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Finite element analysis of lumbosacral soft tissue at sitting posture at desktop computer

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Abstract

Aim: This study aims to numerically determine the biomechanical effect of von Mises stress, induced at different flexion angles of the spine while sitting at a desktop computer, on the soft tissues in the front and back of the lumbosacral region, as well as to contribute to determining the ideal sitting posture.

Materials and Methods: Three-dimensional (3D) soft tissue models were created using Solidworks. Static structural analyses of the tissues were performed in ANSYS with the finite element method (FEM). Stress distribution and stress values occurring in the anterior and posterior sides of the lumbosacral region at 0, 15, 30, and 45 spine flexion angles were analyzed separately. The values of von Mises stress formed in the anterior and posterior soft tissues of the lumbosacral region gradually increased with the increase in the flexion angle. Furthermore, the stress values in the anterior and posterior soft tissues were compared with each other for the same spinal flexion angle.

Results: The von Mises stress values were found to be higher in the posterior side only at 0 degrees, whereas at 15, 30, and 45 degrees, they were higher in the anterior side. As a result, the most suitable position for sitting at a computer was determined. Lower flexion angles of the spine, such as 0 and 15 degrees, create less stress on the anterior and posterior sides of the lumbosacral region.

Conclusion: Sitting postures with a flexion angle of the spine higher than 0-15 degrees are not appropriate, and desktop users are not recommended to adopt such a posture. The results of the analysis could be used to better understand the effects of prolonged sitting on the lumbosacral area and to design interventions to reduce the risk of injury or discomfort.

Introduction

Today, people spend much time with computers, an integral part of modern living. Hence, the number of people who have a sedentary lifestyle has been increasing as well as those who spend their leisure time sitting at cafes or doing desk-jobs [1-4]. Computers have started to be used not only for work, but also for social communication, entertainment, and daily life activities [5]. However, prolonged use of computers, especially when back and spine angles are not maintained at the correct position, can lead to irreparable consequences, whereby a substantial adverse impact on daily life in many ways may be experienced [6].
Information technology is fundamentally changing many applications, including management, business, education, and leisure activities [7, 8]. With the rapid development of modern technology, sitting has become the most common posture in today's workplaces [9], where various factors including table height, sitting position, lumbar support, armrests, seat height, and positioning of the monitor are important. These are also the factors that need to be considered in designing ergonomic working at a computer [10]. Sitting is defined as a body posture in which the head and trunk are upright and the hips and knees are bent at approximately 90 degrees, with the feet firmly in contact with the ground [11].
Occupational risk factors for low back pain (LBP) include prolonged sitting [6, 12-14], inappropriate postures [13], and reduced lumbar lordosis [14]. Prolonged sitting causes malnutrition of the intervertebral discs [15], decreased lumbar spine range of motion [16], and increased lumbar spine stiffness [17]. During sitting, the lumbar spine straightens and the nucleus pulposus shifts back [18]. Pressure on the disc increases, and increased passive strain occurs on the posterior spinal elements [19]. Lumbar pressures can be minimized by maintaining physiological lum-

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bar lordosis [20, 21]. Dynamic sitting behavior is thought to provide biologically and physiologically beneficial effects. Because postural variations can reduce the load on the spine and prevent muscle fatigue through alternative motor unit activation, and damage to the posterior aspect of the annulus pulposus is prevented by low-magnitude dynamic movements [16, 22-24]. Today, guides are being developed to justify proper sitting positions and rest breaks. The neutral, upright sitting position that preserves lumbar lordosis is considered optimal in terms of strain on passive structures (joints and/or intervertebral discs) [25].

Computer use has revealed new types of occupational health problems, namely, health problems associated with computer use. The prevalence of musculoskeletal symptoms in computer users is significantly higher than that in nonusers. Neck, shoulder, upper back, and low back pain have higher prevalence in particular [10, 26-28]. Of these, back pain is experienced by more than 80% of the total population, especially by office workers who are deskbound in a fixed position and sit at a computer for a long time [10, 12, 26, 29, 30]. Hakala et al. [31], in their study conducted with computer users and nonusers, reported that computer use for more than 5 hours creates an independent risk factor for LBP [31].

