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Landing mechanics as a predictor of lower extremity injury risk in elite female wrestlers: A prospective study

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Abstract

This study aimed to investigate the relationship between landing mechanics and lower extremity injury risk in elite female wrestlers. A prospective cohort study was conducted with 47 elite female wrestlers (age: 20.41±1.91 years) from the Turkish national team. Before the competitive season, participants underwent a standardized jump-landing assessment, and LESS scores were recorded. Injury occurrences were monitored throughout the two seasons. We conducted a Receiver Operating Characteristic (ROC) curve analysis to establish the optimal LESS cut-off value for predicting injury occurrence. The relationship between LESS scores and injury risk was evaluated using Pearson's Chi-square and Fisher's exact tests. The optimal LESS cut-off score was identified as 5.5 (AUC = 0.683, p = 0.025), with a sensitivity of 71.43% and specificity of 65.38%. Athletes with LESS scores >5 demonstrated a significantly higher injury incidence (p = 0.012). Notably, among the 21 athletes with LESS scores above the cut-off value, 15 experienced injuries. An increased risk of lower extremity injury was observed in elite female wrestlers exhibiting higher LESS scores. These findings highlight the importance of LESS as a screening tool for injury prevention strategies. Future studies should explore targeted neuromuscular training programs to enhance landing mechanics and reduce injury risk.

Keywords: ACL injury, biomechanics, elite female wrestlers, injury prevention, landing error scoring system

Elit kadın güreşçilerde alt ekstremite yaralanma riskinin öngörülmesinde iniş mekaniği: Prospektif bir çalışma

Öz

Bu çalışmanın amacı, elit kadın güreşçilerde sıçrama-iniş mekaniği ile alt ekstremite yaralanma riski arasındaki ilişkiyi incelemekti. Çalışma, Türkiye milli takımından 47 elit kadın güreşçi (yaş: 20,41±1,91 yıl) ile yürütülen prospektif kohort araştırma desenine sahipti. Katılımcılar, yarışma sezonu öncesinde sıçrama-iniş mekaniği değerlendirmesinden geçirildi ve LESS skorları kaydedildi. Yaralanma durumları iki sezon boyunca takip edildi. ROC eğrisi analizi, yaralanmaları öngörmek için optimal LESS eşik değerini belirlemek amacıyla uygulandı. LESS skorları ile yaralanma riski arasındaki ilişkiyi incelemek için Pearson Ki-kare ve Fisher's exact testi kullanıldı. Analiz sonucunda, LESS için optimal eşik değeri 5,5 olarak belirlendi (AUC = 0,683, p = 0,025) ve bu değer, %71,43 duyarlılık ve %65,38 özgüllük gösterdi. LESS skoru 5'in üzerinde olan sporcular, anlamlı derecede daha yüksek yaralanma insidansı sergiledi (p = 0,012). Ayrıca, LESS skoru eşik değerinin üzerinde olan 21 sporcunun 15'inin yaralanma yaşadığı kaydedildi. Yüksek LESS skorlarının, elit kadın güreşçilerde artan alt ekstremite yaralanma riski ile ilişkili olduğu gözlendi. Bu bulgular, LESS'in yaralanma önleme stratejileri için etkili bir tarama aracı olarak kullanılabileceğini vurgulamaktadır. Gelecekteki çalışmalar, iniş mekaniğini geliştirmek ve yaralanma riskini azaltmak amacıyla hedefe yönelik nöromusküler antrenman programlarının etkinliğini araştırmalıdır.

Anahtar Kelimeler: *Biyomekanik, elit kadın güreşçiler, iniş hata puanlama sistemi, ön çapraz bağ yaralanması, yaralanma önleme*

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INTRODUCTION

Lower extremity musculoskeletal injuries are a common concern for athletes across a wide range of sports (Hussain, 2010). These injuries can be debilitating, leading to decreased athletic performance, prolonged time away from competition, and in some cases, long-term disability. Knee, ankle, and foot injuries are especially concerning because they occur frequently and can lead to long-term health and performance complications for athletes.

There are many factors that contribute to the risk of lower extremity musculoskeletal injuries in athletes, including biomechanical factors, training load, and environmental factors such as playing surface and weather conditions (Hewett et al., 2006). Epidemiological studies indicate that these injuries are particularly prevalent among female athletes, often resulting from non-contact mechanisms (Clifton et al., 2018). This is due in part to differences in anatomy and biomechanics compared to male athletes, as well as differences in training and competition patterns.

