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Original Research

Morphometric Features of Sesamoid Bones in Foot Examined Using Computed Tomography

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ABSTRACT

Objective: Sesamoid bones are structures embedded in a tendon that reduce friction and provide mechanical advantages to joints. In this study, we aimed to determine the frequency and morphometric characteristics (surface area, long diameter, short diameter) of sesamoid bones in the foot using computed tomography (CT) and to investigate the effects of gender, side, and age factors.

Methods: Foot CT images (187 right, 213 left) of 400 individuals (239 males and 161 females) aged 18-86 years who underwent foot CT scans for various reasons were retrospectively reviewed. In axial sections, the surface area, long and short diameter of the sesamoids on the plantar surface of the metatarsophalangeal (MTP I) joint of the hallux were measured, while the presence of sesamoids in the other MTP and interphalangeal (IP) joints was recorded.

Results: Hallux sesamoids were found to be bilateral (medial and lateral) in all cases (100%), while the bipartite rate was determined to be 7%. The frequency of other sesamoids was found to be; MTP II 2.75%, MTP III 0.5%, MTP IV 1.5%, MTP V 9.75%, and Hallux IP 22.50%. All morphometric lengths of hallux sesamoids were found to be larger in males than in females ($p < 0.05$). Hallux sesamoids were larger in individuals aged 60 years and older compared to those aged 18-29 years ($p < 0.05$).

Conclusion: Morphometric lengths of sesamoid bones were determined, proving that they may be larger in males and with increasing age. This age-related increase brings to mind periarticular osteophytic formations secondary to chronic mechanical stress. The data obtained provide an objective anatomical reference in the differential diagnosis of sesamoid pathologies and in planning forefoot surgeries such as hallux valgus.

Keywords: computed tomography, foot, morphometry, sesamoid bones

INTRODUCTION

Sesamoid bones are small, ovoid bones typically found embedded near joint surfaces, within tendons or joint capsules. They reduce friction, protecting tendons from injury and enhancing the biomechanical effect of muscle force [1-3]. Specifically, the sesamoids located at the first metatarsophalangeal (MTP I) joint of the hallux mechanically optimize the toe's pushing force by extending the moment arm of the flexor hallucis brevis muscle tendon. Thus, they play a critical role in supporting weight-bearing function and distributing stress evenly [3-5].

Sesamoids have been reported to account for approximately 9% of foot and ankle injuries [4,6]. However, although these structures present clinically in cases of trauma, infection, sesamoiditis, osteoarthritis, and rare avascular osteonecrosis such as Renander's disease, they are often overlooked or misdiagnosed [2,4]. Another clinical challenge is the confusion between bipartite and multipartite variations and avulsion fractures [1]. The incidence of bipartite sesamoids ranges from 7% to 30% and is most often seen in the medial sesamoid [2,6]. Furthermore, it is thought that the incidence of bipartite medial sesamoid is significantly higher in individuals with hallux valgus deformity compared to normal feet, and this may be a factor in the progression of the deformity [5,7]. Accurate knowledge of the morphometric characteristics of sesamoids is crucial for differentiating these structures from pathologies such as avulsion fractures, infections, or osteonecrosis, thereby preventing misdiagnosis and inappropriate treatment [1,2].

Main Points

- Hallux sesamoid bones are present bilaterally in all individuals (100%); however, the rate of bipartite variation in the medial sesamoid (5.75%) is 4-5 times higher than in the lateral sesamoid (1.25%).
- Morphometric analyses revealed that the area and short diameter of the lateral hallux sesamoid bone are larger than the medial one, while the long diameter of the medial sesamoid is larger than the lateral one. This may be due to the different biomechanical functions of the ossicles and the stresses they are subjected to.
- Sesamoid bone dimensions are significantly larger in men than in women in all parameters, and an increasing trend in bone dimensions is observed with age (especially at 60 years and older).
- These millimeter morphometric data based on Computed Tomography (CT) data serve as an objective guide in clinically differentiating sesamoids from pathologies such as avulsion fractures and osteonecrosis, and in planning percutaneous sesamoid surgery and osteotomy.

Computed tomography (CT) reduces errors such as superposition (bone overlapping) and magnification (image appearing larger than its actual size) encountered in plain radiographs (X-rays), thus providing the possibility of measurements at the true anatomical scale. This supports the reliability of morphometric measurements [2,4]. Particularly due to its section accuracy and high resolution, CT allows for the millimeter-precise measurement of the true dimensions and surface areas of sesamoid bones, providing clinicians with reliable data for presurgical evaluation and differential diagnosis [4,5,8].

