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Review

Sitting and Low Back Disorders: An Overview of the Most Commonly Suggested Harmful Mechanisms

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A B S T R A C T

Prolonged sitting is widely accepted as a risk factor for development and/or persistence of low back pain (LBP), with several etiological mechanisms being proposed so far. Cumulative intervertebral disc injuries were often mentioned in relation to LBP and sitting in older literature. Recent studies more frequently report on posterior lumbo-pelvic ligaments as the origin of pain, as those are under a tensile load when the spine is flexed. Such load can lead to (micro)trauma and changes in sensory-motor function, which increases the risk for overuse injuries of certain structures and even acute trauma. Overuse of facet joints or sacroiliac joint were not investigated to such extent. Another potential origin of LBP, noted also in several textbooks, are the myofascial trigger points. Prolonged sitting is associated with reduction in hip flexors flexibility, which induces unfavorable strain to lumbo-pelvic area and consequently increases the injury risk in lower back area.

Key words: *lower back pain, intervertebral discs, ligaments, back stability, ergonomics*

Introduction

Pain in lumbar and/or sacral spine and adjacent tissues, often referred to as low back pain (LBP) is the most common musculoskeletal symptom in general population nowadays. Up to 84% people suffer from at least one case of LPB in their lifetime[1]. In half of those, the pain starts to recur or becomes chronic[2]. LBP is usually not a life-threatening situation, however, it may have a significant impact on individual's life quality and represents a major socioeconomic problem. The costs related to LBP are estimated to be between 0.8 and 2.1% of gross domestic product in developed countries[3], with treatments representing only about one fifth of the total costs[4,5]. The remaining is attributed to indirect costs, arising from decreased work efficiency, sick-leaves and early retirements[6]. Even though only about 50% of the people suffering from LPB actually seeks medical care[7], LPB is among the most frequently treated conditions[8].

Up to date, several biomechanical, social and psychological risk factors for sustaining LBP have been recognized. In individual cases, it is usually impossible to determine the exact factors and mechanisms that led to the occurrence of pain. Even with the modern imaging technology, an anatomical origin of pain is not found in 85% of LPB cases[9,10]. It is believed that muscles, ligaments and fascia are the source of idiopathic/non-specific LPB[11]. In general, the origin of pain may be in any type of tissue.

People are exposed to several different risk factors for LBP throughout their lifetime. Prolonged sitting is among the biomechanical risk factors that a big proportion of population is exposed to. Sedentary time for average individual has been reported to be between 55 and 60% of awake time[12-14], which equals to almost 10 hours per day. For many, sitting is the most adopted posture throughout the day. Recent technological advance is among the most indisputable reasons behind that, as it led to more and more workplaces which demand the employee to be seated. Another culprit for increased daily sitting time is passive motorized transport, while frequent usage of television, computer and other digital information/entertainment technology led to more sitting during leisure time. It is common to sit at culture and sport events, meetings and waiting rooms in different facilities as well. It seems that modern society has created working and living environment that encourages sitting on almost every step.

Spinal structures are exposed to relatively low loads during sitting, but these become highly unfavorable when the exposure is prolonged – the resistance of the tissues to

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imposed loads is reduced through time, if the exposure is not interrupted[15]. To maintain optimal health and function, tissues require a combination of different, mostly dynamic loads. However, static loads are present for the most time during sitting, and are not optimally distributed between and within structures and tissues[16]. The strain that tissues are exposed to is highly dependent on the sitting posture and morphological characteristics of individual's structures[17].

It has been suggested that long-lasting mechanical loads of otherwise healthy tissues can elicit different symptoms (pain among others), which appear only after prolonged uninterrupted static posture and are relived when the position is changed[18]. Most so called postural syndrome are in the lumbar spine and associated with prolonged sitting. Since the symptoms are transient in nature, this syndrome has not been given much attention by the healthcare professionals, although some authors stressed out that it may be a precursor for more severe issues in the future[19].

To form ergonomic recommendations for sedentary people, it is crucial to know and understand the positions of anatomical structures, muscle activity and passive tissue loadings during different types of sitting. To our knowledge, there is no prominent authoritative organization that would publish detailed recommendations on ergonomics of sitting. Recommendations between individual authors or textbooks often differ substantially and are most commonly not equipped with scientific findings on which they are based on. Additional confusion is caused by numerous chairs and other sitting-related accessories available on market, which are often designed based on false or out-of-the-context conclusions, but are promoted to have ergonomic characteristics.