Lower extremity musculoskeletal injuries are a major concern for female wrestlers due to the sport's intense physical demands and the unique biomechanical stresses exerted on the lower limbs during training and competition. Knee and ankle injuries, in particular, are worrisome, as they can lead to prolonged training absences, reduced athletic performance, and lasting musculoskeletal complications.

According to previous studies, female wrestlers experience a higher risk of lower extremity musculoskeletal injuries compared to male wrestlers and female athletes competing in different sports (Barroso et al., 2011; Park et al., 2019; Daneshmandi et al., 2020). Possible contributing factors include variations in anatomy and biomechanics, alongside wrestling's high-intensity characteristics and the common occurrence of high-risk techniques and positions.

Injuries to the anterior cruciate ligament (ACL) constitute one of the most frequently occurring lower limb injuries in athletic populations (J Agel & Klossner, 2014; Julie Agel et al., 2016). ACL tears and subsequent reconstruction can lead to adverse effects, including persistent knee pain, increased joint instability, and extended periods of absence from sports participation in athletes (Hewett et al., 2010; Theiss et al., 2014). Female wrestlers are at heightened risk ACL injuries due to improper landing mechanics, which create a valgus force on the lower extremity when the knee is in near-full extension (Hewett et al., 2005; Onate et al., 2010; James et al., 2016), inadequate strength and conditioning, and other factors (Hewett et al., 2010; Hewett et al., 2016). These injuries often happen when the knee is nearly fully

extended, with an anterior tibial force and a concurrent valgus moment. Such situations commonly arise during landing, cutting, or pivoting movements (Markolf et al., 1995; Padua et al., 2009; Smith et al., 2012).

The Landing Error Scoring System (LESS) is a widely utilized clinical tool for evaluating lower limb movement patterns during jump landings. Moreover, studies have demonstrated its validity when compared to three-dimensional motion analysis systems (Schurr et al., 2017) and has exhibited favorable inter- and intrarater reliability (interrate reliability: intraclass correlation coefficient [2,1] = 0.84 standard error of the mean = 0.71 (Onate et al., 2010; Padua et al., 2011; Padua et al., 2015). The LESS was designed to detect movement patterns that could potentially lead to an increased risk of lower extremity musculoskeletal injuries, especially those involving the knee and ankle (Padua et al., 2015). In addition, researchers have used the LESS to determine the effectiveness of injury prevention strategies and to follow rehabilitation outcomes post-injury.

The LESS assesses six primary movement components during a jump-landing task: initial ground contact, knee flexion displacement, valgus alignment, internal rotation of the tibia, foot alignment, and trunk positioning. Each component is rated individually on a 0–2 scale, with higher scores indicating less optimal landing mechanics. The overall LESS score can vary between 0 and 17 points, and elevated scores suggest a higher risk of sustaining an injury.

Thus far, studies investigating the link between LESS scores and the likelihood of injury have yielded conflicted results (Everard et al., 2018; de la Motte et al., 2019), including ACL injuries (Smith et al., 2012; Padua et al., 2015). The LESS assesses both an overall score and specific biomechanical movement patterns (individual LESS items), offering valuable insight into faulty movement mechanics associated with injury risk. Identifying these specific errors can aid in injury prevention, evaluating the effectiveness of injury prevention programs, and tracking rehabilitation progress. Additionally, LESS outcomes may also relate to a broader spectrum of lower extremity injuries rather than being solely limited to ACL injuries.

This study aimed to investigate the relationship between LESS scores and lower extremity injuries in female national wrestlers who were injury-free at the beginning of the preseason. It was hypothesized that higher LESS scores would be linked to an increased risk of lower extremity injury in elite female wrestlers.

METHOD

Research group (population-sample)

Between August 2020 and July 2023, a total of 47 healthy and right-leg dominant female elite wrestlers from the Turkish national team (mean age 20.4±1.9 years; range, 18 to 28 years) were included. An a priori sample size estimation was conducted based on previously published data (James et al., 2016). It was determined that a total of 30 subjects would be sufficient to detect statistically significant differences at an α level of 0.05 with a power (1-β) of 0.80. The inclusion criteria required participants to be active elite athletes of national status with no injuries that would impair their ability to complete the LESS assessment. Although a prior history of knee injury did not serve as an exclusion criterion, individuals with any current injury or pain restricting their capability to complete the LESS evaluation were excluded from participation (not meeting inclusion criteria: n=3).

