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Ergonomics assessment and redesign of helicopter transmission assembly fixture using digital human models

Helikopter transmisyon bütünleme tezgahının dijital insan modelleme kullanılarak ergonomik değerlendirmesi ve yeniden tasarımı

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Ergonomics Assessment and Redesign of Helicopter Transmission Assembly Fixture Using Digital Human Models

Highlights

- *Ergonomic assembly process design using Digital Human Modeling.*
- *Using of Rapid Upper Limb Assessment (RULA) and Biomechanical Motion Analyses*
- *Redesign and analysis of conventional assembly line.*

Graphical Abstract

In this study, an assembly fixture has been designed that will be used in the assembly of the helicopter transmission and it has been analyzed for compliance with ergonomic conditions using the DHM method. / Bu çalışmada, helikopter transmisyonunun montajında kullanılacak bir montaj fikstürü tasarlanmış ve DHM yöntemi kullanılarak ergonomik koşullara uygunluğu analiz edilmiştir.

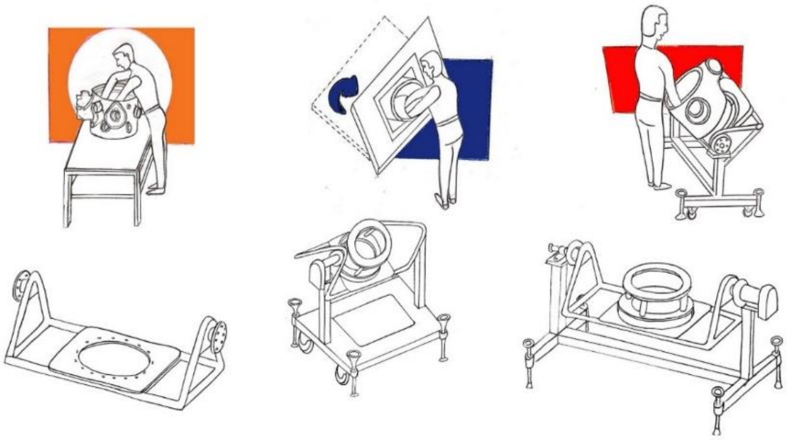

Figure. Developed fixture design within the scope of this study.

Aim

The aim is to design and analysis an ergonomic assembly fixture for helicopter transmission.

Design & Methodology

The ergonomic competence of the human was analyzed empirically for two different assembly conditions. The assembly fixture redesigned has significant ergonomic advantages.

Originality

This study is the first in the literature with its ergonomic fixture design and its application in helicopter transmission.

Findings

As a finding of this study, an ergonomically optimized new fixture has been designed and analyzed.

Conclusion

As a result of this study, The traditional and improver assembly process were compared experimentally and numerically, reducing the loads on the operator's limbs.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Ergonomics Assessment and Redesign of Helicopter Transmission Assembly Fixture Using Digital Human Models

Araştırma Makalesi / Research Article

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ABSTRACT

Digital Human Modeling (DHM) is an integral part of computerized engineering studies. In this study, an assembly fixture has been designed that will be used in the assembly of the helicopter transmission and it has been analyzed for compliance of ergonomic conditions using DHM technique. Rapid Upper Limb Assessment (RULA) and Biomechanical Motion Analyses (BMA) were used in the analyses. The ergonomic competence of the human was analyzed empirically for two different assembly conditions. The assembly fixture redesigned has significant ergonomic advantages over the conventional ones. According to the analyses was provided that 79.6 % advantage in compression loading and 94.3 % advantage in moment loading, which occurs on the L4-L5 lumbar vertebra discs. As a result, it was revealed that the ergonomic assembly fixture designed for workers to work in a more comfortable and safe manner was suitable for its purpose.

Keywords: Digital human modeling, ergonomics, anthropometry, RULA, workers health.

