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J. VĒTRA
V. SKLAREVICH
L. BEILINA
G. ANOUFRIEV
I. KALNIŅŠ
S. UMBRAŠKO
V. KOTOVS

Department of Mathematical Sciences
Division of Mathematics
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Department of Mathematical Sciences
Division of Mathematics
Chalmers University of Technology and University of Gothenburg
SE-412 96 Gothenburg, Sweden
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In this paper we present our study of experimentally measured reliable statistical data related to changes in muscle strength of the extremities, changes in the vertebral column curve, and the functional position of the hip joints which are characteristics of the human position. This position is typical for a person working in front of a computer. We present statistical analysis of the test which was conducted on a group of healthy volunteers. The test was performed on the hand muscles, in sitting/vertical position, with the flexion of the head at 30 degrees. The main goal of our test was to measure the strength of separate muscles in the arms, legs and in the cervical region. Using our statistical study we can conclude that there is strong relationship in the strength change of the observed muscles between vertical position and flexion of head at 30 degrees.

J. Vētra
Department of Morphology, Rīga Stradiņš University, Riga, Latvia, e-mail: Janis.Vetra@rsu.lv

V. Sklarevich
Laboratory of Biomechanics, Rīga Stradiņš University, Riga, Latvia, e-mail: sklarevich@hotmail.com

L. Beilina
Department of Mathematical Sciences, Chalmers University of Technology and Gothenburg University, SE-42196 Gothenburg, Sweden, e-mail: larisa.beilina@chalmers.se

G. Anoufriev
Department of Health and Exercise Science, College of Health Sciences, Appalachian State University, USA, e-mail: anoufrievg@appstate.edu

I. Kalniņš
Department of Physics, Rīga Stradiņš University, Riga, Latvia, e-mail: Imants.Kalnins@rsu.lv

S. Umbraško
Department of Morphology, Rīga Stradiņš University, Riga, Latvia, e-mail: Silvija.Umbrasko@rsu.lv

V. Kotovs, Clinic “Ģimenes veselība”, Daugavpils, Latvia, e-mail: wladja@gmail.com

1 Introduction

The goal of this research was to find out the reasons of changes in muscle strength in targeted muscles of the arm and hand (M.abductor pollicis longus, M.biceps brachii, M. triceps brachii, M.deltoideus), as well as those of the leg (M. extensor hallucis brevis, M. tibialis anterior, Mm.peroneus longus et brevis) in connection with the changes of muscle strength after the flexion of the head at 30ø.

The study involved 100 healthy volunteers (68 women and 32 men), 19 to 30 years old. In our study we have used the MicroFET2 Hand Held Digital Muscle Tester in accordance to the manufacturers recommendations, in order to determine the strength of the muscles of the hand and arm (M.abductor pollicis longus, M.biceps brachii, M. triceps brachii, M.deltoideus), as well as those of the leg (M. extensor hallucis brevis, M. tibialis anterior, Mm.peroneus longus et brevis). The results were then used to analyze the difference in the strength of the muscles of the cervical and lumbar regions with the head flexed at 30ø for the same person sitting in the vertical position. Statistical results were obtained by using IBM SPSS software Statistics20.