Data collection/processing method

Elite female wrestlers performed a standardized jump-landing test to evaluate their landing mechanics before their competitive seasons began. Participants were then monitored throughout their respective competitive seasons for any lower extremity injuries that occurred during training or competition. The incidence of these injuries was recorded. In this study, an "injury" was defined to any injury sustained to the lower extremity during participation in an organized practice, game, or conditioning session. An injury was classified as one that required medical intervention by an athletic trainer and resulted in complete restriction from at least one subsequent practice or game. Only the first injury occurrence per participant was considered for inclusion in the injury group; multiple injuries sustained by the same individual were not counted as separate cases in this study (James et al., 2016; Walbright et al., 2017).

Testing sessions were conducted within the university's performance laboratory prior to the start of competitive season. Athletes were required to wear fitted, dark shorts and low-cut shoes. The study's objectives and methodological procedures were explained in detail, and all participants provided written informed consent. Body mass and height measurements were recorded using a digital device (Seca 769 scale, Seca GMBH, Hamburg, Germany). Later, jump-landing assessment was performed.

Participants completed a jump-landing test involving vertical and horizontal movements, jumping forward from a 30-cm box onto a landing zone marked on the floor, set at half of their individual height. Participants were required to initiate the jump by pushing forward off the box rather than moving vertically, ensuring simultaneous takeoff with both feet. Upon landing just

beyond the designated line with both feet, they were instructed to immediately execute a maximal vertical jump (Padua et al., 2009; Padua et al., 2015; Mauntel et al., 2017; Lisman et al., 2021). Prior to the assessment, participants received a visual demonstration of the task and were asked to confirm their understanding of the instructions. No guidance or feedback regarding landing technique was given, except in cases where participants executed the task incorrectly. Following instruction, each participant performed three practice trials to become accustomed to the testing protocol. After these familiarization trials, retroreflective markers were placed on anatomical landmarks, including the acromioclavicular joint, anterior superior iliac spine, greater trochanter, lateral knee joint line, patellar center, tibial tuberosity, lateral malleolus, and between the bases of the second and third metatarsals. Athletes performed a jump-landing sequence consisting of an initial jump from the box, followed by landing and immediately executing a maximal vertical jump. Each athlete completed this sequence three times. Two built-in digital camera of a smart phones (iPhone X, Apple Inc., Cupertino, CA, USA) were placed 3-m in front and to the right of the participants to capture frontal and sagittal images of all jump landings (Padua et al., 2015). Two-dimensional data were collected at a sampling rate of 240 frames per second. Data were processed using Kinovea Software (version 0.8.27, Kinovea Open Source Project, www.kinovea.org).

The LESS is a standardized screening tool used to evaluate landing technique during jump activities (Padua et al., 2009). The LESS comprises 17 observable criteria designed to detect specific landing technique errors. Higher scores reflect poorer jump-landing mechanics, whereas lower scores represent more optimal landing performance. These 17 criteria are categorized into four groups, detailed in Table 4. The initial group (items 1–6) assesses lower extremity and trunk alignment at the moment of initial ground contact. These items assess alignment of the trunk, thigh, and knee, as well as foot position at initial contact. The second set of items, items 7-11, assess errors in foot positioning. The assessment items are evaluated at three distinct phases: initial ground contact, full foot contact with the ground, and the transition period between initial contact and peak knee flexion. Items 12–15 specifically examine lower extremity and trunk movements during this transition, focusing on the point of maximum knee flexion or maximum knee valgus angle. These measures help assess the quality of landing mechanics, including knee flexion depth and the thigh's positioning relative to the ground. Additionally, two global assessment items (items 16 and 17) provide an overall evaluation of sagittal plane movement and the rater's subjective impression of landing technique, offering a comprehensive assessment of movement quality (Padua et al., 2009).

Data analysis

Statistical analysis was performed using the IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). The normality of the data was assessed using the Shapiro-Wilk test, which indicated a normal distribution. Descriptive data were expressed in mean and standard deviation. To establish the optimal threshold of total LESS score for predicting lower extremity injury, a Receiver Operating Characteristic (ROC) curve analysis was carried out. Associations between injuries and LESS scores exceeding 5 were assessed using Pearson's Chi-square test. Finally, differences between injured and uninjured athletes regarding the frequency of individual LESS errors were analyzed using Fisher's exact test. An alpha level of <0.05 was considered statistically significant.