A proper sitting posture at work is crucial to prevent LBP. Based on the traditional sitting model, a modern standard office chair usually maintains right angles in the ankles, knees, hips and elbows, promoting an upright sitting position [6, 11].

Concerns about musculoskeletal disorders and visual impairments associated with computer use [7, 8, 32] have led to the development of various standards and guidelines for computer workstation design [6]. Among such standards are, international standard ISO 9241 and several national standards worldwide, such as AS-3590.2 of Austria, Can/CSA-Z412-M89 of Canada, and ANSI/HFES-100 of the US. Australia and Hong Kong are also known to have prepared and published national guides and codes of practice [6].

While users often prefer a recumbent sitting posture to an upright posture, alternative positions for sitting at computer workstations have been proposed by many researchers and/or institutions [33]. For instance, the Australian guidelines include three reference postures for computer users, which include the traditional upright posture, the forward-leaning seat-pan position, and the lean-back posture [6].

In this study, 3-dimensional soft tissue models were created in Solidworks software. Static structural analyses of tissues in the most stressed regions during the forward bending spine movement of 0, 15, 30, and 45 degrees were made numerically using the finite element method (FEM) in ANSYS. As such, the biomechanical effect of von Mises stress, induced at different flexion angles of the spine, on the soft tissues in the front and back of the lumbosacral region was determined numerically, and a conclusion with regards to the most appropriate of the examined sitting postures was reached considering the minimum stress values.

Materials and Methods

As the entities that comprise the musculoskeletal structure of the human body are a kind of soft material, the von Mises criterion was considered in their evaluation. In the analyses, the von Mises stress values occurring in the soft tissues in the anterior and posterior sides of the lumbosacral region at spine flexion angles of 0, 15, 30, and 45 degrees in the sitting position against a table were determined separately. In addition, the von Mises stress values at the 0-degree position were compared to those at the 15, 30, and 45 degrees. Furthermore, the von Mises stress values occurred in the anterior and posterior regions of the

Table 1. Material properties used for modeling tissue structures.

Entity	Poisson ratio	Young modulus (MPa)	Density (kg/m^3)
Tissue	0.45	4	1000

Figure 1. The typical body model in the sitting position at a desktop computer.

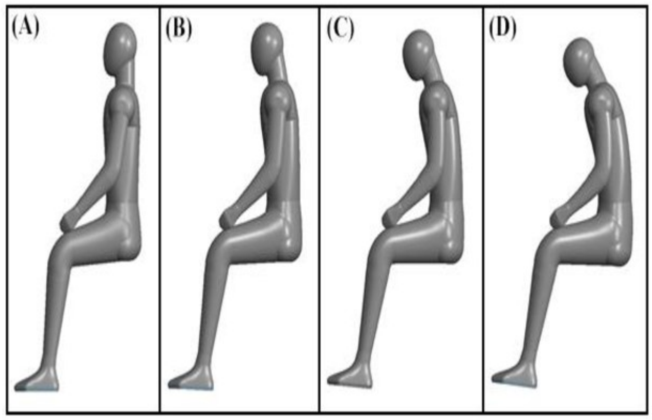

Figure 2. Flexion position of soft tissue models at A) 0, B) 15, C) 30 and D) 45 degrees.

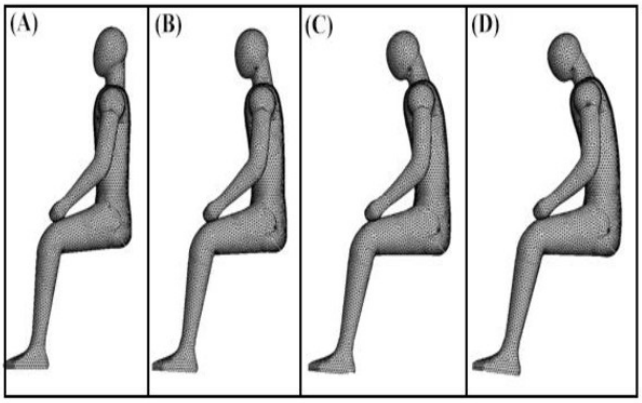

Figure 3. Meshed of soft tissue models at A) 0, B) 15, C) 30 and D) 45 degrees of spine flexion.