Rehabilitation professionals who work in clinical settings observed and described a well known phenomenon: often, the patients muscle strength in the arms and legs changes asymmetrically when tilting the patients head forward (flexio capitis) as well as when the patients torso is tilted forward (flexio trunci) [1]-[6]. This means that changes in the muscle strength of the limb occur when changes in the cervical or lumbar regions take place (in the position of kyphosis, when no lordosis is present). These professionals performed a lateral flexion of the head or torso, which explains the reason for changes of the upper or lower extremity muscle strength. These changes can appear mainly by decreasing the gap between the intervertebral disks, and by pressing the spinal nerves of the arm. This phenomenon is characterized by certain symptoms and is used to verify the tests that were done in this work. Also, in some cases, compression was applied in areas parallel to the longitudinal axis of the body. This created symmetrical narrow intervertebral openings that affected the spinal nerves (Spurling's test) and reduced the muscle strength according to the spinal cord segments. This information can be found in the mechanical geometric explanation. The flexion of the head or the torso is resulted in the change of the strength of the lib muscles. This fact can be explained: during the change of position in the cervical and lumbar spine from lordosis and kyphosis, the intervertebral gap expands and thus reduces the possibility of mechanical pressure on the spinal nerves. Therefore, according to the empirical clinical observations, patients with chronic back pain, notice changes in limb muscle strength. The available scientific literature sources mention this phenomenon, see for example, [7], but the information they provide is based on patient observation only. No explanations are given with regards to its possible cause. Hereby, we are trying to clarify the nature of this phenomenon and establish certain parameters, in order to better understand it.

In this context, we conducted a feasible study involving healthy voluntary subjects, as well as using data obtained from rehabilitation practitioners on the patients

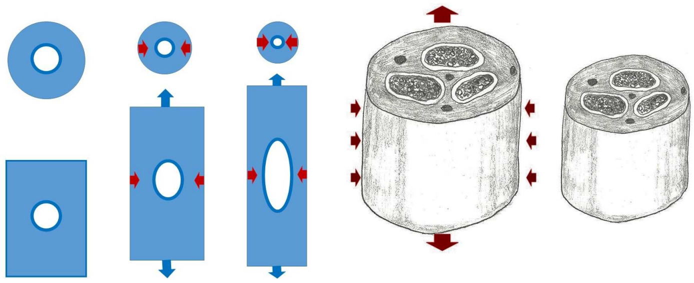

Fig. 1 *Deformation of structure in elastic cylinder, such as the spinal cord or nerve during flexion of the spine.*

in clinical observation. Our experimental study has allowed us to identify the following:

- Manually verifiable changes in limb muscle strength. The ability to change the spine curves from lordosis to the kyphosis are presented in all subjects, both healthy and with locomotion apparatus pathology, with varying degree of expressiveness. Changes in arms muscle strength, by our experience, gives a universal response to a movement of the spine.
- Reduction of muscle strength occurs immediately after the cervical spine or lumbar lordosis changes in the position of kyphosis. After restoring normal lordosis, the muscle strength reduction disappears.
- The reduction of the limb muscle strength is always asymmetrical. This phenomenon is more expressed for patients with chronic back pain.
- When the flexion of the head or torso is within a physiological range, our test does not cause pain in the locomotion apparatus.

We are taking into consideration the changes in the limb muscle strength which are synchronized with the changes in the spinal functional curvature stage. We can assume that such a phenomenon could cause changes only in the conductivity of the central nervous system. As mentioned above, the peripheral nervous system includes spinal nerves and the area of their exit from the spine. During the head or torso flexion they cannot be the reason for the decline of the limb muscles strength. During the study, it was found that changes in the supportive elements of the musculoskeletal (locomotion) apparatus such as ligaments, tendons, bones, cartilage, or muscles, cannot occur so rapidly. The abnormal curvature of the spine in its functional stage leads to a mechanical stretch and functional change of the spinal cord, see Figure 1. The abnormal curvature of the spine and functional stage leads to a mechanical stretch and change of the spinal cord.

The purpose of our research is to study various related changes in the muscle strength, as well as to find out what level of spinal cord changes could be attributed as a possible causes for this phenomenon and the findings in the clinical practice. Thus, the main goal of our research is to measure the relative changes in mus-

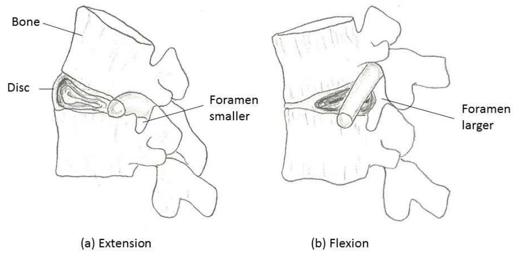

Fig. 2 *Nucleus pulposus movement by neck extension and flexion.*

Age	**Female**	**Male**	**Total**
19	5	5	10
20	28	11	39
21	25	11	36
22	3	2	5
22	3	2	5
23		1	1
24	1		1
25	2		2
26	1	1	2
27	1	1	2
28	1		1
30	1		1
Total	**68**	**32**	**100**