Helikopter Transmisyon Bütünleme Tezgahının Dijital İnsan Modelleme Kullanılarak Ergonomik Değerlendirmesi ve Yeniden Tasarımı

ÖZ

Bu çalışmada, helikopter transmisyonunun montajında kullanılacak bir montaj fikstürü tasarlanmış ve Dijital İnsan Modelleme (DHM) yöntemleri kullanılarak ergonomik koşullara uygunluğu analiz edilmiştir. Analizlerde Hızlı Üst Ekstremite Değerlendirmesi (RULA) ve Biyomekanik Hareket Analizleri (BMA) kullanılmıştır. İnsanın ergonomik yeterliliği, iki farklı montaj koşulu için deneysel olarak analiz edilmiştir. Yeniden tasarlanan montaj fikstürü, geleneksel olanlara göre önemli ergonomik avantajlara sahiptir. Analizlere göre L4-L5 lomber vertebra disklerinde oluşan kompresyon yüklemesinde % 79,6, moment yüklemesinde % 94,3 avantaj sağlanmıştır. Sonuç olarak, işçilerin daha rahat ve güvenli bir şekilde çalışması için tasarlanan ergonomik montaj armatürünün amacına uygun olduğu ortaya çıkmıştır.

Anahtar Kelimeler: Dijital insan modelleme, ergonomi, antropometri, RULA, işçi sağlığı.

1. INTRODUCTION

Ergonomics is a discipline that sets up projects with a purpose to optimize the performance of the humans and the general system, and that tries to work out the interactions and other factors of a system among humans through the instrument of applied theory, principles, data and methods [1]. In consequences of repeatedly performing body postures and moves that are not ergonomically right or suitable, musculoskeletal disorders do arise [2]. Musculoskeletal disorders are disorders that are commonly seen in workers and have significant social and economic effects on individuals [1, 3, 4]. One of the disciplines that the ergonomics places emphasis on is the determination of which body postures, during working, are riskier in terms of occupational health and safety.

Nowadays, musculoskeletal disorders are the most common occupational disorders originating from profession [5]. Due to adverse working conditions and lack of effective occupational accident prevention programs, this creates many problems in many of the developing countries. The main reason for this is the working conditions that were formed without considering anthropometric characteristics. The workers are forced to work in working conditions that are designed without considering anthropometric characteristics and/or in body postures that are not suitable for performing duties, which are not planned in line with ergonomic principles [6]. The minimization of the discomfort felt during work and designing of a workplace that is safe and sound are some of the most significant factors that affect the quality of the production

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and the performance of the process. If the posture is not right, this comes back to the operator as a burden, tiredness and pain [7].

Research made demonstrate that the sum of the direct and indirect costs that the musculoskeletal disorders impose on the industry is 14 billion dollars [8]. In the study, it is expressed that some significant 42 % of the occupational diseases is constituted by the musculoskeletal disorders. In another study, however, it was remarked that furniture that is not manufactured in accordance with the ergonomic rules and standards increased the possibility of the neck, back, lower back pains and lordosis being seen at the stages where growth and development were rapid [9]. Design of the work processes, fixtures, tools, working environment and the work organization are significant constituents that trigger the ergonomic risk factors. Analysis of the working environment and the process within the shortest time possible is quite important in terms of keeping production costs at a reasonable level [10]. Research made indicate that a good ergonomics has a positive economic impact apart from preventing occupational diseases [11]. Research made show that ergonomic rehabilitations made in assembly lanes greatly increase the productivity and decrease the discomforts of the workers [12].

In this paper, helicopter transmission-assembly operation of an assembly technician working in the department of original helicopter prototype production at the factory was monitored and it was seen that the production assisting fixtures that were used for this operation were inadequate in terms of occupational health and safety. The adverse effects that standing postures of a worker working with conventional assembly workbench may impose were initially identified through Rapid Upper Limb Assessment (RULA) analysis. In addition, through the Biomechanical Motion Analyses (BMA) carried out, the compressions on the musculoskeletal system and the damages it may cause on the worker were identified. Then, the design of a transmission assembly fixture was realized, intended for diminishing the ergonomic problems, which are also identified with the results of the analysis. Ergonomic performance of the new design was yet tested by means of RULA and BMA. Analyses were carried out digitally on a computer using digital human models.

2. DIGITAL HUMAN MODELING

Digital Human Modeling (DHM) technique gradually draws attention in product design and manufacturing fields as a new field that joins Computer Aided Design (CAD), engineering of human factors and applied ergonomics [13]. The purpose of DHM is to assist in ergonomic design and assessment for a number of workers populations. Moreover, it helps to visualize a person at work in 3D (Three Dimension) and creates the directives for designing a workstation by carrying out ergonomic analyses [14]. DHM allows engineers to consider ergonomic and human factors at the earliest stages of product development and reduces the need for original prototypes. Industrial manufacturers use, ever more, the DHM to mimic the workers of the new plants or processes on a computer simulation [15]. The advantage of a DHM based design is the possibility of ergonomic assessment, at the early stages of the design process, of a workstation without the need for making direct measurements on human test subjects [16].