Unfortunately, such false claims are more likely to reach people than appropriate guidelines, supported by science. This contributes to spreading of poor or even completely false knowledge and understanding on ergonomics of sitting. Providing people with a high-quality recommendations based on the latest scientific findings would contribute to a more successful management of health issues associated with prolonged sitting. Additionally, it is important that healthcare professionals – who are responsible for spreading the recommendations – are familiar with the scientific background (i.e. knowledge and understating the human body and the influences of sitting on it). Only then will they be able to judge the both existing recommendations or products, and especially the innovations and novelty on the field.

For this purpose, this narrative review article discusses the most common sitting-related etiological mechanism behind the development and/or persistence of LBP. We also provide recommendations, following from the aforementioned findings. The influence of sitting on spinal structures and consequently on trunk neuromuscular function is dependent upon the type and duration of sitting, and the characteristic of the individual's anatomical structures (geometry, internal tissue properties, presence of other pathologies, etc.). The mechanisms behind LBP development can be divided into direct and indirect, acute and chronic, reversible and irreversible, etc. For the clarity of the text, we divided them based on the affected tissue type.

Effects of Sitting on Bony and Cartilaginous Tissues

In older literature on injurious effects of sitting, intervertebral discs were given the most attention. Because of posterior pelvic tilt, the spine (particularly the lower segments) is in slightly flexed position even during upright sitting posture (Fig. 1). During flexion, the load is unequally distributed between the anterior (increased compressive load) and posterior (tensile load in case of full flexion) part of the intervertebral disc[20]. This combination forces the disc's nucleus to move backwards (Fig. 2), which contributes to the development of radial fissures in posterior annulus fibrosus (outer fibrous ring)[21-23]. The injury starts with the lamellae of the annulus being distorted. Radial fissures on inner lamellas are forming, permitting the nucleus to enter the delaminated pockets. The fissures are then spreading progressively radially outwards. In time, the extrusion of the nucleus may occur, resulting in an injury known as disc hernia, though this process may take years to reach such severe state. Several studies have reported an increased incidence of disc hernia in sedentary population[24-26]. The aforementioned mechanism of disc behavior is supported by a landmark study, during which the posterior shift of the nucleus was observed in asymptomatic healthy subjects after only 10 minutes of unsupported relaxed upright sitting (the lumbar lordosis is somewhat reduced during such posture). These changes were seen for L4/L5 and L5/S1 discs (5.7 mm and 6.9 mm on average, respectively), but not for higher segments[27]. These changes were even more pronounced after slouched sitting, but were not significant when a lumbar support was added during upright sitting. Based on these findings, we recommend that neutral position of the spine is maintained during sitting, with properly designed lumbar support being among the accessories that can be of substantial help.

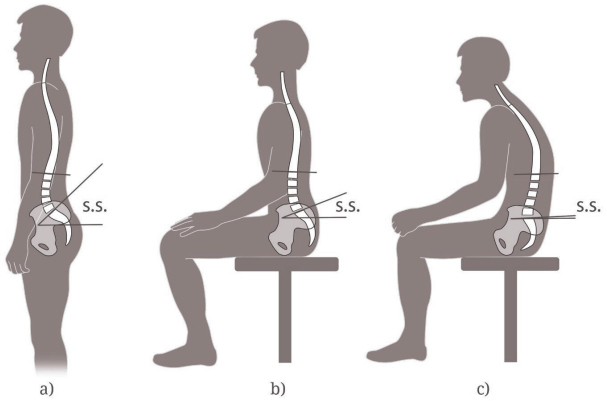

Fig. 1. Spinal curvatures and pelvic orientation are postural dependent. Compared with relaxed standing (a), there is a posterior pelvic tilt (e.g. diminished sacral slope (S.S.)) and a decrease in lumbar lordosis in unsupported upright sitting (b). The effect is even more pronounced in slouched sitting (c).

Another commonly discussed mechanism is a decrease in disc hydration and/or nourishment as a consequence of static compressive load during prolonged sitting. The nutritional supply to the discs, mainly achieved by diffusion, is hindered when disc is dehydrated[28]. The metabolism of the disc is additionally impaired due to the absence of fluid transport within the disc during static loading[29]. On the contrary, water is intermittently forced in and out of the disc during dynamic loads, which supports the efflux of various macromolecules (waste products, growth factors, proteases, newly formed molecules of disc matrix, etc.). Additionally, poorly nourished disc is more prone to degeneration [30].