Although several studies have investigated the prevalence of sesamoid bones in the foot, the lack of morphometric data (area, long, and short diameter) makes it difficult for clinicians to differentiate between asymptomatic variation and pathological growth [1,5,9-11]. In this study, we aimed to present clinically relevant data on the morphometric characteristics and frequency of occurrence of sesamoid bones using advanced imaging techniques such as CT.

MATERIALS AND METHODS

Sample Selection

This study was conducted with the approval of the Selcuk University Faculty of Medicine Local Ethics Committee (Date: 2022-12-08, Approval number: 2022/490). Foot/ankle CT images (slice thickness 1 mm) obtained during routine emergency department evaluations between 2022-2025 from the CT unit (Siemens Somatom 16 Scope, Erlangen, Germany) in university medical faculty hospital radiology database (PACS) were retrospectively reviewed. This study is retrospective-based and performed on anonymized medical images; therefore, patient consent is not required. A moderate effect size (Cohen's d=0.50) was predicted for sesamoid bone size and area measurements between genders and sides. Calculations using G*Power (v3.1.9.7) software showed that at least 105 feet were sufficient for each group (female/male or right/left) when aiming for a two-sided hypothesis, α=0.05 significance level, and 95% statistical power (1−β). Foot CT images of 658 individuals aged 18 and over were retrospectively examined. Of the 658 feet, 258

were excluded from the study due to cases lacking diagnostic quality or containing metallic artifacts, comminuted fractures, excessive osteoporosis, arthrodesis, amputation, osteophytic cysts, and severe hallux valgus deformity (Angle>40°) that could disrupt the anatomical position and morphometry of the sesamoids. A total of 400 feet were evaluated, 187 right and 213 left, all belonging to different individuals, and the analyses were performed at the foot level.

Examination of the Images

All measurements of the Hallux sesamoids located inferior to the first MTP joint were performed on standardized axial CT slices selected based on clearly defined anatomical landmarks. The reference slice was defined as the section in which the sesamoid bone margins were most clearly visualized with maximal cortical continuity. Anatomical reference points such as the anterior and posterior cortical borders of the sesamoid bones were used to ensure consistency across all measurements and to minimiz. Multiplanar reconstruction was not utilized in this study in order to maintain methodological standardization and avoid potential variability arising from reformatting angles, thereby ensuring consistency of measurements across all specimens. The distance between the two furthest points in the antero-posterior direction of each sesamoid was considered as the long diameter. The short diameter was the distance at which the bone was measured at its widest point, perpendicular to this long axis. The area surrounding the bone was recorded as the surface area [1,5]. Measurements of the bipartite bones were taken separately and their sums were recorded (Figure 1). Three sections showing the largest possible image of each sesamoid bone were selected, and three separate measurements were taken using equal magnification ratios. The largest value obtained for each variable was recorded. The interphalangeal and other MTP (II-III-IV-V) joint sesamoids were not measured; their presence was only recorded (Figure 2). All measurements were repeated at two different times by an experienced (10 years) anatomist, and the average of these two measurements was used. The intra-observer reliability coefficient (ICC) was found to be 0.949 (95% CI: 0.930-0.970), indicating excellent agreement between the measurements.

Statistical Analysis

Statistical analysis of the data was performed using the SPSS 22.0 (IBM Corp. USA) software package. The skewness/kurtosis values and Kolmogorov-Smirnov Test results showed that the data regarding age and hallux sesamoids were normally distributed in gender and right/left groups [12]. Independent Samples t-Test was used to compare variables following normal distribution in gender and right/left groups, and Paired Samples t-Test was used for comparisons of medial and lateral sides. However, the data did not have a normal distribution among the created age groups (18-29, 30-39, 40-49, 50-59 and ≥ 60 years). Therefore, to compare the groups, the Kruskal-Wallis multiple comparison test was followed by the Mann-Whitney U test and Bonferroni correction. While $p < 0.050$ was accepted for primary tests, Bonferroni-corrected (0.05/10 paired test = Adjusted $p <$ 0.005) significance was used for post-hoc tests.