Table 1 Volunteer demographics.

cle strength in specific muscles of the arm (M.abductor pollicis longus, M.biceps brachii, M. triceps brachii, M.deltoideus,) and the leg (M. extensor hallucis brevis, M. tibialis anterior, Mm. peroneus longus et brevis) when the cervical and lumbar spine are in vertical position, while the head is flexed at 30^o. This position is important in order to determine the possible reasons for the changes in muscle strength.

2 Materials and Measurement Methods

Our study involved 100 volunteers age 19 to 30 years old, with no health issues, see Table 1 for volunteer demographics. All measurements were performed on persons in sitting position, using a standardized chair DXR ACER ©. The functional ele-

Fig. 3 *Models of typical examples of disk deformation.*

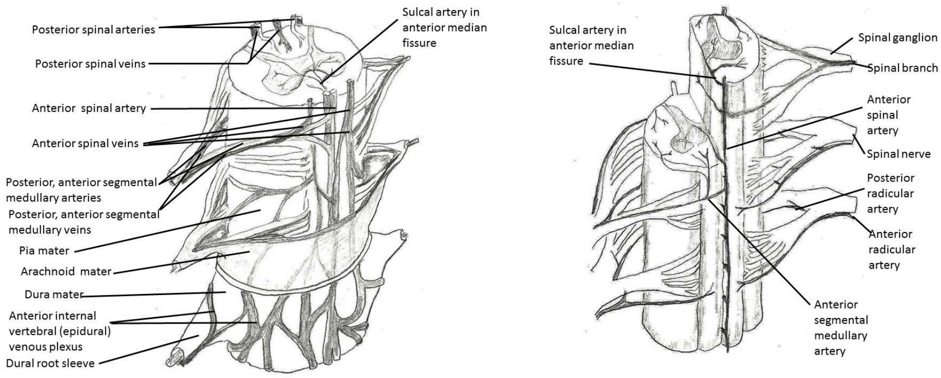

Fig. 4 *Spinal cord and intervertebral nerves arteries.*

ments of the chair were adjusted in such a way so that the individuals elbow joints should be at a 90ø - arms should be supported on the armchair.

We used the MicroFET2 Hand Held Digital Muscle Tester according to the manufacturers recommendations. In our tests we measured the strength of the muscles of the hand, arm (M.abductor pollicis longus, M.biceps brachii, M. triceps brachii, deltoideus,) and leg (M. extensor hallucis brevis, M. tibialis anterior, Mm.peroneus longus et brevis). Each muscle test was performed at least twice (with one repetition). The time which was spent for each test of muscle measurement was the same. This time was determined automatically by the MicroFET2 Hand Held Digital Muscle Tester manual test system. We finished the test only when we got a message “valid” on the machine display. All measured results of strength of the muscles were given in Newtons $N = \frac{kg \cdot m}{s^2}$. The trials were performed on the same subjects to determine the strength of the same muscles in two different body positions. Each produced result of mesurement of muscle strength was recorded during the flexion of the cervical spine (in vertical position) and the head at 30ø. The main tendency