FINDINGS

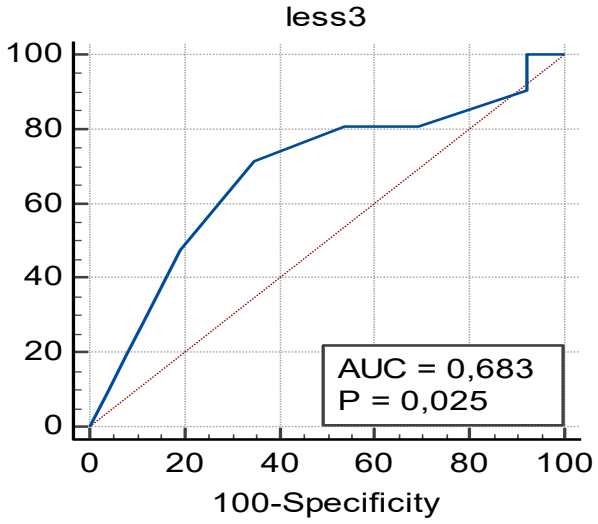
Table 1. Descriptive statistics of the participants

Variables	n	Mean	Standard Deviation	Median	Minimum	Maximum
Age	47	20.41	1.91	20.00	18	28
Height	47	163.81	7.02	164.00	150	180
Mass	47	60.72	10.16	61.00	40	80
Body Mass Index	47	22.49	2.47	22.57	16.61	27.34
LESS total score	47	5.49	2.37	6	1	10
Variable			**Frequency (n)**	**n**		**Percentage (%)**
Injury Status (n=47)			No	26		%55.3
			Yes	21		%44.7

When examining Table 1, descriptive statistics for 47 athletes are presented. The mean age and standard deviation of the athletes are 20.41±1.91 years, their height is 163.81±7.02 cm, body weight is 60.72±10.16 kg, body mass index is 22.49±2.47, and LESS scores range from 5.49±2.37. The youngest athlete is 18 years old, while the oldest is 28 years old. The tallest athlete is 180 cm, whereas the shortest is 150 cm. The highest recorded BMI is 27.34, while the lowest is 16.61. When examining LESS scores, the lowest recorded score is 1, and the highest is 10. Additionally, 55.3% (n=26) of the athletes did not experience any injuries, while 44.7% (n=21) reported having sustained an injury.

Table 2. ROC curve analysis

Risk Factors	AUC (%95)	Cut-off	p	Sensitivity	Specificity
LESS total score	0.683 (0.531 – 0.811)	5.5	0.025	%71.43	%65.38



When examining Table 2, it was concluded that the ROC curve for the LESS score is significant (AUC = 0.683, standard error = 0.082, p = 0.025). The analysis determined a cut-off value of 5.5, with a sensitivity of 71.43% and a specificity of 65.38%. In this study, the LESS score threshold for injury risk assessment was set at >5.

Table 3. The relationship between the determined cut-off value and injury status

		Cut-off		
		0 for ≤5 (No)	**1 for >5 (Yes)**	Total
Injury Status	No	17	9	26
	Yes	6	15	21
	Total	23	24	47

(Pearson Chi-square = 6.300, degrees of independence = 1, p = 0.012)

Table 3 presents the cross-tabulation of actual injury status and the condition calculated based on the cut-off value, along with the Pearson Chi-square test results. The Pearson Chi-square test statistic was found to be 6.300, and since p = 0.012 < 0.05, the null hypothesis (H0) was rejected. A significant relationship was identified between the determined cut-off value and injury status. Based on calculations from Table 3, the accuracy was determined to be 68.09%, sensitivity 71.43%, and specificity 65.38%.