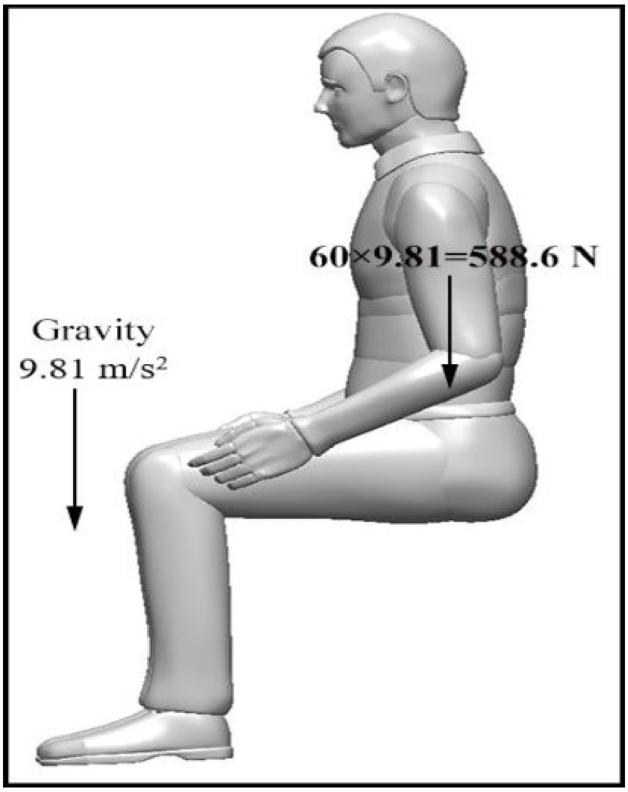

Figure 4. Analysis design of human soft tissue structure in the sitting position.

lumbosacral region were compared for all flexion angles. By comparing these von Mises stress values, we aimed to find the most suitable sitting posture during computer use and to provide objective numerical evidence that can be used for the ergonomics guides. Ethical approval was obtained from Atatürk University Faculty of Medicine Clinical Research Ethics Committee before the study (Approval number: B.30.2.ATA. 0.01.00/539).

Another aspect that adds novelty to this study is that it also compares some FEM codes and theories with other examples, such as static analysis. A comparison is made between open-source code and FEM code. FEM is a numerical or computational technique for solving different field variables given that the boundary conditions of the field variables, such as displacement, voltage, strain, temperature, and electric charge, are given. Mathematically, the FEM, also called finite element analysis (FEA), is an approximation method for solving problems. In FEM analysis, real-life structures are broken down into finite pieces, called elements, to provide solutions to a large class of engineering analyses. An element is defined as having one, two, or three dimensions whereby they represent lines, surfaces, or areas, or solids or volume elements, respectively. Each element consists of a group of nodes interconnected through shape functions [34]. Reverse modeling is known as one of the fastest and most accurate options for reproducing complex 3-dimensional objects such as the human body. Modeling the body without any background aid in CAT software is very difficult and impractical. In this study, the 3-dimensional models of tissue geometry were built from a scanned (.stl) files in Solidworks, and a complex 3-dimensional model was created by creating anatomical points and curves. The reverse modeling technique created an accurate and fast 3-dimensional spine model. A 3-dimensional model as a body tissue system (.stl) file was created in SolidWorks, and high-grade 3-dimensional body geometry was achieved by refining the model and creating geometric reference entities. Spine models made in Solidworks were exported in (.stp) format to be transferred to the ANSYS workbench for structural analysis. Thus, the most stressful lumbosacral regions at 0, 15, 30 and 45 degrees during flexion of the spine were determined using the FEM method.

The body tissue (.stp) format was then transferred into the Ansys workbench, and a cleaning tool was used for missing data, such as edges and corners. Uniform contact tissue models based on the inhomogeneous construction law were applied. The models were transferred to the Ansys workbench (structural) for von Mises stress analysis, for which the details are given in Table 1 [35-37].

Static structural stress analyses were applied to the models whose boundary conditions were determined with finite element-based codes. Material properties were considered uniform for soft tissue; thus, the real biological system was approached more simply. The typical sitting position considered in the study is given in Figure 1. The soft tissue models of the back and neck at flexion positions of 0, 15, 30, and 45 degrees are shown in Figure 2.

A tetrahedral mesh was made for the accuracy and efficiency of these simulations, and the mapped mesh technique was used to keep the model quality within the criteria.