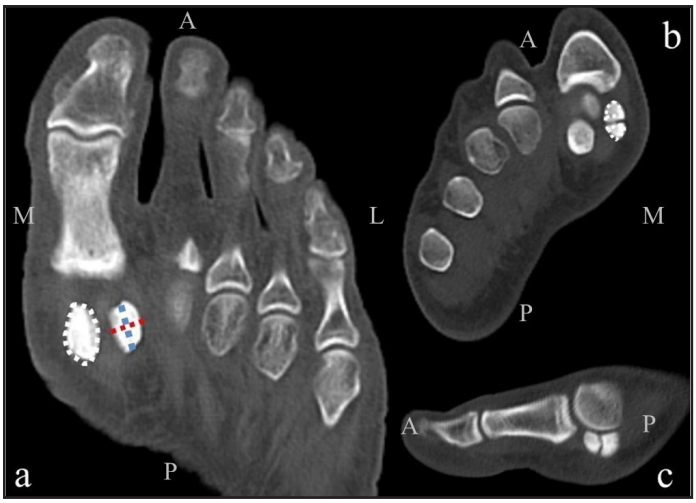

Figure 1. Hallux sesamoids. **a**: The white dashed line represents the surface area, the blue dashed line represents the long diameter, and the red dashed line represents the short diameter. **b**: Surface area measurement of bipartite sesamoid bone. **c**: Sagittal view of a bipartite sesamoid bone. A-anterior, P-posterior, M-medial, L-lateral.

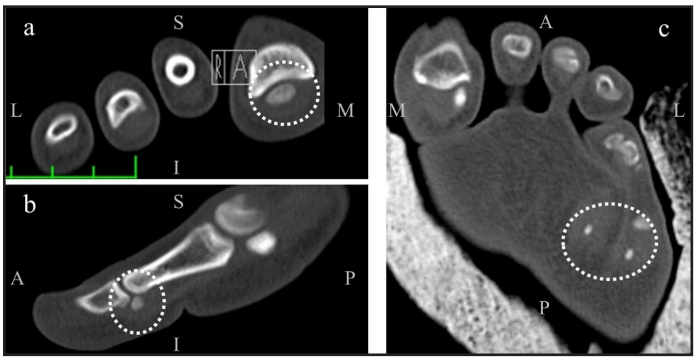

Figure 2. a: Coronal view of the interphalangeal joint (IP) sesamoid. **b**: Sagital view of the IP sesamoid. **c**: Axial view of the metatarsophalangeal joint (MTP IV-V) sesamoids. A-anterior, P-posterior, M-medial, L-lateral, S-superior, I-inferior.

RESULTS

Of the 400 feet evaluated (187 right, 213 left), 161 belonged to females and 239 to men. The mean age of the individuals was 36.78 ± 15.41 (18-86 years). The mean age of females (40.81±16.36) was significantly older than that of males (34.05 ± 14.13) ($p = 0.001$).

All individuals had bilateral hallux sesamoids. The frequency of bipartite variation was approximately 4-5 times higher in the medial sesamoid (23, 5.75%) compared to the lateral sesamoid (5, 1.25%). No sesamoid bones with more than two parts were found. The area of the lateral sesamoids was found to be 7% larger on average, and their short diameters were 12% larger than the medial sesamoids ($p < 0.050$). The long diameters of the medial sesamoids were found to be 4% larger on average than the lateral sesamoids ($p < 0.050$). All measured values of hallux sesamoids were found to be 12% higher in males than in females ($p < 0.050$) (Table 1). However, the difference between the right and left feet was not significant ($p > 0.050$). MTP II sesamoid bone was found in 11 (2.75%), MTP III in 2 (0.5%), MTP IV in 6 (1.5%), and MTP V in 39 (9.75%) feet. The overall prevalence of MTP II-V sesamoids was found to be 14.5%.

In the multiple comparison test conducted between age groups, significant differences were found in all measurement variables except the lateral sesamoid short diameter ($p < 0.050$). Post-hoc analyses revealed that the medial sesamoid area and short diameter were significantly larger in individuals aged 60 and over compared to those aged 18 to 39 (Adjusted $p < 0.005$). Similarly, both the long diameters of the sesamoids and the lateral sesamoid area were found to be significantly larger in individuals over 60 compared to those aged 18 to 29 (Adjusted $p < 0.005$). Accordingly, sesamoid morphometry tended to increase with age (Table 2).

Table 1. Comparison of hallux sesamoids between genders and sides.