Reduced disc hydration shows as a decrease in disc height and volume. When discs are in such state, the compressive load is partially shifted to the annulus fibrosus and facet joints, while the pressure within the disc is decreased [31]. When the vertical component of compressive force exerted on annulus fibrosus exceeds the horizontal force, caused by inter-discal hydrostatic pressure, injuries of interlaminar matrix could occur[20], which stimulates or accelerates the degenerative processes. These injuries could occur on the anterior aspect of the disc, where the compression is the highest during spine flexion. One of the ground-breaking studies reported that symmetrical disc degeneration is more prevalent in those who spent most of their worktime seated [32].

in disc height due to sitting exposures were within the range of diurnal variations. It is not unusual for the spine to be up to 26 mm shorter at evening compared to morning time[38]. During normal daily activities the spine is exposed to spinal loading which causes a decrease in discs height, mainly due to fluid outflow. Around 80% of the spinal height difference is present as soon as three hours after night sleep[39]. We did not find any evidence that sitting would lead to detrimental decrease in disc height. It seems that disc dehydration during sitting is not as significant as it is sometimes promoted to be and that other postures may be just as harmful in this respect. Relaxed sitting with reclined backrest causes lower loads than relaxed standing[40]. One study reported partial restoration of disc height with such type of sitting posture, after it was reduced by standing work[37].

After prolonged sitting with flexed lumbar spine, it takes a certain amount of time for discs to return to their neutral shape. It has also been discussed that such reversible deformation (flattened anterior part and posteriorly shifted nucleus) changes the position of the mechanical fulcrum[23], which temporarily decreases the resistance to loading[15]. The injury risk is increased particularly when loads are applied on flexed spine. To restore the geometry of the discs, most importantly the position of the nucleus, few minutes of standing and/or walking is recommended. Moreover, any substantial mechanical strain (e.g. lifting

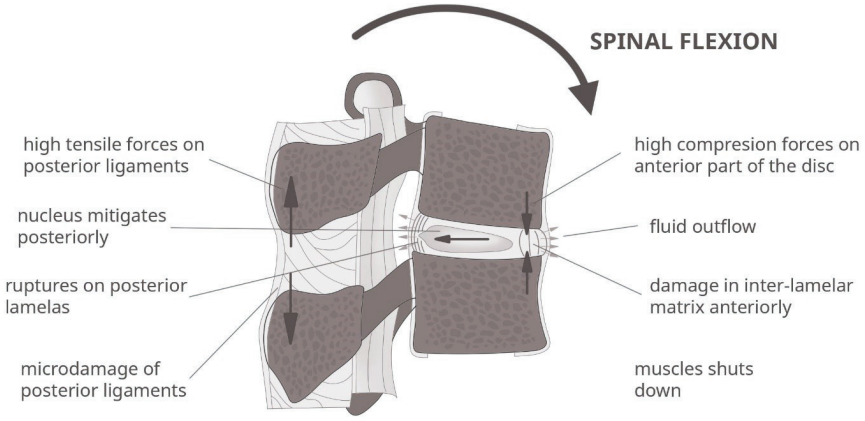

Fig. 2. Spinal flexion is associated with higher compressive forces acting on the anterior part of the intervertebral disc and tensile forces acting on the posterior ligaments of the spine. Prolonged exposure to spinal flexion has detrimental effects on spinal tissues. Several often proposed harmful outcomes due to sustained spinal flexion are shown.

The degree of dehydration and consequent drop in disc height is dependent upon the magnitude, type and duration of the load. Higher and continuous loads lead to a more substantial dehydration[33]. Frequent subtle trunk movements (like in sitting on a chair with movable seat and/or backrest) are better for preserving disc hydration compared to static posture[34,35], while vibrations exacerbate the dehydration[36]. In line with the size of the load, the decrease in disc height is most noticeable after slouched sitting, followed by unsupported upright sitting[33] and lowest after sitting on a chair with reclined backrest with good lumbar support[37]. The reported degree of differences

heavy loads), especially in spinal flexion condition, should be avoided immediately after prolonged sitting[15].

The potential influences of prolonged sitting on facet joints, sacroiliac joint or pubic symphysis have not been often discussed in the present literature. During slouched sitting, the upper medial part of the superior facet joints is believed to be under increased load[41,42]. It was also reported that cross-legged sitting slightly increases the strain on the sacroiliac joint and pubic symphysis[43]. However, short periods of such sitting posture are most likely not harmful.