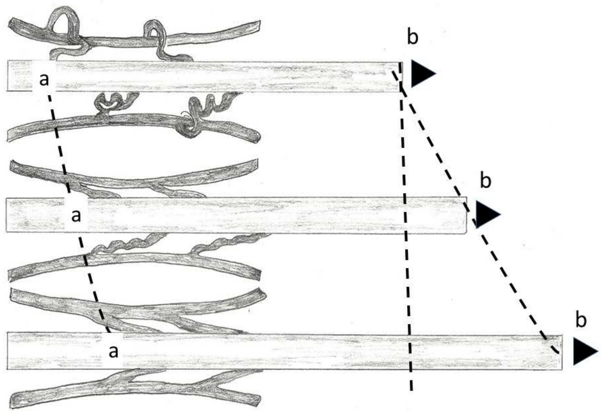

Fig. 5 *Small blood vessels (a) between nerve fibers (b) of spinal cord.*

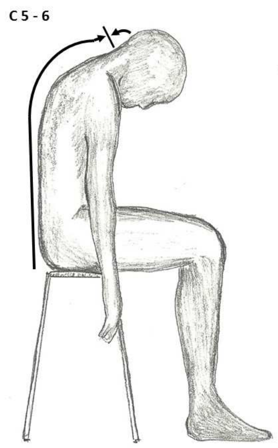

Fig. 6 *Flexion of the cervical spine producing convergence of the neural tissues at C5-C6, but not at the lumbar region.*

is described by the average value and distribution of the standard deviation. A t-test pairs of samples were used to determine if developed muscle strength and flexion of the spine in a vertical position are statistically significantly different. All measured results were processed by using a computer program IBM SPSS Statistics20.

For computation of statistical significance p in Tables 2, 3 we used following *null hypothesis*: There is no difference in the strength change of the observed muscles between vertical position and flexion of head at 30^o. Our *null hypothesis* is rejected when p values are less then significance of level α which is usually set to 5%. This means that the conditional probability of our *null hypothesis* is 5%. Results of Tables 2, 3 show that values of $p < 0.05$ are statistically significant.

To estimate standard deviation we use measurements for 100 persons of Table 1. These measurements were performed at least twice for every person. The standard deviation σ in Tables 2, 3 is computed as

$$\sigma = \sqrt{\frac{1}{M}\sum_{i=1}^{M}(x_i - \mu)^2}, \text{ where } \mu = \frac{1}{M}\sum_{i=1}^{M} x_i, \tag{1}$$

where M is number of measurements for one person, and $x_1, \ldots, x_M$ are values of measurements.

3 Analysis of results

All results of mesurements are presented in Tables 2, 3. The results in these tables show statistically significant changes in the three muscles (M.abductor pollicis longus, M.biceps brachii, M. triceps brachii, M.deltoideus) when the maximum strength values are obtained at the position of the flexion of the cervical spine (in vertical position and the head at 30ø). We have established that the potentially affected areas of the functional changes in the spinal cord are the C5, C6 and C7 segments, which are responsible for the corresponding muscle innervation. Significant statistical differences between the muscle strength of the spine in vertical position and flexio capitis position can be explained by the fact that, in sitting position, making flexio trunci 30ø extent, the movement occurs mainly in the cervical region,(changing from the lordosis to kyphosis position), but the lumbar spine curvature has a minimal change.

We evaluated the possible reasons that could lead to a rapid and reversible change in the innervation of the three muscles on the right and left side, as well as the mechanical stretch of the spinal cord, the mechanical pressure on the spinal cord, and the changes in the blood supply to the spinal cord. Once again, we emphasize that it is a normal function of the locomotion apparatus in healthy subjects, not associated with pain or any subjective or functional impairment. The mechanical nervous stretch with an elongation within 5-12% range may cause transient disturbances in innervation, see Figures 1, 2. Since the spinal cord is made of nervous tissue, it can be assumed that this mechanism could be one of the reasons for the relative change in the muscle strength phenomenon. During a longitudinal stretch of peripheral nerves, the increase in intraneural pressure occurs in proportion to the width of the nerves (Figure 1).

