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RESEARCH

Radiologic and anatomical evaluation of scapular inclination, glenoid version, and scapulothoracic angle in healthy adult subjects

Sağlıklı yetişkin bireylerde skapular eğimin, glenoid versiyonun ve torakoskapular açının radyolojik ve anatomik değerlendirmesi

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Abstract

Purpose: The aim of this study is to determine the normal reference values for natural glenoid version, scapulothoracic angle, and scapular inclination angle in a healthy population, and to assess whether these parameters vary according to age and gender.

Materials and Methods: This study was conducted on 120 healthy adult subjects (58 females, 62 males) aged 21 to 75 years, using Computed Tomography (CT). The participants were divided into two primary groups based on gender (female and male), and further categorized into six age-based groups. Five parameters were evaluated in total. The glenoid version was measured at three levels: middle (GVM), below (GVB), and above (GVA) the glenoid.

Results: The mean ages of the female and male participants were 51.54 ± 20.16 years and 49.60 ± 18.82 years, respectively. The GVA, GVM, GVB, SIA, and STA were found as 5.53°±8.01°, -0.02°±5.08°, 1.37°±5.03°, 47.03°±9.42°, and 41.30°±9.55° in females, respectively. The same dimensions were -4.25°±8.62°, -0.53°±5.49°, -0.02°±5.57°, 44.90°±8.40°, and 44.82°±9.19° in males, respectively. Post hoc test demonstrated that the SIA and STA values showed significant differences across age groups 1 to 6.

Conclusion: This study provides data that may serve as a reference for distinguishing between normal and pathological anatomy, while also offering essential anatomical and radiological parameters that will enable clinicians particularly radiologists and orthopedic surgeons to assess, reconstruct and design this anatomical structure.

Keywords: Shoulder joint, glenoid version, scapulothoracic angle, scapular inclination

Öz

Amaç: Bu çalışmanın amacı, sağlıklı bir popülasyonda doğal glenoid versiyonunun, skapulotorasik açının ve skapular inklinasyon açısının normal referans değerlerini belirleyerek, bu parametrelerin yaş ve cinsiyete göre değişiklik gösterip göstermediğini belirlemektir.

Gereç ve Yöntem: Bu çalışma, yaşları 21-75 arasında değişen 120 sağlıklı yetişkin (58 kadın; 62 erkek) üzerinde Bilgisayarlı Tomografi (BT) kullanılarak gerçekleştirildi. Veriler sağlıklı yetişkin kadın ve erkekler olmak üzere iki gruba ve ayrıca yaşa göre altı gruba ayrıldı. Beş parametre değerlendirildi. Glenoid versiyonu orta versiyon (GVM), alt versiyon (GVB) ve üst versiyon (GVA) olmak üzere üç seviyede ölçüldü.

Bulgular: Kadınların ve erkeklerin yaş ortalamaları sırasıyla 51,54±20,16 yıl ve 49,60±18,82 yıldır. VA, VM, VB, SIA ve STA kadınlarda sırasıyla 5,53°±8,01°, -0,02°±5,08°, 1,37°±5,03°, 47,03°±9,42° ve 41,30°±9,55° olarak bulunmuştur. Aynı parametreler erkeklerde sırasıyla -4,25°±8,62°, -0,53°±5,49°, -0,02°±5,57°, 44,90°±8,40° ve 44,82°±9,19° idi. Ayrıca Post Hoc testine göre, SIA ve STA parametreleri grup 1 ile 6 arasında anlamlı bir fark gösterdi.

Sonuç: Bu çalışma, normal anatomi ile patolojik anatomiyi ayırt edebilmek açısından referans oluşturabilecek veriler sağlarken; özellikle radyologlar ve ortopedik cerrahlar başta olmak üzere klinisyenlerin bu anatomik yapıyı değerlendirmelerine, yeniden yapılandırmalarına ve yeniden tasarlamalarına olanak sağlayacak temel anatomik ve radyolojik veriler sunmaktadır.