Sesamoid Bones		Total (n=400)				Female (n=161, 40.25%)	Male (n=239, 59.75%)	p
		Min	Max	Mean±SD	P	Mean ± SD	Mean ± SD	
Area (mm²)	Medial	23.70	122.49	61.32 ± 18.56	<0.001*	54.65 ± 15.22	65.81 ± 19.26	<0.001*
	Lateral	18.80	129.02	65.85 ± 18.14		59.32 ± 15.03	70.25 ± 18.75	<0.001*
Short d. (mm)	Medial	3.68	11.28	6.70 ± 1.14	<0.001*	6.40 ± 1.02	6.91 ± 1.17	<0.001*
	Lateral	3.69	12.38	7.56 ± 1.27		7.21 ± 1.09	7.80 ± 1.32	<0.001*
Long d. (mm)	Medial	5.28	18.67	10.27 ± 2.07	<0.001*	9.61 ± 1.81	10.71 ± 2.12	<0.001*
	Lateral	4.77	15.50	9.86 ± 1.64		9.34 ± 1.54	10.20 ± 1.61	<0.001*

*Statistically significant, significant level $p < 0.050$; P: Paired Sample T-Test; p: Indepented Sample T-Test; Min: Minimum; Max: Maximum; SD: Standart deviation; d. Diameter.

Table 2. Comparison of hallux sesamoids across age groups.

Sesamoid Bones		Age Group (Year, Mean ± SD)					p
		18-29 (n:177)	30-39 (n:66)	40-49 (n:65)	50-59 (n:49)	60 ≤ (n:43)	
Medial	Area (mm²)	57.92 ± 17.17	60.18 ± 17.26	63.73 ± 21.12	63.34 ± 18.91	71.10 ± 17.99	0.001*
Lateral		63.29 ± 16.68	65.28 ± 19.51	66.53 ± 20.70	69.34 ± 15.61	72.28 ± 18.80	0.021*
Medial	Short diameter (mm)	6.45 ± 1.04	6.58 ± 1.08	6.94 ± 1.32	6.96 ± 1.15	7.29 ± 1.01	<0.001*
Lateral		7.44 ± 1.17	7.39 ± 1.43	7.72 ± 1.43	7.79 ± 1.12	7.80 ± 1.20	0.089
Medial	Long diameter (mm)	10.07 ± 1.97	10.01 ± 1.92	10.46 ± 2.30	10.29 ± 2.26	11.17 ± 1.93	0.022*
Lateral		9.63 ± 1.56	9.69 ± 1.59	9.85 ± 1.74	10.24 ± 1.57	10.62 ± 1.72	0.004*

*Statistically significant, significant level $p < 0.05$; Kruskall-Wallis Test; SD: Standart deviation.

DISCUSSION

Congenital absence of hallux sesamoids is a rare variation and difficult to distinguish in images of children under 10 years of age [13]. This study was conducted on adult individuals, and hallux sesamoids were present medially and laterally in all participants. The prevalence of the hallux and other sesamoid bones was compared with previous studies in Table 3.

Studies generally agree that hallux sesamoids are present in all individuals [8,9,11,14-16]. However, the small difference of 0.04% in the study by Sun et al. [8] may be due to the fact that individuals over five years of age were examined, and the large difference of 13.6% in the study by Bilir et al. [10] may be due to the fact that individuals over one year of age were examined, and therefore the sesamoids with incomplete ossification could not be visualized in direct radiography. Furthermore, there are significant differences in the prevalence of other sesamoids (MTP II-V) among studies in the literature. For example, while MTP V sesamoid bone was observed in 9.75% of cases in our study, Candan et al. [11] reported this rate as 5.8%, and Yammine [16] reported it as 13%. This difference in results may be due primarily to ethnic differences, and secondarily to differences in imaging modalities. The literature emphasizes that the prevalence of sesamoids is higher in individuals of European origin compared to those of African origin [16]. In the presented study, CT was used, which eliminates the superposition that can occur in direct radiography, thus allowing for a higher accuracy in determining anatomical reality [2,4]. After the hallux sesamoids, the MTP V sesamoid is the most frequently reported, while the MTP III sesamoid is the least frequently reported. This may be because the load distribution in the foot is mainly transmitted medially through the hallux sesamoids and laterally through the MTP V sesamoid. Considering the role of the lateral column of the foot in bearing the load during the stance phase of gait, the presence of the MTP V sesamoid can be interpreted as an adaptation for absorbing mechanical stress in this region.