DHM based ergonomic analysis technique is recently a new work field with these aspects [17-20]. DHM consists of 3D anthropometric human models used for estimating body sizes, mobility, the range of vision and postural disorders [21-23]. In order to develop DHM kinematics used for estimation of postures and movements and to increase the applicability, the Human Mobility Simulation (HUMOSIM) project has developed databases for the records of human movements [24, 25]. This project is quite significant in terms of ergonomic analyses [25].

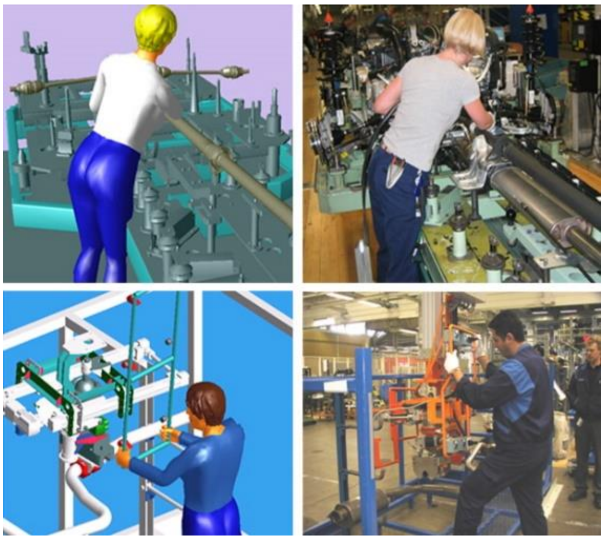


Figure 1. Digital human models for industrial application [30].

Through DHM technique and in a CAD environment; the structure of the product and the workplace, working postures and motions, lifting and carrying activities, body center of gravity and joint angles can be investigated in a broad area of application. The most significant advantage of DHM is that it is repeatable and changeable using genuine human characteristics [26]. Thus, a significant reduction can be provided in the cost of product development processes of companies [27]. Companies should make ergonomic arrangements in accordance with the anthropometric measurements of the workers before making prototypes in the product design and development stages (Figure 1) [28]. This aspect of DHM has resulted in it being an intensive research field recently and many DHM systems have begun to be used in design processes [29].

Common competencies and functions of DHM consists of the ability to move the models in predefined motions, research analyses, posture analyses, push/pull analyses and transport analyses. It also has the means to scale 3D models using existing anthropometric data. Moreover, a series of limitations were defined in relation to use of the DHM such as, for instance, biomechanical methods, statistical calculations, description of the possible future situation or statistical data in relation to human performance features. Designing machines, tools and working environments should ensure the increase of performance by supporting the posture and motions of humans. Instead of forcing workers to adapt to working environments that have weakening effects on productivity, process evaluation should be done with commercial analysis software. Through these implementations, workplaces should be organized in accordance with the requirements of the individuals [31]. As well as minimize the musculoskeletal disorders that may occur during working, the costs are reduced, productivity and product quality increase [32].

3. ERGONOMICS ASSESSMENT AND REDESIGN OF THE ASSEMBLY FIXTURE

In this study, considering the average anthropometric data of the technicians in helicopter transmission assembly, their working positions were evaluated ergonomically. Ergonomic analysis processes were completed by using RULA and BMA with DHM technique. RULA is a working posture analysis method developed with a purpose to identify the work-related upper limb disorders and damages considering the power needed for the work performed and repetitive motions [33]. In RULA method, loadings that might cause discomfort in the upper limbs (hands, wrists, elbows, forearms, upper arms, shoulders, neck) of the body and effects of these loadings on the musculoskeletal system are evaluated by scoring table [34]. Through BMA, fatigue that occurs in the spine under loadings originated from the postures of the working personnel are identified. With the results of DHM, the loadings on lumbar vertebrae, L1-L5 of the workers and the discomfort caused by these loadings are identified. Musculoskeletal system disorders that might arise from the working postures can be identified and disorders that are likely to occur can be eliminated.