Mesh convergence is an important behavior of the numerical model that ensures the independence of the analysis results from the size of the mesh. Therefore, modeling achieves the optimum mesh size by remeshing at different densities. In this study, with the number of elements as 9734108 for the tissue model, the simulation was ensured to be carried out independently of time (Figure 3).

For an average man, the load on the lumbar spine is approximately 300 N when standing at ease, which is the most convenient position in terms of lumbosacral load. The second most convenient sitting positions, approximately 30% greater, are the relaxed position with the arms resting on the thighs and the straight position with the arms at the sides. On the other hand, at the same sitting position, e.g., in the relaxed position, the position of the arms, i.e., free at the sides or rested, incurs a difference of approximately 30% in terms of load [38]. While several configurations of office chairs, such as linked backrests and seat pan tilts, or being equipped with armrests, may vary as desirable or undesirable, as mentioned earlier, having the arms rested on a support alleviates the compression load on the spinal column. Leaning backward on a small lumbar board backrest drastically decreases the load on the third lumbar disc. This holds true for large backrests; the load on the lumbar discs is much smaller when the leaning angle is beyond vertical, whereas it is almost useless when the occupant maintains an upright posture [38]. The highest benefit from a backrest is achieved when it has an S-like shape similar to that of the spinal column [39], lumbar lordosis in particular.

The loading condition for the models that will be analyzed, i.e., the lumbosacral spine of a seated human, was selected to be 588 N, considering that the mass of the upper body, the part of the body that is unsupported by the seat and above the level thereof, is 60 kg (Figure 4).

Results

In this study, the von Mises stresses induced in the soft tissues located in the anterior and posterior sides of the lumbosacral spine during different flexion movements of the spine were analyzed by the FEM model. The von Mises stress values that occur in the soft tissues in the anterior and posterior sides of the lumbosacral region at the spine

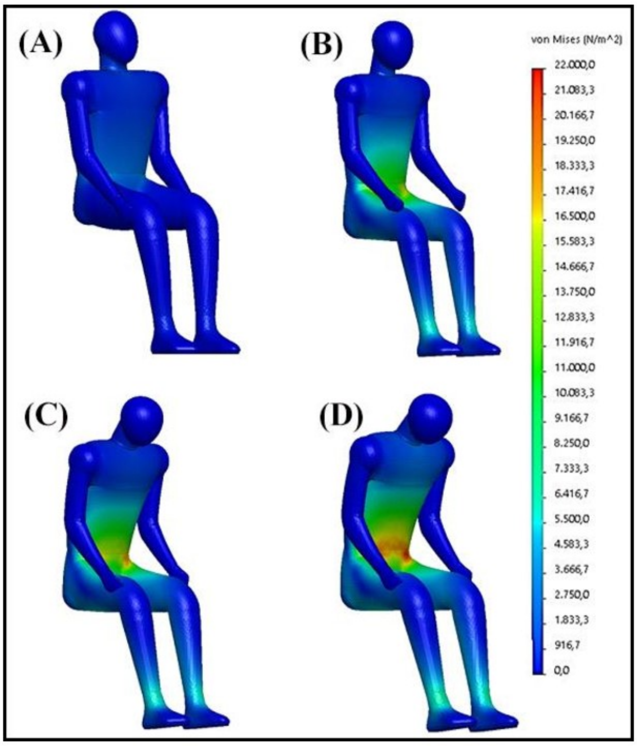

Figure 5. Von Mises stress distribution in the soft tissues in the anterior lumbosacral region at A) 0, B) 15, C) 30 and D) 45 flexion angles of the spine.

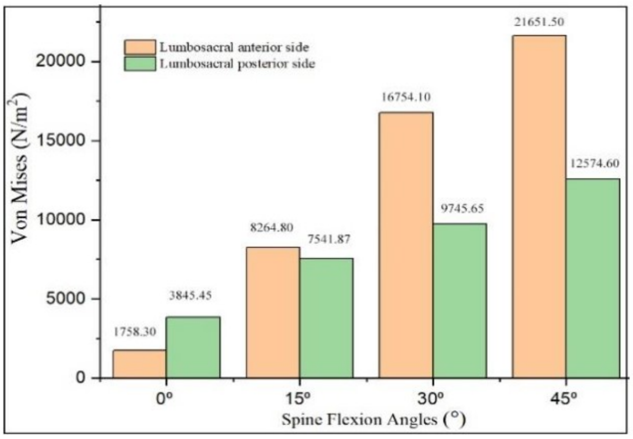

Figure 6. Von Mises stress values in the soft tissues in the anterior and posterior lumbosacral region at 0, 15, 30 and 45 flexion angles of the spine.

