven persons were positively evaluated for the presence of blockades in the cervical spine. Manipulation was objectively accompanied by the acoustic phenomenon of joint cracking with a subsequent release of tone in the soft tissues and by increasing the range of movement in the cervical spine. The patients sensed a subjective relief, a decreased muscle tension, and an increased range of motion in the cervical spine.

In one patient, the MRI scanning was able to detect a shift of the meniscoid in the left intervertebral joint segment C6/7 from the ventral side. This corresponds to the meniscoid entrapment theory (Figure 4). Using manual segmentation of a meniscoid on a computer screen, it is possible to compare its size and location in the joint cavity before and after the manipulation treatment. It is evident that, in the case of pre-therapy, the meniscoid is bulky and extends deep into the articular cavity. The part of the joint cavity without the meniscoid is bounded with the red lines. During the manipulation, the articular casing is tightened and the meniscoid slides out of the articular cavity and thus looks to be relatively shorter. The volume of the joint cavity, without the meniscoid tissue, increases significantly after the manipulation. The Figure 4 shows that the displayed length of the meniscoid after manipulation was reduced to approximately 60% of its original length before handling.

TVS method

The summary results from the experimental survey ($N_{TVS}=2$) by the TVS method are shown in the graphs in Figure 5. The following findings arise from them. Before the manipulation treatments (graphs A and C), the strongest response of the vertebrae to the vibrational load in a defined range of excitation frequencies f is evident in both the investigations (cf. Table 1). Specifically, for the subject No. 1, this is the band of 110-150 Hz, for subject No. 2, this is at the intervals of 60-90 and 130–170 Hz. They also contain all the resonance frequencies ω_r^i of the system under study. Their values are identical to the corresponding excitation frequencies f^i and correspond, positionally, to the local extremes of individual curves. Thanks to 3D graphics, it is well-perceptible that these local extremes form one or two continuous ridges in the cases prior to manipulation treatment (A, C).

Conversely, in the cases after the manipulation treatment (graphs B, D), there is a strong dispersion of these local extremes or resonance frequencies, respectively. Depending on the individual vertebrae, they include 3/4 of the frequency band used (cf. Table 1).

From the observed dependencies (Figure 5), it is possible to determine the attenuation coefficient b of the entire cervical segment of the spine. The results are shown in Table 1. It is evident that in both the subjects, after the application of manipulation treatment, this parameter was increased. This result indicates an increase in the damping ability of the axial system due to manipulation treatment.

In principle, it is also possible, from the obtained data, to estimate the viscosity μ or its change. Here, however, it should be noted that this parameter is, inter alia, dependent on the resonant frequency of the entire segment. With regard to the heterogenity of the axial system as a whole, such a frequency of resonance