Anthropometric measurements of the assembly technician discussed in this study; height is 1.80 cm, weight is 75 kg. The verified anthropometric measurements were recorded in CATIA V5 software and a DHM compatible with real human measurements was created. Ergonomic analyses were performed on the virtual manikin and the effects of working postures on the musculoskeletal system and muscle fatigue were confirmed. The most suitable work fixtures, working postures and positions were revealed as a result of the analysis. According to the results, an ergonomic mounting fixture that will allow technicians of different body sizes to work was designed and analyzed ergonomically.

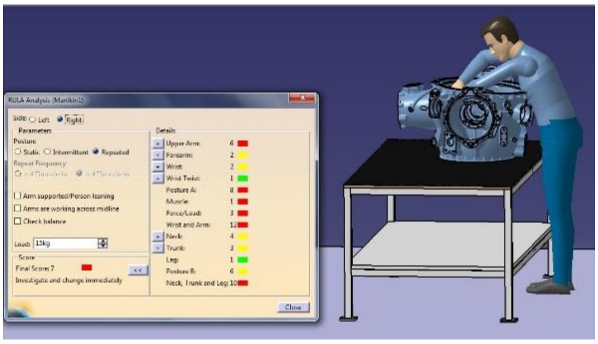


Figure 2. RULA analysis results for working position on conventional workbench.

3.1. RULA Analysis of Conventional Assembly Workbench

After the evaluation of the complaints from the workers, the observations made in the work area and the anthropometric studies, ergonomic analyses were made to see the problems caused by the existing assembly bench, which seemed problematic. The currently used conventional workbench with 800×100×2000 mm dimensions were created in CAD software. While this workbench is not specifically designed for the transmission assembly process, the discomfort that may occur in the worker during operation has been verified by the RULA analysis method. The results of the RULA analysis for the working positions during the assembly process performed on the existing bench are presented in Figure 2.

When the RULA analysis results of the assembly process using the conventional workbench were examined, it was found that the upper limbs of the assembly worker's body were under threat. According to the results of the analysis: It seems that the posture during the study is acceptable in the green colored areas with 1 point. It was confirmed that more research is needed for the working posture of areas of yellow color such as the forearm and wrist, and changes may be necessary. It was seen that the areas such as the upper arm, body posture, musculoskeletal system, strength/load ratio, and the red neck and leg should be investigated immediately, and the body position changed. The final score for body posture while working on this workbench was confirmed to be 7, indicating that the workbench needs to be changed immediately.

3.2. Design and RULA Analysis of An Ergonomic Fixture

Regulations should be made in the work environment regarding the data obtained with the ergonomic analysis results of the conventional workbench. A new fixture was designed to have a working position suitable for the

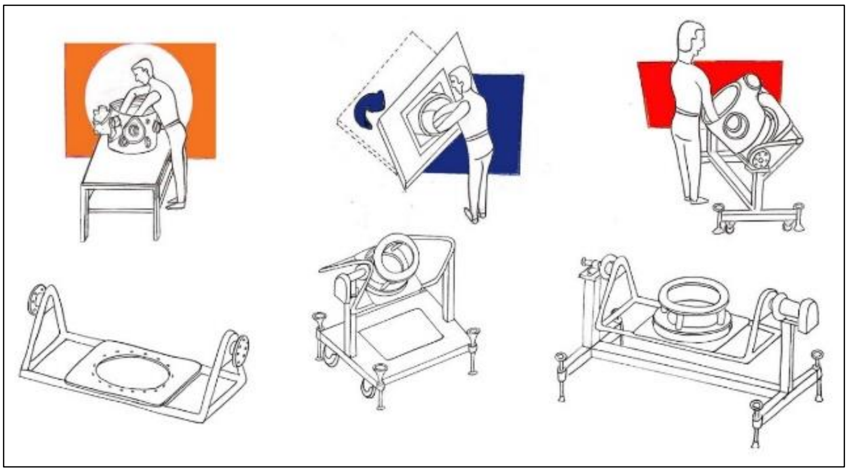
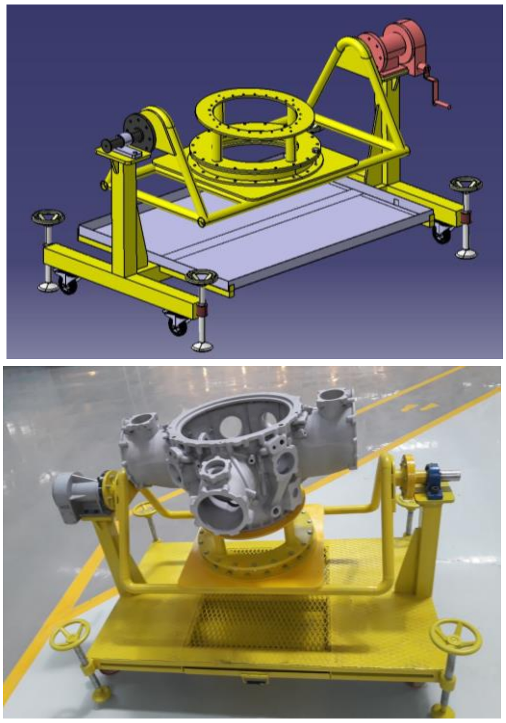