When head is flexed, cervical lordosis position is changed to kyphosis, mechanical loading on the spinal columns intervertebral disc can cause nucleus pulposus dorsal movement which is illustrated at Figure 2. This is very possible scenario because our study included individuals who were 30 years old, see Table 1 for vol-

	Muscles	The average value (N)	Standard deviation ρ, (N)	Statistical Significance p
Pair 1	a1k Abductor Pollicis Longus a1k Abductor Pollicis Longus	51.1 53.3	26.1 26.5	0.092
Pair 2	a2k Extensor Hallucis Brevis b2k Extensor Hallucis Brevis	53.9 54.6	24.1 22.2	0.558
Pair 3	a3k Biceps Brachii b3k Biceps Brachii	123.1 113.2	56.8 49.3	0.004
Pair 4	a4k Triceps Brachii b4k Triceps Brachii	121.4 108.6	57.0 52.0	< 0.001
Pair 5	a5k Midle Deltoid b5k Midle Deltoid	107.3 96.9	45.4 43.6	< 0.001
Pair 6	a6k Tibialis anterior b6k Tibialis anterior	69.0 72.5	36.7 38.9	0.192
Pair 7	a7k Pereneus Longus et Brevis b7k Pereneus Longus et Brevis	59.1 57.8	26.8 27.5	0.369
Pair 8	a1l Abductor Pollicis Longus b1l Abductor Pollicis Longus	50.3 51.0	29.5 27.1	0.678
Pair 9	a2l Extensor Hallucis Brevis b2l Extensor Hallucis Brevis	55.0 57.3	25.6 25.5	0.094
Pair 10	a3l Biceps Brachii b3l Biceps Brachii	144.7 133.1	68.5 62.4	0.006
Pair 11	a4l Triceps Brachii b4l Triceps Brachii	132.3 120.2	57.6 50.3	< 0.001
Pair 12	a5l Midle Deltoid b5l Midle Deltoid	107.6 99.1	44.1 41.8	< 0.001
Pair 13	a6l Tibialis anterior b6l Tibialis anterior	69.8 71.5	36.3 35.8	0.452
Pair 14	a7l Peroneus Longus et Brevis b7l Peroneus Longus et Brevis	62.1 61.7	34.1 31.4	0.781

Table 2 Summary of measurements. Mean values of the extremities muscle strength. Abbreviations: a - the spine is vertical; b - flexio capitis ; k - the left side; l - right side; digits - the size of the number in the database. For example: a1k Abductor Pollicis Longus - the left side muscle, spine upright.

unteer demographics. The nucleus pulposus contains liquid of jelly consistency and is not yet fully transformed into cartilage which is filled with collagen fibers, see Figure 3. The neck lordosis condition has an essential function. In that case the vertebral bodies and nucleus pulposus are driven by pressure to the front part of the vertebral body. There they effectively oppose the vertebral anterial longitudinal ligament. This is firmly fixed to the vertebral body bone structures and its width corresponds to the width of the vertebral bodies.

In the cervical spine kyphosis position, the nucleus pulposus is moved to the rear where there is virtually no supportive structure that can limit its movement. The a posteriori longitudinal ligament is a rudimental formation, which is fixed itself to the intervertebral disc structures, moving together with the mechanical forces. Basically, the a posteriori longitudinal ligament keeps the intervertebral discs nucleus pulposus in central position in respect to the vertebral bodies in lordosis neck

Left side							
	Abductor Pollicis Longus	Extensor Hallucis Brevis	Biceps Brachii	Triceps Brachii	Midle Deltoid	Tibialis anterior	Peroneus Longus et Brevis
Vertical	51.1 (26.1)	53.9 (24.1)	123.1 (56.8)	121.4 (57.0)	107.3(45.4)	69.0(36.7)	59.1(26.8)
Flexion	53.3 (26.5)	54.6 (22.2)	113.2(49.3)	108.6(52.0)	96.9(43.6)	72.5(38.9)	57.8(27.5)
Stat. significance p	0.092	0.558	0.004	< 0.001	< 0.001	0.192	0.369
Strength change (%)	4.4	1.4	-8.1	-10.5	-9.6	5.0	-2.1
Right side							
	Abductor Pollicis Longus	Extensor Hallucis Brevis	Biceps Brachii	Triceps Brachii	Midle Deltoid	Tibialis anterior	Peroneus Longus et Brevis
Vertical	50.3 (29.5)	55.0(25.6)	144.7(68.5)	132.3(57.6)	107.6(44.1)	69.8(36.3)	62.1(34.1)
Flexion	51.0(27.1)	57.3(25.5)	133.1(62.4)	120.2(50.3)	99.1(41.8)	71.5(35.8)	61.7(31.4)
Stat. significance p	0.678	0.094	0.006	< 0.001	< 0.001	0.452	0.781
Strength change (%)	1.3	4.2	-8.0	-9.1	-7.9	2.4	-0.7