Tablo 4. Frequency of participants making errors on LESS scoring items by injury status

LESS Item		**No Injury**	**Injury**	***p*-value**
Knee felxion angle at inital contact	0	3	23	0.684
	1	4	17	
Hip flexion angle at inital contact	0	26	0	0.447
	1	20	1	
Trunk flexion angle at initial contact	0	13	13	0.414
	1	13	8	
Ankle plantarflexion angle at initial contact	0	19	7	0.414
	1	13	8	

LESS Item		No Injury	Injury	*p*-value
Knee valgus angle at initial contact	0	11	15	0.529
	1	7	14	
Lateral trunk flexion angle at initial contact	0	15	11	0.529
	1	14	7	
Stance width – Wide	0	25	1	0.579
	1	19	2	
Stance width – Narrow	0	2	24	1.000
	1	2	19	
Foot position - Toe In	0	25	1	0.311
	1	18	3	
Foot position - Toe Out	0	17	9	0.805
	1	13	8	
Symmetric initial foot contact	0	9	17	0.927
	1	7	14	
Knee flexion displacement	0	24	2	0.644
	1	18	3	
Hip flexion at max knee flexion	0	25	1	1.000
	1	20	1	
Trunk flexion at max knee flexion	0	15	11	0.491
	1	10	11	
Knee valgus displacement	0	6	20	0.953
	1	5	16	
Joint displacement	0	25	1	0.003*
	1	12	9	

(The p-value from the Fisher's Exact Test was used when the expected minimum value was less than 5; otherwise, the p-value from the Pearson Chi-square test was used.)

Table 4 presents the frequencies of LESS parameters in relation to the athletes' injury status, along with the p-values from the Chi-square analysis.

DISCUSSION AND CONCLUSION

The purpose of the current research was to evaluate the association between landing mechanics and the likelihood of future lower extremity injuries in elite female wrestlers. While several studies have examined the predictive ability of LESS scores for injury risk, their outcomes remain conflicting. The discrepancies in these findings may be attributed to variations in research methodologies and participant characteristics. This study is the first to be conducted with elite-level female wrestlers, and the findings indicate a statistically significant relationship between LESS scores and lower extremity injuries. The results obtained from this specific group of participants suggest that, as widely reported in the literature, the LESS assessment tool can be utilized to determine injury risk.

In the LESS procedure, which is performed by kinetically evaluating the jump and landing phase from a fixed height, the test outcome is determined by the error scores recorded. A lower error score indicates a lower risk of injury. To achieve successful performance in the test, an adequate level of neuromuscular control mechanisms is essential. Research has

highlighted that insufficient neuromuscular control is a risk factor for non-contact ACL (Hewett et al., 2005; Zazulak et al., 2007) and lower extremity injuries (Butler et al., 2013; Gribble et al., 2016), emphasizing the importance of injury prevention approaches (Myer et al., 2013; Sugimoto et al., 2016; Foss et al., 2018). This study is the fourth prospective examination within the existing literature. In prior research, Padua et al. (2015) observed a notable association between LESS scores and injury occurrence, reporting that soccer athletes with LESS total scores equal to or exceeding 5 had a higher likelihood of sustaining non-contact ACL injuries than athletes scoring below this value. However, other studies have reported findings that contradict those of Padua et al. In their study involving high school and college athletes, Smith et al. (2012) did not find a relationship between LESS scores and non-contact ACL injuries. Similarly, Lisman et al. (2021) reported that their study, conducted with female collegiate athletes from various sports (basketball, field hockey, gymnastics, lacrosse, softball, volleyball), did not identify a relationship between lower extremity injuries and LESS scores. These differences can be attributed to methodological variables, modifications in the LESS assessment tool, participant differences, or variations in the definition of injury types. In the present study, a broad definition of injury was adopted because non-contact ACL injuries constitute only a small proportion of overall injury incidents. Thus, rather than limiting the scope to ACL injuries, using a more inclusive injury definition enabled a comprehensive analysis of the association between LESS scores and general lower extremity injuries. Furthermore, consistent with other clinical screening assessments, the LESS provides insight into specific biomechanical patterns of the lower extremity and trunk (individual LESS items), previously linked with injury risk across various studies (Lisman et al., 2021). In this study, it was determined that 21 participants experienced lower extremity injuries, and 15 of them (71.4%) had LESS error scores of 5 or higher, which was set as the threshold value.