Effects of Sitting on Muscles

Low and relatively static muscle activity during sitting can lead to discomfort and muscle pain[44]. It was shown that as soon as after 30 seconds of 2% of maximal voluntary contraction (MVC), the oxygen transport in *m. erector spinae* is significantly reduced[45]. After 30 minutes of exposure, the signs of fatigue are already present[46]. The level of muscle activity in healthy individuals differs between sitting types. Values seen during unsupported upright sitting have been reported to be 4 to 12 % of MVC for thoracic part of *m. erector spinae*, between 2 and 17% for *m.multifidus*, 10% for *m. psoas major* and between 2 and 4% for abdominal muscles (*m. trasnversus abodminis, obliquus internus and obliquus externus)*[47-49]. Prolonged sitting of such type is therefore to be avoided, as it certainly leads to muscle discomfort. When sitting on chairs without backrest or with a poorly designed backrest, people will eventually adopt a slouched sitting position, which require less muscle effort to maintain[48]. Namely, near full lumbar flexion, muscle silence occur. The phenomenon is known as a flexion-relaxation phenomenon[47] and it was proposed that muscle silence occur when the major part of the counter torque to prevent excessive flexion is generated by passive tissues – vertebral column and posterior spinal ligaments[50]. The influence of sitting on those are discussed in previous and further chapter, respectively.

A good lumbar support on the backrest enables the user to sit upright, preserving the neutral lumbar lordosis, while the muscle activity is relatively low. Muscle activity does not exceed 2 % of MVC when sitting on an office chair[51-53]. However, even when such optimal posture is achieved, slight movements in all directions are still advised. Another benefit of good back support is a decrease of the load imposed to spinal structures (40 % less compared to straight sitting without backrest)[54]. Further reductions can be achieved by tilting the backrest backward. It is important to stress that higher muscle activity (and consequent higher force) leads to an increase in compressive spinal load. Studies have shown that office workers seldom exploit the benefits of using the backrest – they adopt a slouched sitting posture even on office chairs[53,55]. People should be encouraged towards using a backrest with good lumbar support.

Local painful spots, (sensitive to touch, contraction and/or stretch) known as myofascial trigger points may develop after prolonged static muscle activity, probably because the alterations in local muscle metabolism[56]. They are often present in individuals suffering from LBP, mainly in the muscles of lumbo-pelvic-hip complex. Liu & Palmer[57] reported an increased prevalence of myofascial trigger points in m. illiacus in students, sitting >8h/day, compared to those sitting less. In office workers, shoulder and upper back musculature is affected more often[58]. Preventive measures include using properly-designed backrest and performing small movements of the trunk during sitting. It was proposed that frequent changes in sitting position (when loads are mitigating from one tissue to another) have also overall important role in avoiding specific spinal tissue overload[15].

Sufficient level of everyday physical activity is essential to preserve normal and/or healthy muscle status. Sedentary lifestyle, combined with physical inactivity leads to decline in muscle mass[59], alterations in muscle fiber performance[60], muscle imbalances[61], deterioration of trunk sensory-motor function[62] etc. Efficient muscle system is important to maintain spinal health, as it provides stability and resistance to imposed loads, together with passive (ligaments, discs, bones) and control (nervous) systems[63]. The incidence of LBP was shown to be increased with poor strength and endurance of trunk musculature[64], functional (agonist-antagonist) trunk asymmetries[65] and limited hip flexion range of motion[66].

During sitting, hip, knee and usually the spine as well, are in flexed position. Consequently, certain muscles are in shortened position, while others are stretched, making them prone to become shortened or overstretched, respectively. Muscle groups that may become short with sitting include single-joint hip flexors (*m. psoas* and *illiacus)* and sometimes two-joint hip extensors (*m. semitendinosus, semimembranosus* and *biceps femoris*), horizontal shoulder flexors (*m. pectoralis major*) and neck extensors (*m. trapezius, splenius,* etc.). Muscles that are significantly stretched during sitting are single-joint hip extensors (*m. gluteus maximus),* certain external hip rotators (*m. piriformis),* trunk extensors (*m. erectors spinae)* and scapular adductors (*m. trapezius, rhomboideus major* and *minor).* In case of either irregularities, dysfunction in movement patterns and abnormalities in posture will begin to show. Features of typical posture in sedentary people include accentuated anterior pelvic tilt, pronounced lumbar lordosis, and protracted and sometimes even protruding scapulae. Lumbar lordosis may become less pronounced in individuals who spent a majority of time in slouched sitting position, due to the stretching of spinal passive tissues on posterior site and shortening of two-joint hip extensors (i.e. the hamstrings)[67].