Table 3 Limb muscle strength changes measured in Newtons (N) in the spine (in vertical position with flexed cervical and lumbar spine) compared to the left and right sides. Values in brackets show standard deviation ρ in Newtons (N).

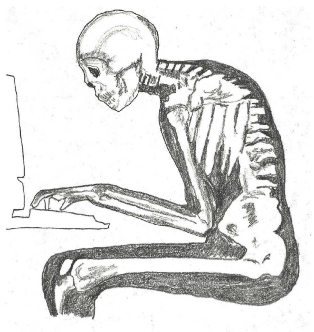

Fig. 7 *T*ypical position of people working with computer.

position, but does not affect the movement of dorsal kyphosis position. The blood supply to the spinal cord system is complex, with high adaptability under various functional conditions, and it is composed out to three large longitudinal arterial trunks. Together, these trunks constitute a single circulatory circle. On the other hand, the spinal cord gray and white matter has blood supply which is carried out by the segmental artery and terminal branches. These arteries are perpendicular to the longitudinal axis of the spinal cord, see Figures 4, 5. Using our experimental study we can conclude that the changes in blood supply will be directly affected by the spinal cord deformation caused by the mechanical stretch [7]. Because of this, it is most likely that the segmentally vessels will be compressed, worsening the blood supply of the segment. At the same time, the neural functional capabilities are directly dependent on the adequate blood supply [8, 9, 10].

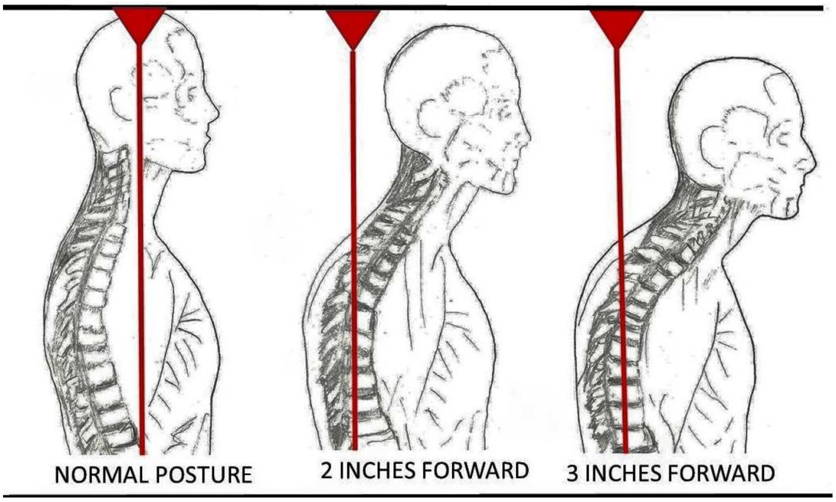

Fig. 8 *Different loading of cervical region in vertical position: 5.5 kg (left figure), head flexion 15 grades - 14.5 kg (middle figure), head flexion 30 grades - 19.5 kg (right figure).*

Overall, we are confident that, combining the three main results of this study, we can change the relative strength of the extremities. Since we have not found any statistical significant changes in muscle strength in the M. abductor pollis longus being in-nervated from C8 segment, we can conclude that the flexion of the head is created by a mechanical stretch up and down of the C5-C6 segments. However, the mechanical distension (tension) in these segments remains neutral. Using results of our experimental study we also can conclude that the neutral mechanical stretch is in the C8 segment. The fact that changing the functional range of the cervical spine from kyphosis to lordosis does not create any significant change in the muscle strength of the lower limbs supports the assumption that the change is segmental in nature, and it is influenced by the deformation of the remote places in the spinal cord segments [11, 12, 13], see Figure 6.