Anahtar kelimeler: Omuz eklemi, glenoid versiyon, skapulatorasik açı, skapular inklinasyon

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INTRODUCTION

The shoulder or glenohumeral joint (GHJ) is a ball-and-socket type joint that permits a wide range of motion. The key bony structure is the scapula. The glenoid cavity on the lateral aspect of the scapula constitutes the articular surface of the GHJ[1]. Shoulder function is enabled through the synchronized movement of the sternoclavicular, acromioclavicular, and glenohumeral joints, as well as the scapulothoracic pseudojoint[2]. Most studies examining normal or impaired synchrony in the shoulder joint have reported the presence of numerous static and dynamic mechanisms that ensure the critical balance between shoulder mobility and stability. Additionally, the rotator cuff muscles (RCMs) play a crucial role in shoulder dynamic stability due to their close positional relationship with the joint. These muscles provide stability to a dynamic reference point during shoulder abduction. Furthermore, they help maintain the humeral head within the glenoid concavity and reduce shear forces[3-7].

Glenoid version (GV), an important anatomical angle, is defined as the angle between the glenoid face and the scapular body [8]. This angle can be measured using 3D scapula computer models, by the Friedman Method, or by the Robertson Method[9]. Other important angles in the shoulder joint are the scapulothoracic angle (STA)[10], and the scapular inclination angle (SIA)[11]. The glenoid dimension measurements, including version and inclination are significant in revealing the pathomechanics of the GHJ. There are studies on the role of GV in joint stability and RCTs, as well as studies examining the mechanism of action of glenoid tilt in various shoulder pathologies[12-16]. Glenoid version (GV) and scapular inclination angle (SIA) are parameters utilized by orthopedic surgeons to reconstruct the anatomy of the humerus and glenoid[17].

Understanding the glenoid version, scapulothoracic angle, and scapular inclination angle is essential for assessing the normal glenohumeral relationship, ensuring the longevity of total shoulder prostheses, and comprehending shoulder function and pathology, particularly with regard to range of motion, instability, and rotator cuff tears (RCTs). Furthermore, knowledge of glenoid version and inclination is critical for achieving proper anatomical reconstruction. A thorough understanding of the normal anatomy of a structure is vital, as it enables the orthopedic surgeon to effectively reconstruct and redesign the structure when pathological anatomy is present[17-19]. In surgical interventions involving the glenoid region, preoperative planning with imaging methods is very important. Computed Tomography (CT) scans are most commonly preferred to assess the glenoid position because of more accurate information than the other imaging techniques[3]. Our hypothesis in this study is to investigate whether the values of glenoid version, scapular inclination, and scapulothoracic angle in healthy adult individuals fall within a specific anatomical reference range and whether these parameters show statistically significant differences based on age and gender. Also, this study aims to determine the normal reference ranges of key scapular anatomical parameters, such as glenoid version, scapular inclination, and scapulothoracic angle, in healthy adult individuals. By examining the impact of demographic factors such as age and sex on these parameters, the study provides valuable data for the accurate assessment of shoulder pathologies and the optimization of anatomical alignment in surgical interventions. The findings offer a reliable foundation for clinical practice and serve as a valuable reference source for orthopedic surgical decisions.

MATERIALS AND METHODS

Sample

The present study was conducted with 120 healthy adult subjects (58 females and 62 males) aged 21-75 years, using CT scans (128-slice multidetector, Siemens Somatom Definition AS, Siemens Healthcare). Initially, 220 images from healthy subjects were available for evaluation. However, 40 of these images were deemed unsuitable for analysis due to unclear visibility of the measurement points. Additionally, 45 images displayed shoulder joint instability, with suspected rotator cuff tears, and 15 images showed signs of osteoporosis.

The data were divided into two groups: healthy females and males, and six groups according to age (Tables 1-3),

Group 1, 23 healthy subjects (HS) (12 males, 11 females) aged 21-30 years,

Group 2 (31-40 years), 17 HS (10 males, 7 females),

Group 3 (41-50 years), 20 HS (10 males, 10 females),

Group 4 (51-60 years), 20 HS (10 males 10 females),

Group 5 (61-70 years), 20 HS (10 males, 10 females),

Group 6 (71 years and over), 20 HS (10 males, 10 females).