Figure 3. Sketches for the fixture design.

anthropometric measurements of the staff and at the same time reduce the load on the upper limbs and muscles of the body [35]. The designed mounting apparatus allows the assembled part to rotate around its own axis unlike the existing fixture and can also be aligned circularly at a desired position. Thus, the installer will be able to align the bench at a suitable angle to its ergonomic working position. In addition, the height of the mounting element from the legs can be adjusted according to the height of the mounting element. In cases where the working area needs to be changed, it can be easily moved since it has wheeled legs. The sketches in the process of developing ideas for the fixture design of the product are presented in Figure 3.



(a)

(b)

Figure 4. a) 3D CAD model of the fixture design, b) Prototype of the fixture design.

Results of the RULA analysis carried out on the working conditions of the assembly technician in the designed fixture are given in Figure 4. When the results of the ergonomic analysis for the new assembly fixture are investigated, it is seen that the many regions that were previously colored in yellow and red had turned into green and reductions were made in scorings as well. The fact that many regions such as the upper arm, wrist, body posture, neck, and the body have the green color indicates that the existing posture can be accepted and repeated for a long time. The final score of 7 with red colors of the conventional assembly workbench was reduced to 4 and the color turned into yellow. This indicates that working position was changed to the necessary extent with the new fixture design and that works can be performed ergonomically for a long time in this position.

3.3. Biomechanical Motion Analyses

The ergonomic factors that have influence over the physiologic workload of the personnel should regularly and continuously be assessed and the workers should be ensured working in a safe and sound manner [36]. In consequences of wrong working postures, the viscous fluid in between the lumbar vertebrae (L1-L5) exerts compression on the spine or the nerve roots and may cause pain, mental disorders, and paralyses. With thinning of the discs between discs and compression of the neighboring tissues, fluid within the discs exerts out compression and causes pain, muscle cramps, loss of sense and numbing [37].

In this study, the load on the L4-L5 lumbar vertebrae of the technicians working in a conventional assembly workbench was calculated with BMA (Fig. 4). In long-term studies, it is possible that this load causes problems in the musculoskeletal system. The BMA results of the redesigned assembly fixture and working conditions according to the RULA analysis results are also given in Figure 5. According to the results obtained, the moment loads on the L4-L5 bones were reduced by 94.3 % and compression loads by 79.6 %.

4. RESULTS AND DISCUSSION

The ergonomic analysis value of the working postures of the assembly fixture designed within the scope of the study was reduced from harmless “7” to dangerous “4”. Lifting, carrying, and postural disorders mainly cause injuries to the musculoskeletal system and pain in the neck and back (spinal deformities, slipped disc), which reduces worker's productivity [38-40]. Any exposure to body vibration over a long period of time damages the spine and musculoskeletal system [40, 41].

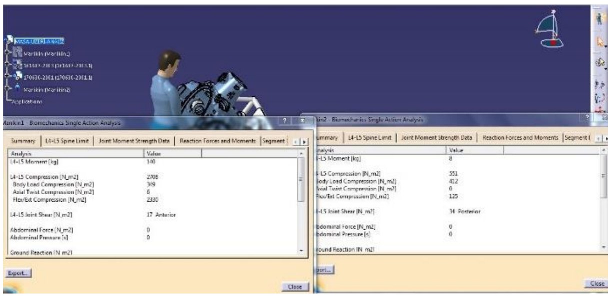


Figure 5. Results of biomechanical analysis.