Muscle asymmetries represent a significant risk factor for pain syndromes and injuries[61], as they lead to unfavorable strain imposed to musculoskeletal system. Non-optimal joint alignment and movement trajectory of individual structures of the joint causes to uneven load distribution within the joint surface[68-70]. Active breaks, including both resistance exercise and stretching, are often recommended to perform during worktime. No solid epidemiological evidence is present to support the presumption that flexibility and/or posture are affected by prolonged sitting. Individuals, spending a majority of worktime in seated position should regularly engage in physical activity to preserve their muscle function and overall well-being.

Effects of Sitting on Ligaments and Related Tissues

Sitting is usually accompanied with some degree of flexion in lumbo-pelvic area. Consequently, tensile load is place on posterior spinal ligaments[71], sacroiliac joint ligaments[72], as well as fascia[73] and facet joint capsules[74] in this

area. All of those tissues play an important role in preserving spinal health. Ligaments in particular are essential for ensuring spinal stability[75], not only mechanically, but also as a source of numerous proprioceptors, providing necessary sensory information to the nervous system. Ligaments are also frequently the limiting factor in maximal range of motion, and help to maintain the contact between joint surfaces and proper arthrokinematics.

With prolonged tensile loads, both mechanical and sensory properties of the ligaments are altered, due to the (micro)trauma, which is often accompanied with inflammation. Recovery is dependent upon the type, magnitude and duration of the load, and does not proceed linearly through time. It has been reported that only 40-60% of mechanical stiffness is restored in the first hour after 20-50 minutes of tensile strain, while up to 48 hours is needed for full recovery. During this period, the neuromuscular control is deteriorated, which shows as reduced kinesthetic ability and alterations in reflex responses. While some changes in the latter are believed to be compensatory – protecting the joints from injuries which are more likely to occur when the passive joint stiffness is reduced[76].

As with any other tissue, degradation is a common response of the ligaments when no load is applied. However, (micro)trauma may occur in case of overload, usually accompanied with pain and inflammation. When sufficient unloading is not provided, the inflammation may become chronic, leading to tissue degradation. As more than 24 hours is often needed for full recovery, microtrauma incurred in one day may not heal until the next, which would lead to cumulative and more permanent ligament injury. In conclusion, ligament vitality is determined by the volume and duration of the load and the duration of unloading, with the optimal ratio between those still to be exactly determined[76].

Influences of various loadings on ligaments have mostly been explored with animal studies. Generalization to humans is not possible – the underlying mechanisms are probably very similar in nature, but the dose-response relationship may be different. Viscoelastic creep, a reversible mechanical deformation was shown on humans after the exposure of lumbar flexion, resulting in increased range of motion. In one study, flexion range of motion increased for 4.2° after only 10 minutes of sustaining maximal flexion[77], while 5,5° increase was observed after 20 minutes[78]. A hour-long exposure to 70% of maximal flexion was reported to cause 2.3 ± 2.5° increase[79]. Such increases of ligament mechanical compliance results in decreased joint stiffness, consequently impairing joint stability. About a half of the stiffness is restored after a 2-minute rest[78]. Another study reported 1.6 ± 11.5 %, 7.7 ± 15.8 % and 24.5 ± 12.3 % decrease in passive stiffness after 2 minutes of exposure to 33, 66 and 100% of maximal lumbar flexion, respectively. After 5-minute rest, all values were close to baseline[80]. A change in length-tension relationship after sustained lumbar flexion was also shown with the increase in angle at which flexion-relaxation phenomenon occurs, however, this angle was unchanged when accounted for the increase in range of motion[81].

Additionally, alterations in neuromuscular control of the trunk have been observed after relatively short exposure to lumbar flexion. Latencies of reflexes responses of certain back muscles were shown to be increased after one hour of sustaining 70 % of maximal lumbar flexion[79]. Amplitudes of those responses also seem to increase after prolonged flexion, in line with the percentage of range of motion used[80,82]. Longer latencies were attributed to reduction in sensibility of proprioceptors in viscoelastic tissues and consequent decrease in afferent input. When reflex responses are delayed, the spine is more exposed to mechanical perturbations[83,84]. Increased latencies were also reported to be a risk factor for developing LBP[83]. Increase in the amplitude of the responses is probably a compensatory mechanism to counteract the reduction in passive stiffness. Deformation of viscoelastic tissues was also shown to result in impaired kinesthetic ability. Five minutes of slouched sitting was reported to cause a significant increase (+3.92 ± 4.35°; $p < 0.001$) in trunk reposition error[85]. After short exposure to maximal lumbar flexion, postural control during sitting on unstable seat is also impaired, but is being normalized as soon as after 10 minutes of upright relaxed standing[86].