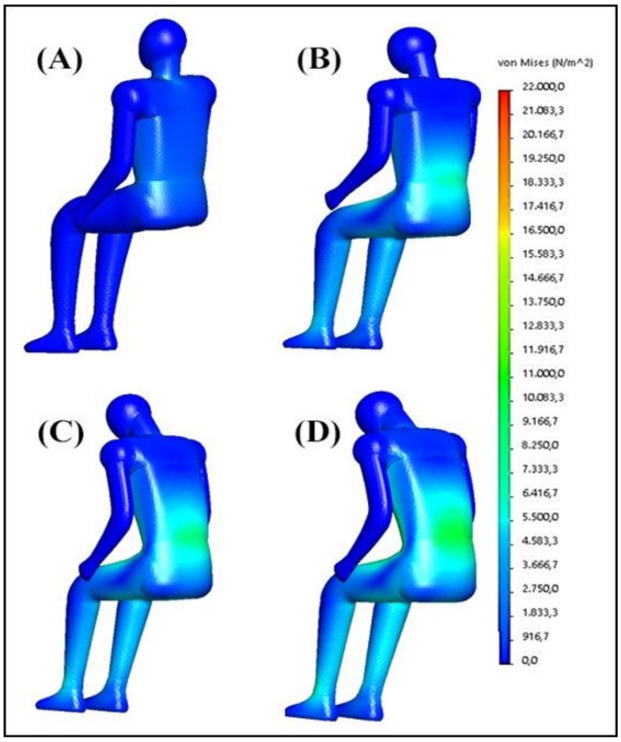

Figure 7. Von Mises stress distribution in the soft tissues in the posterior lumbosacral region at A) 0, B) 15, C) 30 and D) 45 flexion an-gles of the spine.

flexion angles of 0, 15, 30, and 45 degrees in the sitting position at a desk were determined separately. The von Mises stress distribution in the soft tissues in the anterior and posterior sides of the lumbosacral region obtained in the analyses are given in Figures 5 and 7.

In agreement with the results of this numerical study, von Mises values in the anterior side of the lumbosacral region at spine flexion angles of 0, 15, 30, and 45 were determined as 1758.30, 8264.80, 16754.10, and 21651.50 N/m^2, respectively. On the posterior side, stress values were obtained as 3845.45, 7541.87, 9745.65, and 12574.60 N/m^2, respectively (Figure 6).

According to the results, von Mises stress values in the soft tissues on the anterior and posterior sides of the lumbosacral region gradually increase with increasing flexion angles. In addition, von Mises stress values at 15, 30, and 45 degrees in the soft tissues on the anterior and posterior sides of the lumbosacral region were compared with the values at the 0-degree position of the spine.

The von Mises stress values in the anterior part of the lumbosacral region increased approximately 4.70, 9.53 and 12.31 times at 15, 30 and 45 degrees relative to 0 degrees, respectively. Likewise, von Mises stress values occurring in the posterior part of the lumbosacral region at 0 degrees were compared with those at 15, 30 and 45 degrees of flexion of the spine. Compared to the 0-degree position, the increases at 15, 30 and 45 degrees were 1.96, 2.53 and 3.27 times greater, respectively.

Comparing the stress values in the anterior and posterior sides of the lumbosacral region among themselves at the same spinal flexion angle, at 0 degree, it was 2.18 times higher on the posterior side; at 15 degrees, it was 1.09 times higher on the anterior side; at 30 degrees, it was 1.71 times higher on the anterior side; and at 45 degrees, it was 1.72 times higher on the anterior side.