Study design

Since our study is retrospective, individuals who met the inclusion criteria were included, while cases with unclear images or indistinct reference points for measurement were excluded. The sample size for the study was calculated based on these considerations. The measurements performed on the computer screen with an electronic caliper were expressed as degrees (°). This study was conducted at the Department of Radiology, Bozyaka Education and Research Hospital, University of Health Sciences, İzmir. The CT analyses were performed by three independent observers: Observer 1, a radiologist (MÖ); Observer 2, a radiologist (FYÖ); and Observer 3, a radiologist (ÖY). The study was approved by the Clinical Research Ethics Committee of Cukurova University, with Decision No: 2025/151-6. Additionally, the data were obtained from official hospital records, and all file security procedures were carried out in accordance with the protocols established by the relevant institution.

Data collection tools

The inclusion criteria were;

Subjects were selected by criteria of optimal health.

The exclusion criteria were;

1) having a neurologic disease or rheumatic disease,

2) having a surgical operation related to the spinal cord, brainstem, or upper extremity,

3) a pathology or an anomaly involved in upper extremity

4) having a fracture or sprain related to the upper extremity

5) having no rotator cuff tear

Moreover, those with low vertebral density on CT were considered to have osteoporosis. In more detail, those with T12 vertebral density below 100 Hounsfield Unit (HU) on CT were considered to have osteoporosis. In addition, the presence of instability in the patient was also determined by using CT images.

The measurements used in this study were as follows[3,12,14-16].

The glenoid version was measured at three levels. The first measurement was performed at the cranio-caudal center of the glenoid, with additional measurements taken 9.5 mm above and below this level, designated as version middle (GVM), version below (GVB), and version above (GVA). Additionally, the scapular inclination angle (SIA), formed by the scapular axis and the frontal plane, was measured. The scapulothoracic angle (STA), defined as the angle between the scapular axis and the reference plane passing through the vertebral body, spinal canal, and the spinous process vertex of the adjacent vertebra, was also measured.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS) version 21.0 for Windows was used for statistical analysis of the study data. The normality assumption was decided by the Shapiro-Wilk test. Mean and standard deviation were calculated. In all statistical analyses, a p-value under 0.05 was considered to be statistically significant. In addition, based on the analysis of the measurements, the following statistical methods were applied. The p-values for the data and means were analyzed using ANOVA, while a post hoc test was conducted to assess age-related changes.

RESULTS

The study included 120 healthy individuals aged 21-75 years. The mean age of the females in the study was 51.54±20.16 years, while the mean age of the males was 49.60±18.82 years. Also, 72 subjects were right dominant (28 females and 34 males) and 48 individuals were left dominant (30 females and 28 males). No statistically significant difference was found between the mean ages of females and males ($p=0.699$). In Table 1, the gender-dependent changes in the data are shown. According to this table, the GVA, GVM, GVB, SIA, and STA were found as 5.53°±8.01°, -0.02°±5.08°, 1.37°±5.03°, 47.03°±9.42°, and 41.30°±9.55° in females, respectively. The same dimensions were -4.25°±8.62°, -0.53°±5.49°, -0.02°±5.57°, 44.90°±8.40°, and 44.82°±9.19° in males, respectively. The two values (GVA and STA) were higher in males than in females. Among the two values, TSA was statistically significant and higher in males than in females. The distribution of scapular

inclination and glenoid version measurements according to the dominant limb and gender is shown in Table 2. Only two values, including GVA, and STA showed a significant difference between the right and left sides, and the two values were lower on the right side than on the left side. Moreover, in Table 3, age-related changes in scapular inclination and glenoid version measurements were shown. All measurements showed no significant difference between decades. Also, the Post Hoc test was applied. According to this test, the SIA value showed a significant difference between Group 1 and Group 4 (p=0.043), Group 2 and Group 5 (p=0.046), and Groups 4-5 (p=0.023), Groups 5 and 6 (p=0.036). In STA measurement, a significant difference between Group 1 and Group 4 (p=0.044), Groups 4-5 (p=0.039), Groups 4 and 6 (p=0.049).