Sesamoid bones can sometimes be found bipartite. Knowing the variation rates and normal sizes of bipartite sesamoid bones can prevent misdiagnosis of avulsion fractures, which are frequently encountered in emergency departments [1,17]. In differential diagnosis, sclerotic bone edges (appearing brighter white on CT) are indicative of bipartite sesamoid. In fracture cases, loss of cortical continuity and surrounding soft tissue edema are present in the acute phase [2,18]. The dimension data provided in our study offer an objective criterion for making this distinction. A comparison of the literature studies based on the side and frequency of occurrence of bipartite hallux sesamoids is given in Table 4. All studies agree that bipartite formation is most common in the medial hallux sesamoid [7,8,10,16,17]. The results of the study presented are quite similar to the study by Munuera et al. [7]. In the study by Bilir et al. [10], the medial bipartite rate was reported to be the lowest. The reason for the difference in other studies may be due to measurement techniques or population differences.

In the gender-based analysis presented in the study, although the average age of males was younger, all sesamoid bone measurements were significantly larger than those of females. This can be explained by general gender-specific biometric differences in the skeletal system [1]. The prevalence of sesamoid bones is generally similar in both male and female cases. However, comparisons between age groups show an increase in sesamoid size, particularly in individuals aged 60 and over. This increase observed in the elderly group may be related to the adaptive growth and volumetric expansion process triggered in bone tissue by cumulative biomechanical stress experienced throughout life [1,3]. Perhaps this situation is due to the fact that marginal osteophytes (bone spurs) developing in sesamoid bones due to osteoarthritis and aging can cause larger bone surface area and diameter measurements in radiological measurements, as reported by Shah and Patel [2]. Sclerosis and cortical thickening processes caused by chronic stress and repetitive microtraumas may lead to sesamoid structures appearing much more voluminous and prominent in high-resolution methods such as CT scans [4,6]. In conclusion, morphometric characterization of these hypertrophic and degenerative changes observed in the elderly population is important for differentiating normal signs of aging from acute sesamoid pathologies [1,11]. Average dimensions of the hallux sesamoid were compared with the limited number of studies in the literature in Table 5.

Our study found that the lateral sesamoid had a larger surface area and shorter diameter than the medial sesamoid, while the medial sesamoid had a longer diameter than the lateral sesamoid. The larger long diameter axis of the medial sesamoid provides a longer moment arm for the flexor hallucis brevis muscle, increasing the flexion force of the hallux; while the larger surface area of the lateral sesamoid may help distribute the load over a wider surface, providing stability against the risk of lateral subluxation. However, Table 5 shows that Zhang et al. [5] found the medial sesamoid bone to be rounder and shorter,

while the lateral sesamoid bone was longer and wider. This is because they are making measurements using 3D images, and there may be ethnic variations. Furthermore, the results were smaller compared to the measurements of Değermenci et al. [1]. This difference may be due to their measurements being taken direct radiography. Because dramatic advancements in medical imaging software have ushered in a new era in the evaluation of these structures, researchers can now perform area and diameter measurements with millimeter precision using high-resolution digital tools and 3D images [5]. All studies seem to agree that the lateral sesamoid bone is larger than the medial one. Understanding these differences and the normative lengths of sesamoid dimensions is crucial for surgical planning and success in biomechanical deformities such as hallux valgus [5].

Table 3. Comparison of sesamoid bones prevalence with previous studies.

Studies		n	Hallux (%)	MTP II (%)	MTP III (%)	MTP IV (%)	MTP V (%)	Hallux IP (%)
Longo et al. (2013/Italy)	X-Ray	505	100	3	1.2	1.8	19.2	4.16
Yammine (2015/meta-analysis)	All	14385	100	1.8	0.32	0.9	13	22.4
Sun et al. (2016/China)	X-Ray	8716	99.96	3.08	0.39	0.69	8.94	59.22
Koo et al. (2017/ South Korea)	X-Ray	213	100	8	1	2	25	65
Al Shabibi et al. (2020/Oman)	X-Ray	774	100	3.7	1	0.9	13.7	9.9
Candan et al. (2022/Turkey)	X-Ray	1651	100	0.6	0.06	0.66	5.87	0.87
Bilir et al. (2022/Turkey)	X-Ray	506	86.4	2	N/A	0.4	6.7	2
Present study (2025/Turkey)	CT	400	100	2.75	0.5	1.5	9.75	22.5

MTP; Metatarsophalangeal joint. IP; interphalangeal joint.

Table 4. Comparison of the prevalence of bipartite hallux sesamoids with previous studies.