The present research is the first prospective analysis evaluating the link between landing mechanics and lower extremity injury incidence in elite female wrestlers at the national team level. One of the key distinctions of this study is that, unlike previous prospective studies conducted on high school and collegiate athletes, it focuses on elite-level athletes. A review of past research reveals varying findings, which, as previously mentioned, are largely thought to result from methodological differences. For example, a study comparing LESS scores between male and female soccer players reported that gender did not result in a statistically significant difference in LESS scores. However, the study did not examine the relationship between LESS outputs and injury occurrence (James et al., 2016). From this perspective, this study is

significant in assessing future injury risk based on the obtained LESS test scores. Along with methodological differences, it is evident that factors such as variations in the scoring rubric, gender, athletic background, and age play a role in research findings. Regarding the age variable, high school athletes have been reported to have relatively higher LESS scores compared to collegiate athletes (Smith et al., 2012). Additionally, a meta-analysis study found that women had higher LESS scores than men, though this difference was not statistically significant (Hanzlíková et al., 2021). As can be understood, multiple factors may influence how LESS performance relates to injury incidence, suggesting the need for future studies that include athletes from different levels while also considering the gender variable.

In this study, the relationship between LESS scores and only future lower extremity injuries were examined. However, there are also studies in the literature that investigate the relationship between LESS scores and all musculoskeletal injuries (de la Motte et al., 2019; Everard et al., 2018). Unlike this research, different rubrics, such as 17- and 22-item versions, have been used, and different research designs, such as implementing training programs, have been applied. Findings indicate that individuals with higher LESS scores also have an increased risk of musculoskeletal injuries. These studies emphasize the necessity of interpreting findings with caution, highlighting that scoring errors and observer experience may influence the calculation of LESS scores. The motion capture technique used in this study, which involves video recording with markers attached to participants followed by motion analysis software application, may help prevent potential assessment errors. In this study, the frontal and sagittal plane recordings of participants' jump and landing performances were analyzed using the "Kinovea 0.8.27" software. After capturing the markers placed on the athletes via the software, scoring was conducted by observers. This approach aimed to minimize potential scoring errors.

The LESS scores obtained from this study were not used to provide injury prevention guidance to athletes during the follow-up period. Additionally, potential injury prevention programs or exercises that non-injured athletes may have participated in were not monitored. Previous research has shown that neuromuscular training programs, including at least six weeks of plyometric exercises and jump-landing mechanics training, improve LESS scores (Hanzlíková et al., 2021). Given the high neuromuscular demands required by the participants' sport, this factor may play a significant role in explaining the presence of non-injured athletes or their lower LESS scores.

This study has certain limitations. It was conducted exclusively with elite national-level female wrestlers. Participants self-reported their injury histories prior to inclusion in the study, and medical records were not utilized. When evaluating the relationship between landing mechanics and future injury risk, only the total LESS score for each participant was considered; the relationship between individual items in the rubric and injury occurrence was not separately analyzed.

In current study, a positive relationship was found between LESS outputs and future injury risk. It is believed that utilizing the LESS assessment tool to identify athletes at risk of injury and implementing appropriate injury prevention training programs may help reduce this risk. Athletes whose LESS scores were above the cut-off value but did not sustain injuries may have participated in preventive exercise programs or, if applicable, may have been cleared to return to sport following injury treatment without any restrictions. Additionally, since the LESS assessment tool identifies various errors across multiple trunk and lower extremity movements, the individual item scores could be valuable for designing injury prevention programs. Therefore, future research examining the relationship between individual LESS item scores and injury risk across different athlete groups would provide significant contributions to the field.

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KATKI ORANI ***CONTRIBUTION RATE***	**AÇIKLAMA** ***EXPLANATION***	**KATKIDA BULUNANLAR** ***CONTRIBUTORS***
Fikir ve Kavramsal Örgü *Idea or Notion*	Araştırma hipotezini veya fikrini oluşturmak *Form the research hypothesis or idea*	Ajlan SAÇ
Tasarım *Design*	Yöntem ve araştırma desenini tasarlamak *To design the method and research design.*	Ajlan SAÇ
Literatür Tarama *Literature Review*	Çalışma için gerekli literatürü taramak *Review the literature required for the study*	Ajlan SAÇ
Veri Toplama ve İşleme *Data Collecting and Processing*	Verileri toplamak, düzenlemek ve raporlaştırmak *Collecting, organizing and reporting data*	Ajlan SAÇ İsa SAĞIROĞLU
Tartışma ve Yorum *Discussion and Commentary*	Elde edilen bulguların değerlendirilmesi *Evaluation of the obtained finding*	Ajlan SAÇ

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This research was conducted with the decision of Trakya University Ethics Committee dated 30.10.2019 and numbered 2019.08.07