The position of the regular computer user affects the strength in some of the upper limb muscles, see Figure 7. Posture and the functional status of the spinal cord are important factors in various spinal pathology-related diseases. These factors must be taken into consideration because the flexion of the neck, and the position of the body may be overextended some periods of time, on a daily basis, see Figures 8, 9.

4 Discussion

Changing position of head and neck from neutral-cervical lordosis to flexed-cervical kyphosis results in the big mechanical overloading in the structure of the spine cer-

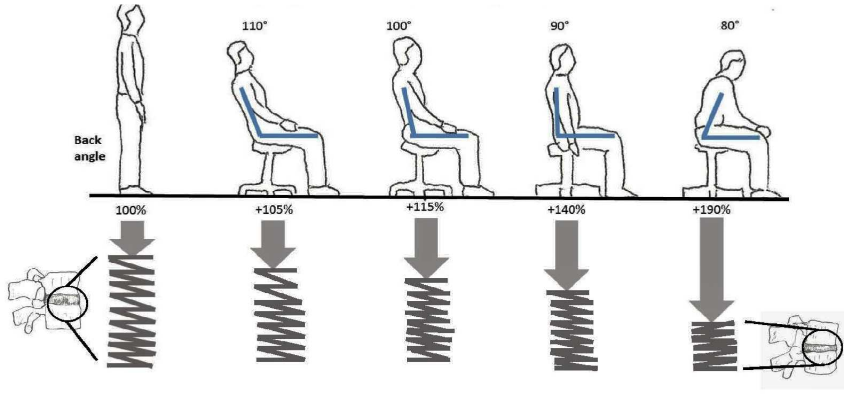

Fig. 9 *T*he effect of posture to the disc pressure. Disc pressure was measured between 3-rd and 4-rd lumbar vertebrae. Results are presented according to Nachemson and Elfström.

vical region, see Figures 8, 9. That overloading can bring musculoskeletal disorders and shoulder-neck pain when that position becomes fixed during long period of time [2, 3].

The cervical spine position changes kyphosis to lordosis physiological extent, by flexio capitis 30 extent, leads to a significant change in muscle strength between the right and left side of the asymmetric changes in arm muscle (M.biceps brachii, M. triceps brachii, M.deltoideus) strength.

The results of our study support the hypothesis that the changes in the strength of these muscles are related to the mechanical distension of the spinal cord by applying mechanical pressure on the spinal cord, which leads to changes in blood supply to the spinal cord. The kyphosis position of the cervical spine, at flexio capitis $30^{ø}$ extent, according to the indirect signs can show changes in muscle strength of the spinal cord segments C5, C6 and C7 where are formed mechanical distension, but changes in segment C8 were not detectable.

In principles of adjusting of computer workplace [14], p. 86, is stated that visual angle to the computer should be about $20^{ø} – 30^{ø}$ downward. Typically, this recommendation will lead to a position of flexion of head at 30 degrees which is studied in this note. Using our experimental study we can conclude that a such position can result in a neck, upper back and shoulder problems and thus the above recommendation should be commented in accordance with our study.

5 Conclusion

Statistically significant differences between the same muscle strength were found in M.biceps brachii, M. triceps brachii, M.deltoideus. This is most likely due to the stretching of the spinal cord and the possible functional circulatory changes in the spinal cord segments of C5, C6 and C7.

Using our experimental study we can conclude that the changes in the cervical region when the head is flexed at 30ø caused significant changes in the strength of the hand muscles (M.biceps brachii, M. triceps brachii, M.deltoideus).

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