Studies	Type	n	Medial (%)	Lateral (%)
Munuera et al. (2007/Spain)	X-Ray	474	5.9	1.68
Yammine (2015/meta-analysis)	All	14385	10.7	1.24
Sun et al. (2016/China)	X-Ray	8716	6.19	0.27
Padmanaban et al. (2021/India)	X-Ray	1000	7.4	
Bilir et al. (2022/Turkey)	X-Ray	506	2.37	N/A
Present study (2025/Turkey)	CT	400	5.75	1.25

X-Ray radiography. CT computed tomography

Table 5. Comparison of average measurements of hallux sesamoids with previous studies.

Studies	Type	n	Medial sesamoid bone		Lateral sesamoid bone	
			Long diameter (mm)	Short diameter (mm)	Long diameter (mm)	Short diameter (mm)
Zhang et al. (2020/China)	CT (3D)	150	8.48 ± 2.65	7.4 ± 2.2	11.88 ± 1.36	8.95 ± 1.13
Present study (2025/Turkey)	CT	400	10.27 ± 2.07	6.70 ± 1.14	9.86 ± 1.64	7.56 ± 1.27
			Area (mm^2)			
Değermenci et al. (2024/Turkey)	CT X-Ray	115	90.98 ± 27.41		93.01 ± 24.56	
Present study (2025/Turkey)	CT	400	61.32 ± 18.56		65.85 ± 18.14	

X-Ray radiography. CT computed tomography, 3D three dimensional.

Clinically, the morphometric data presented in this study can assist surgeons in preoperative planning, particularly in procedures where sesamoid dimensions are necessary for implant selection and surgical guidance, such as hallux valgus correction, sesamoidectomy, or osteotomy. Furthermore, these measurements can aid in differentiating normal anatomical variations from subtle pathological findings and in distinguishing bipartite sesamoids from acute fractures.

Limitations

This study is a retrospective analysis of data from patients who presented to the emergency department of a hospital in a specific region; therefore, it may not represent the entire general population and healthy individuals. And, since the average age of women was higher than that of men, the effect of age on gender-specific differences remained unclear. Furthermore, the relationship between sesamoid bone dimensions and foot pathologies, as well as individual lifestyle factors such as physical activity level or body mass index, could not be evaluated due to the nature of the available data. Another limitation of this study is the absence of fracture cases; this did not allow for a visual presentation of the difference between bipartite sesamoids and this study. Despite these limitations, our study is significant because it is one of the limited studies in the literature that comprehensively analyzes the morphometric characteristics (area, short diameter, long diameter) of hallux sesamoids and the frequency of other MTP joint sesamoids via CT images. Clinically, these measurement data, specifically bipartite ratios, serve as an objective guide in emergency departments to prevent confusion of sesamoids with pathologies such as avulsion fractures, sesamoiditis, or osteonecrosis.

CONCLUSION

The morphometric characteristics and prevalence of sesamoid bones in the Central Anatolian population have been determined, and it has been proven that their size may increase in males and with advancing age. It was found that medial and lateral sesamoids differ from each other to achieve maximum biomechanical advantage, and that chronic mechanical stress can cause osteophytic formations, increasing the size of the sesamoids. These data provide an objective reference, particularly in percutaneous sesamoid surgery or osteotomy planning, for predicting the actual size of the bones. Furthermore, this study may inspire new research on the correlation of sesamoid bones with functional variables such as hallux valgus severity, body mass index, and physical activity levels.

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Conflict of Interest: The authors declare that they have no conflicts of interest.

Informed Consent: Retrospective archival study.

Data Availability Statement: We respect the importance of transparency and reproducibility in research, but we are committed to the privacy of the participants involved in our study. Therefore, raw data are protected and cannot be publicly disclosed. However, we offer a comprehensive guide within the sections detailing our methodology and statistical analysis. This thorough explanation aims to enable other researchers to replicate our methods and compare their findings with ours.

Ethical Approval: All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval (Approval number: 2022/490, Date: 2022-12-08) was given by the Non-Intervention Clinical Research Ethics Committee of the Selçuk University Faculty of Medicine.

Author Contributions: Conception: TUK, ZF; MSD, AKK - Design: TUK - Supervision: ZF - Fundings: None -Materials: MSD - Data Collection and/or Processing: TUK - Analysis and/or Interpretation: HK - Literature: TUK - Review: NUD - Writing: TUK - Critical Review: AKK.

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