Table 1. Comparison of scapular inclination and glenoid version measurements between genders

Measurements (degree)	Females (n=58)	Males (n=62)	P value
Glenoid version above (GVA)	-5.53±8.01 (-26.70-20.40)	-4.25±8.62 (-25.10-19.70)	0.401
Glenoid version middle (GVM)	-0.02±5.08 (-12.00-19.10)	-0.53±5.49 (-11.50-12.00)	0.597
Glenoid version below (GVB)	1.37±5.03 (-9.50-20.20)	-0.02±5.57 (-10.00-19.00)	0.156
Scapular inclination angle (SIA)	47.03±9.42 (22.10-73.50)	44.90±8.40 (22.70-72.20)	0.193
Scapulothoracic angle (STA)	41.30±9.55 (16.50-67.90)	44.82±9.19 (17.80-67.30)	0.042

Table 2. Distribution of scapular inclination and glenoid version measurements according to dominant extremity and gender

Measurements (degree)	Right side (n=72)	Left side (n= 48)	P value
Glenoid version above (GVA)	-6.09±7.65	-3.03±9.01	0.048
Glenoid version middle (GVM)	-0.92±5.37	0.66±5.04	0.108
Glenoid version below (GVB)	0.32±5.32	1.16±5.37	0.398
Scapular inclination angle (SIA)	47.11±8.28	44.15±9.65	0.075
Scapulothoracic angle (STA)	41.68±8.91	45.27±10.01	0.042

Table 3. Age-related changes in scapular inclination and glenoid version measurements

Measurements	Group 1 (n=23)	Group 2 (n=17)	Group 3 (n=20)	Group 4 (n=20)	Group 5 (n=20)	Group 6 (n=20)
Glenoid version above (GVA)	-4.02±5.35	-2.85±7.31	-4.78±8.37	-4.93±10.47	-7.34±11.52	-5.06±7.56
P value	0.696					
Glenoid version middle (GVM)	-1.38±3.68	0.62±5.13	0.27±4.96	0.96±5.40	-1.02±7.06	-0.88±5.29
P value	0.636					
Glenoid version below (GVB)	0.50±4.16	1.68±4.92	-0.55±4.64	1.64±4.29	-0.39±6.68	1.21±6.95
P value	0.658					
Scapular inclination angle (SIA)	48.71±5.42	43.78±12.83	45.68±9.18	43.24±5.60	49.60±11.63	43.82±6.03
P value	0.086					
Scapulothoracic angle (STA)	40.90±4.96	46.22±12.83	44.23±8.51	46.72±5.58	40.55±11.52	40.89±10.90
P value	0.114					

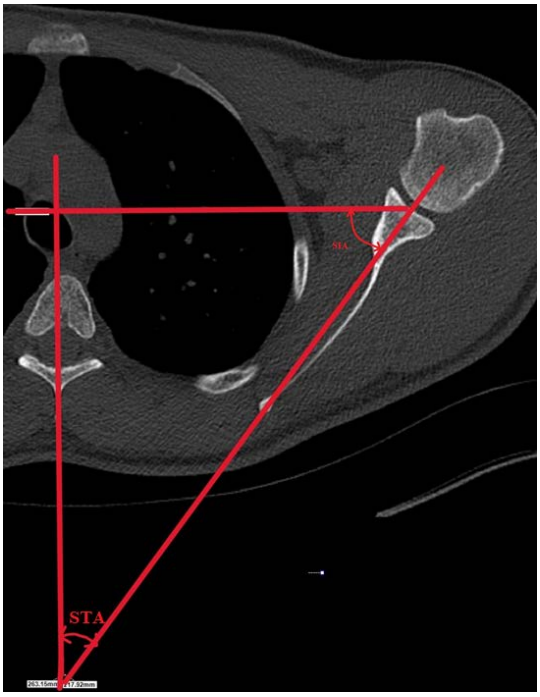

Figure 1. Scapular inclination and scapulothoracic angles (SIA – scapular inclination angle, STA – Scapulothoracic angle).

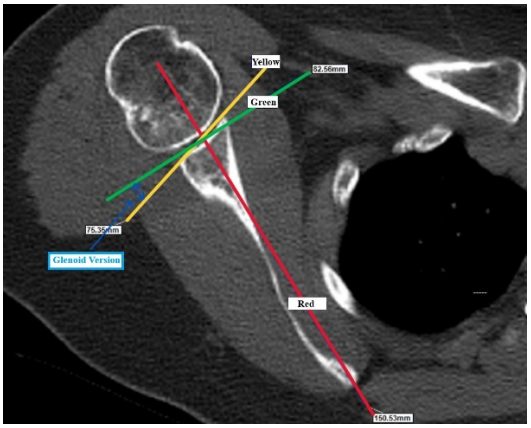

Figure 2. The scapular axis (Friedman line) is indicated in red. The line perpendicular to the scapular axis, passing through the center of the glenoid, is shown in green. The line connecting the rims of the glenoid is marked in yellow, and the angle of glenoid version is represented in blue.