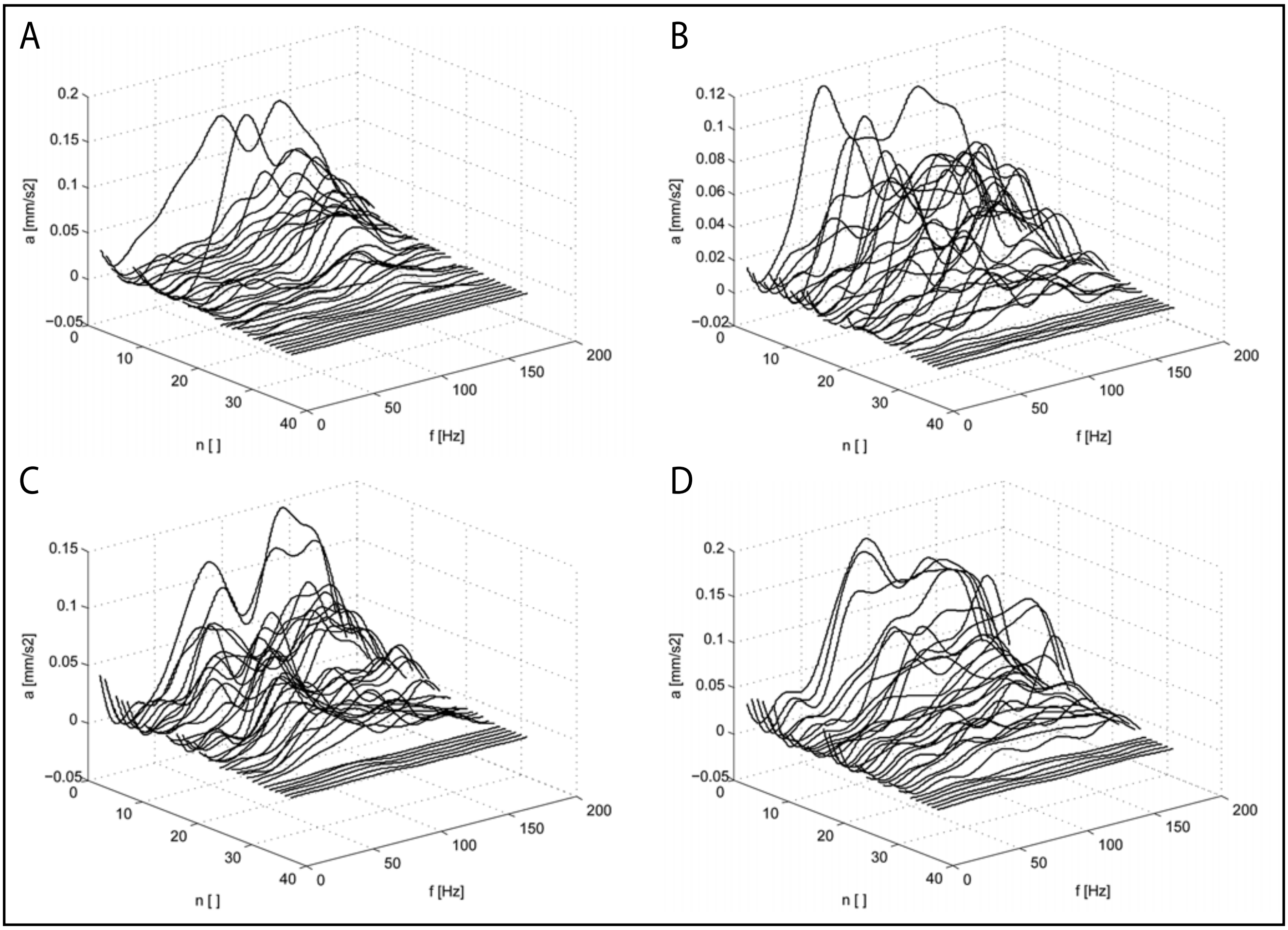

Fig. 5. Comparison of the results by the TVS method in the cervical spine. The 3D graphs show the responses (acceleration a) of each vertebra, depending on the excitation frequency f. To the left before handling, right after handling, the subject 1 at the top, the subject 2 on the bottom. The graph shows the results from the sensors on C6-C0 and always after 6 reps. The variable n has the following meanings: 1 to 6 measurements on C6, 7 to 12 measurements on C5, 13 to 18 measurements on C4, 19 to 24 measurements on C3, 25 to 30 measurements on C2, 30 to 36 measurements on C0. The resonance frequencies ω_r are displayed as the local extremes of the respective curve for each vertebra.

that suitably characterizes the whole system cannot be uniquely chosen. This is particularly noticeable in cases after the manipulation treatment (graphs B, D). These graphs show a distinctly higher number of own resonant frequencies of the monitored section than before manipulation. The increase in the number of individual resonant frequencies of individual vertebrae can be explained by releasing the appropriate joint block by the manipulation therapy applied. Therefore, this calculation of unambiguous viscosity determination in this section could not be made.

DISCUSSION

The aim of the research study was to objectify the role of meniscoids in the functional joint blocks of the axial system. From the initial experiments on MRI, the appropriate sequences were obtained to evaluate meniscoids of the cervical spine *in vivo*. Using the head coil at the apparatus with a magnetic field force of 3T, a cube volume resolution level of 0.7 mm was reached. The cranial sections of cervical spine were evaluated best, where the bulky meniscoids in the C1/2 segment were identified from both the dorsal and ventral sides of the spine.

In other segments of individual persons, the meniscoids were found irregularly in the left and right intervertebral joints of the cervical spine. They varied in sizes and locations – ventral, dorsal or bilateral. Due to the small sizes of meniscoids and the low image sharpness, caused by the movement artifacts of the investigated persons, it was not possible to identify meniscoids in some segments. It can be stated that the MRI method allows, under appropriate circumstances, to detect changes in the shape and location of meniscoids *in vivo*.

In one subject, a trapped meniscoid was found between the articular surfaces of vertebra C6/7. By applying the manipulation techniques, we managed to release it, as described by the meniscoid entrapment theory.

Using the TVS method, it has been found that the manual therapy of functional joint blocks affects the change in the AS mechanical properties, in particular the attenuation coefficients, which reached 39% in the case of the 1st subject, after manipulation therapy, and even 135% in the case of the 2nd subject, compared to the baseline. The viscosity, as an additional rheological parameter of AS, was not possible to determine unambiguously. It will be necessary to look further at the methodology of calculating the viscosity from the values detected of the AS response to mechanical excitation.

CONCLUSION

The result of the study is the visual documentation of the release of the trapped meniscoid *in vivo*. This is probably the primary objective documentation of this focus.

Due to the fact that more than one blockade was diagnosed in the investigated subjects without a corresponding shifting of the meniscoids to the MR, we assume that more mechanisms are involved in the development of the joint block than just the incarceration of the meniscoidal tissue.

On the basis of the investigations carried out, it can be assumed that the blockades also have a negative effect on the mechanical properties of the axial system, especially on the damping ability of the spine. However, in the follow-up studies, it will be necessary to verify the theoretical interpretations indicated on a larger statistical set.

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