To sum up, even a short exposure to (partial) flexion of lumbar part of the spine induces reversible viscoelastic deformation of passive tissues, showing as increased lumbar flexion range of motion, decreased passive stiffness, unfavorable alterations in reflex reactions of trunk musculature, deteriorated kinesthetic ability and impaired postural control in sitting position. These changes are likely to increase LBP incidence. Even though the effects of sitting on ligaments and trunk neuromuscular control are poorly researched, we can be confident to recommend avoiding slouched sitting positions and avoiding heavy work immediately after sitting period. The resistance of the spine and surrounding tissues is probably temporarily reduced after sitting.

Conclusion

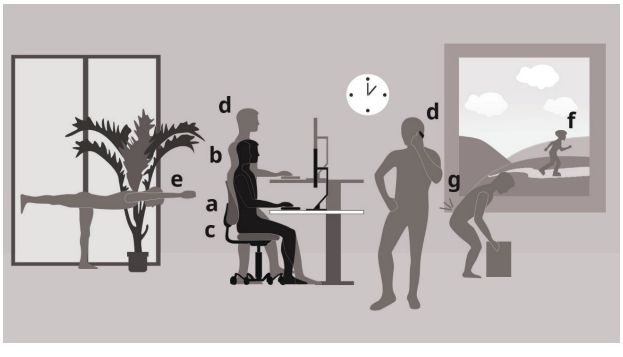

Fig. 3. Recommendations of sitting exceeds the frames of the office chair-table context. Recommendations are listed as follows: [a] maintaining the neutral spinal curves, [b] change sitting positions frequently, [c] reduce the loads acting on the body, [d] implement frequent bouts of standing/walking, [e] incorporate short active breaks during prolonged sitting, [f] follow the physical activity recommendations and [g] avoid heavy labor immediately after prolonged sitting period.

Prolonged sitting is a widespread phenomenon of modern society. Unfortunately, it is associated with numerous health risks, which also include pathologies and syndromes of musculoskeletal system. Daily sitting time should be cut to the minimum, and science-based recommendations should be followed when sitting. The aim of this article was to review currently available scientific literature, which contribute to understanding of the influence of sitting on human body (particularly its locomotor system) and are the basis for current recommendations on sitting. We believe that professionals, as well as the interested general population, should know about the background of these recommendations. With increased awareness and understanding on this field, the power of "ergonomic" products, falsely promoted as healthy and/or pain reliving, will also be reduced.

To conclude, the recommendations to improve sitting ergonomics are briefly reviewed (Fig. 3). To avoid pain syndromes and more serious injuries of musculoskeletal system, it is recommended to: (1) maintain neutral spinal curvature during sitting, (2) avoid prolonged static postures and (3) reduce the biomechanical loads. Additionally, it is important to (4) implement frequent bouts of standing or walking and to (5) incorporate short active breaks into the worktime. Individuals spending a majority of the day seated, should (6) follow the recommendations on physical activity engagement. After prolonged sitting, (7) performing heavy labor should be avoided.

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SJEDENJE I BOL U DONJEM DIJELU LEĐA: PREGLED ETIOLOŠKIH MEHANIZAMA

S A Ž E T A K

Dugotrajno sjedenje se općenito smatra rizičnim faktorom za nastanak i/ili trajanje boli u donjem dijelu leđa (low back pain, LBP) za koju je do sada utvrđeno više uzročnih mehanizama. U starijoj literature bol u donjem dijelu leđa i sjedenje se obično povezuju s kumulativnim oštećenjima intervertebralnog diska. Novije studije sve češće uzrok boli pripisuju posteriornim slabinsko-zdjeličnim ligamentima koji se nalaze pod vlačnim opterećenjem pri pognutoj kralježnici. Takvo opterećenje može dovesti do (mikro)trauma i promjena u osjetno-motoričkoj finkciji, što povećava rizik za prekomjerno trošenje određenih struktura i akutnu traumu. Prekomjerno trošenje fasetnih ili sakroilijakalnih zglobova do sada nije u većoj mjeri istraživano. Neki priručnici navode miofascijalne žarišne točke kao mogući uzrok boli. Dugotrajno sjedenje je povezano sa smanjenom pokretljivošću pregibača kuka, što izaziva nepovoljan pritisak na slabinsko-zdjelično područje i povećava rizik oštećenja u slabinskom dijelu kralježnice.