DISCUSSION

The scapulothoracic joint is a complex articulation between the anterior surface of the scapula and the surface of the thoracic cavity. This joint shows 6 degrees of freedom by moving in 3 planes. These are up/down rotation, internal/external rotation, and anterior/posterior tilt. It also provides dynamic shoulder alignment with the trunk during pitching[20]. A slight retroversion can also be seen in the glenoid version under physiological conditions. In this context, 0° represents a neutral glenoid version, while positive and negative values indicate anteversion and retroversion, respectively. The glenoid version is typically measured using either the Friedman method or the glenoid vault method. In the technique described by Friedman et al., the version is measured by drawing a line from the most medial point of the scapula to the midpoint of the line connecting the anterior and posterior rims of the glenoid. In addition, anterior shoulder instability is associated with lower glenoid concavity in the coronal planes. The role of the GV in the context of anterior glenohumeral stability is still a matter of debate[21].

GV and SIA are parameters commonly utilized by orthopedic surgeons in the anatomical reconstruction of the humerus and glenoid[17]. Individuals of different races, genders, and body structures are of interest to surgeons because they may show some variations in glenoid morphology. Of them, gender is a powerful independent sign of glenoid dimensions. Understanding these anatomical variations constitutes a critical step and a practical approach when restoring normal glenohumeral structure during shoulder reconstruction surgery[22]. The means of the GV indicates that most glenoids are in the retroversion position. In addition, the measurements show that the glenoid retroversion decreases from top to bottom. The retroversion decreases even more in the caudal direction. The glenoid reaches its highest retroversion values in the cranial section, and the decrease in retroversion in the center of the glenoid is evidence of spiral bending, which should be taken into account when planning joint replacements[3]. The study by Bouchaib et al also confirms that the retroversion decreases from top to bottom[23].

The glenoid dimension measurements, including version and inclination are significant in revealing the pathomechanics of the GHJ. There are studies on the role of GV in joint stability and RCTs, as well as studies examining the mechanism of action of glenoid tilt in various shoulder pathologies[12-16]. Moreover, in shoulder arthroplasty (SA), impaired positioning of the glenoid component, excessive

retroversion, and inclination may be reasons for prosthetic instability and early component loosening or failure. Incorrect prosthesis size has been demonstrated to cause malalignment, which can result in an unstable fixation. This has been shown to lead to the loosening of the prosthesis and early implant failure. For this reason, GV parameters' preoperative assessment is critical, and the implant size must be chosen accordingly[12]. The GV is described as the angle between the scapula and the glenoid and varies from 0-10 degrees. Preoperative determination of the GV is the most essential method, and it affects the placement of the glenoid component of SA. Many factors, including handedness, gender, race, and pathology affect the GV. The GV has a significant impact on the GHJ biomechanics. It also varies in some pathologies like arthritis and GHJ instability. Clinically, glenoid retroversion is related to anterior superior RCTs. The anteversion is linked with posterior RCTs. Determination of GV becomes crucial for subjects undergoing arthroplasty, as maintaining a normal degree of GV will decrease stress and wear on the glenoid component of SA[24]. The mean values of retroversion may vary across studies. Mizuno et al and Piponov et al found that the glenoid version varies in various ethnicities and genders[22,25]. Furthermore, a comprehensive understanding of the role of glenoid version (GV) in shoulder biomechanics is essential for the early detection of pathologies, effective preoperative planning of shoulder arthroplasty (SA), and successful surgical restoration of a functional glenohumeral joint (GHJ)[22,25,26].