Comparison of the results of RULA analysis of conventional workbench and the fixture designed is given in Table 1. The final score was identified to be “4” (more research should be made) in consequences of the RULA Analysis for the ergonomic working posture as per the ergonomic design made. In the working posture with the ergonomic fixture designed, it was concluded that loads on the upper body limbs and the musculoskeletal system would be decreased significantly.

When the results in Table 1 are considered; thanks to the fact that the newly designed assembly fixture allows the assembly part to rotate on its own axis, a significant rehabilitation was achieved in the position of the upper arm and the score was reduced from 6 to 1. Same rehabilitation was also achieved in the arm and the wrist, and the result of the ergonomic analysis, which was 12, was reduced to 4. The fact that the height of the newly designed assembly fixture can be adjusted in accordance with the height of the assembly technician was reflected on the results of the ergonomic analysis of the neck, trunk and leg and the score was reduced from 10 to 4. With this working posture, the assembly personnel will be able to work for longer hours with less fatigue and less discomfort in terms of occupational health and safety in a more productive manner.

Results of biomechanical analysis carried out on the working postures of the assembly personnel with existing fixture and the fixture newly designed are presented in Table 2. As per the results of the biomechanical analyses, the maximum loads forming on L4-L5 lumbar vertebrae were rehabilitated in the body posture on the newly designed ergonomic fixture. Moment loadings forming on L4-L5 lumbar vertebrae were reduced by 94.3 %, compression loadings forming on L4-L5 lumbar vertebrae by 79.6 %, Axial twist compression by 100 % and the flexing/extension compression on the spine by 94.63 %.

Table 1. RULA analysis results of existing fixture and the assembly fixture newly designed.

Limbs	Existing Fixture	Assembly Fixture
Upper Arm	6	1
Upper Arm	2	2
Upper Arm	2	1
Wrist Twist	1	1
Force/Load	3	2
Wrist and Arm	12	4
Neck	4	2
Trunk	3	1
Leg	1	1
Neck, Trunk and Leg	10	4
Total Score	**7**	**4**

In consequences of the biomechanical analyses and the research made, significant reductions are seen in the results of the analyses for the working position on the fixture newly designed. The results obtained indicated that the newly designed assembly fixture had ergonomically superior attributes over the conventional assembly workbench.

Table 2. Results of biomechanical analysis.

Loading Region	Existing Fixture	Assembly Fixture Designed
L4-L5 Moment Loading	1400 Nm	80 Nm
L4-L5 Compression Loading	2708 N/m^2	551 N/m^2
Axial Rotation Compression	6 N/m^2	0 N/m^2
Flexing / Extension Compression	2330 N/m^2	125 N/m^2

5. CONCLUSION

Workplace design should be arranged in a way that supports an ergonomic working position in accordance with the anthropometric measurements of the employees. Occupational disturbances may occur in individuals who stay in the same working position for a long time. At the same time, the work efficiency of employees may decrease due to pain and numbness.

With the ergonomic analysis applications of CAD software used today, the working conditions and positions of people are simulated into the software and possible problems are detected at an early stage.

In this study, the analysis results of the helicopter transmission assembly workbench, which was evaluated ergonomically as a result of the complaints of the employees in a factory, showed that the current working conditions are quite dangerous. According to the results of BMA and RULA analysis, an ergonomic mounting fixture was designed in accordance with the anthropometric measurements of the employees. The fact that the designed fixture can be adjusted according to the measurements of people with different body and height is very important in terms of occupational health and safety and musculoskeletal disorders. Thus, employees will have a comfortable and safe working environment.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Ömer KOÇ: Primary author. Performed the mechanical design and experimental analysis of the ergonomic fixture model.

Neslihan TOP: Performed the numerical analysis of the ergonomic fixture model.

Cengiz ELDEM: Provided revisions to the scientific content of the manuscript.

Harun GÖKÇE: Wrote the manuscript.

İsmail ŞAHİN: Provided revisions to the scientific content of the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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