Discussion

No significant studies in the literature numerically analyzed the von Mises stress distribution and values in soft tissues in the lumbosacral region of a person sitting at a desktop computer. In this study, the stress values incurred in the soft tissues in the anterior and posterior sides of the lumbosacral region at 0, 15, 30, and 45 flexion angles of the spine were numerically examined. The stress distribution and values thereof were found to have increased with increasing flexion angles. They were greater at 30 and 45 compared to 0 and 15. Based on our results, the ideal flexion angles of the spine to incur the least stress in the soft tissues on both the anterior and posterior sides of the lumbosacral region are 0 degrees (upright posture) and 15 degrees. Although there are few similar quantitative studies in the literature, an upright sitting position is generally recommended, consistent with the present study's findings, when sitting at a desk or at a desktop computer by other studies conducted with different methods. A neutral, upright sitting position that supports lumbar lordosis is considered optimal in terms of pressure on passive structures such as joints and/or intervertebral discs [24, 40]. As expressed in nineteenth-century publications on seating ergonomics, the back should be straight when sitting. A straight back when sitting in a seat is still implicit in descriptions of correct sitting. The loads on the spine and working muscles should be minimized, as sitting postures that put pressure on the spine and muscles for long periods can cause damage or disorder. The posture that imposes the smallest load on the muscles around the spine is called the 'neutral' position. When the neutral position is changed, when bent forward, for instance, the inclination angle of the trunk increases due to the resisting moment, resulting in stress and strain induced in the muscles erector spinae as well as other supporting trunk muscles to support the trunk. Accordingly, the discs are forced to carry a greater gravity load that disproportionately increases the restraining moment [40].

Maintaining an upright body posture is associated with reduced neck, shoulder, and back pain as well as greater confidence, mood, and strength when compared to a sustained slouched posture, which is associated with greater chronic neck, shoulder and back pain as well as lower confidence and energy, depressive memory bias, and failure-related emotions [41-45]. In fact, body posture was reported in another study as one of the best indicators of stress level and mental workload [46]. Furthermore, another study found that sitting in a hunched and bent position was accompanied by a recall of negative memories, whereas sitting upright was accompanied by reminders of positive memories and pride. Therefore, researchers recommended sitting upright to increase positive affectation and reduce depression [47].

When comparing the stress values in the anterior and posterior sides of the lumbosacral region at the same flexion angles, only at 0 degrees the stress value was 2.18 times higher on the posterior side, whereas at all other flexion angles, i.e., 15, 30 and 45 degrees, the stress, in terms of both distribution and values, was greater in the anterior side by 1.09, 1.71, and 1.72, respectively.

The relationship between posture and LBP is multifactorial and not clearly identified. Many factors affect the spine's flexion, hence, working postures. It is necessary to evaluate multiple factors together. It is ideal for the spine to be upright or at 15-degree flexion when working at a desktop computer. We recommend that the numerical data obtained in our study be considered in preparing standards or guidelines for computer workstation design and in ergonomic instructions for office workers. Thus, it can reduce the incidence of LBP incurred by computer use. On the other hand, it should be borne in mind that the stresses incurred in the anterior and posterior of the lumbosacral region are different in nature, namely, the stresses on the anterior side are compressive while those in the posterior are tensile. Although the amount of stress may not change, certain materials can withstand compression and tension at different levels. Namely, a material can withstand a certain amount of compression but may fail under the same amount of tension, or vice versa. Further studies can be carried out on this aspect of the stresses incurred in the soft tissues in the lumbosacral region.

Limitations

There are some limitations to the study. With the method applied in this study, soft tissue stress at increased flexion angles in the lumbar region was investigated. More accurate and reliable data could be obtained by analyzing the spine together with the soft tissue, i.e., with the inclusion of bone structures and discs, or by applying a method that enabled analysis of the stress in the entire spine.

Conclusion

Today, the use of desktop computers is increasing daily in our work, education, social communication, entertainment, and daily lives. There are studies and guidelines on the ideal ergonomic sitting posture on a desktop computer. However, there are no objective studies that quantitatively evaluate the stress value of soft tissues at different angles in the lumbosacral region. According to the results obtained in this study, the lowest stress values were obtained at low flexion angles up to 15 degrees with upright posture on the front and back sides of the lumbosacral region in front of the desktop computer, and these low flexion angles are recommended for desktop users.

Conflicts of interest

The authors declare that they have no competing interests.

Ethics approval

This study was approved by Atatürk University Faculty of Medicine Clinical Research Ethics Committee (Approval number: B.30.2.ATA. 0.01.00/539).

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