Matsumura et al. stated that retroversion showed a link between male, and hand dominance[26]. In a study conducted by Sarı et al., retroversion angles of 1.07° and 1.04° were observed in favor of the dominant side in right-handed and left-handed individuals, respectively, while the gender parameter was found to have no significant effect on glenoid version[27]. Similarly, Friedman et al. and Tackett et al. conducted studies in which no relationship between gender and GV was identified. Bouchaib et al. noted in their study that GV appears to decrease with age in certain regions of the glenoid. The hypothesis proposed by the researchers was that the decrease in retroversion with age could be explained by compression of the subchondral bone resulting from mechanical restrictions in the glenoid cavity[22]. In this paper, although retroversion was more common on the right side and in males, no statistical correlation was found between dominant side and gender and glenoid version. Although retroversion was more common in individuals in Group 5 among age groups, no significant difference was found between age groups. Additionally, the GVA, GVM, and GVB were found as 5.53°±8.01°, -0.02°±5.08°, 1.37°±5.03° in females, respectively. The same dimensions were -4.25°±8.62°, -0.53°±5.49°, -0.02°±5.57° in males, respectively. The GVA was higher in males than females. Only GVA showed a significant difference between right and left sides, and the value was lower on the right side than on the left side.

Scapular inclination may vary due to anatomical variations such as the shape of the chest, the shape of the scapula, the anatomy and functional status of the muscles surrounding the scapula, or as a result of various pathological conditions. Awareness of SIA during preoperative planning can eliminate potential surgical errors. Additionally, knowledge of SIA is essential for optimal centering of the spine of the glenoid component of a shoulder prosthesis implant[3]. In this study, the scapular inclination angle (SIA) was higher in females, with an average of 47.03°, compared to 44.90° in males; however, this difference was not statistically significant. Similarly, the mean SIA values were 47.11° on the right side and 44.15° on the left side, but again, the difference was not statistically significant. When analyzed by age groups, the highest average SIA was observed in Group 5, although no statistically significant differences were found between age groups. In a study by Fulin et al., which aimed to assess the variability of SIA, 104 CT scans of the glenohumeral joint were evaluated. The mean SIA was reported as 44.54° ± 8.29°, with a range of 21.0° to 76.9°. Fulin and colleagues emphasized that in preoperative planning, surgeons should consider not only the glenoid version (GV) relative to the scapular axis but also the SIA value. This approach has the potential to eliminate possible surgical errors, optimize prosthesis implantation, and consequently reduce the risk of functional limitations of the GHJ [3].

The scapulothoracic angle is defined as the angular difference between the intersection of lines passing through both scapula bodies and the tangent of a single line passing through the upper parts of the ribs in both thoracic cages [10]. In a study performed by Fulin et al., the STA was reported as 45.46° (range from 13.10° to 69.0°) [3]. In this paper, the average scapulothoracic angle in males was 44.82°, higher

than in females (41.30°). However, this was not statistically significant. In left-sided dominant subjects, the average was 45.27°, higher than in right-sided dominant subjects (41.68°), but this was not statistically significant. There are several limitations in our study. One limitation of the study is that, due to its retrospective nature, the data were analyzed solely based on existing patient records and images. This has led to the study being limited to a specific group and a single center. Another limitation is the lack of demographic data, such as body weight and height, which could not be obtained due to the design of the study. We suggest that long-term follow-up studies to monitor anatomical changes can help better understand how these parameters evolve over time in healthy individuals, providing clearer insights into age-related alterations. Additionally, examining the effects of factors such as physical activity, lifestyle, shoulder function, strength, and range of motion on anatomical parameters may offer valuable contributions to the field.

The ergonomics of workplace design increasingly recognize the impact of scapular inclination on musculoskeletal health among workers. Technically, inappropriate scapular positioning during prolonged activities can lead to muscle imbalances and overuse injuries. Addressing this problem is crucial as it has direct implications for workforce productivity, employee well-being, and healthcare costs related to work-related injuries. Required research may involve epidemiological studies linking scapular inclination to occupational injury rates, ergonomic assessments of workplace design, and intervention studies evaluating the effectiveness of posture training programs. Also, this paper confirmed that glenoid retroversion decreases from top to bottom. Furthermore, the variability of the scapular inclination was evaluated by measuring the scapulothoracic angle. We think that the values of scapular inclination angle, scapulothoracic angle, and glenoid version are very important in the preoperative planning of shoulder surgeries. In conclusion, we think that it is very important to consider the scapular inclination scapulothoracic angle when evaluating the orientation of the glenoid.

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