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Association between Proximal Tibiofibular Joint Morphology and Knee Alignment in Osteoarthritis Patients

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Abstract: This study aimed to determine whether proximal tibiofibular joint (PTFJ) morphology was related to knee alignment in osteoarthritis (OA) patients. Methods: 67 OA patients were enrolled in this study. The morphology of the PTFJ including articular shape type, articular surface area, joint inclination, relative articular height, and joint declination were measured from 3D models. The knee alignment of each subject was characterized as varus, normal, or valgus according to the femorotibial angle (FTA). The FTA was measured on weight-bearing X-rays. Multinomial logistic regression analysis was used to evaluate the association between PTFJ morphology and knee alignment. Results: there were significant differences between varus, valgus, and normal FTA groups in terms of shape type ($p = 0.021$), inclination of the PTFJ ($p = 0.025$), relative articular height ($p = 0.019$), and PTFJ declination angle ($p = 0.011$). A higher relative articular height (OR: 0.608, 95% CI: 0.205–0.998, and $p = 0.017$) and lower declination angle (OR: 0.632, 95% CI: 0.601–0.887, and $p = 0.019$) were found to be associated with an increased likelihood of having a valgus FTA rather than a varus FTA. Conclusion: our results indicate that PTFJ morphology is associated with knee alignment.

Keywords: knee osteoarthritis; proximal tibiofibular joint; bone model; femorotibial angle; knee alignment; biomechanics

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1. Introduction

Knee osteoarthritis (OA) is a musculoskeletal disorder that has been reported to affect 303 million people globally, with a cumulative incidence rate of up to 8.5% among middle aged and older people in China [1,2]. Proximal fibulectomy was recently shown to be as an effective way to relieve pain and to improve knee functionality in patients with medial knee OA [3]. Good short-term clinical outcomes of this surgery demonstrated improved knee alignment and the restoration of joint spacing [3–5]. However, some complications were also reported, including neuropraxia of the superficial and deep branches of the peroneal nerve, wound hematoma, and post-surgery infection [6]. In addition, previous studies only considered the short-term outcome of proximal fibulectomy. The long-term performance of this surgery is unclear. Thus, it is essential to study the association between proximal fibula morphology and knee OA to better understand how changing the structure of the joint affects knee performance.

The proximal tibiofibular joint (PTFJ) is a synovial joint composed of the tibial condyle and the fibular head and acts to dissipate torsional stresses applied to the ankle, to dissipate lateral tibial bending moments, and to alleviate tensile weight-bearing [7]. Several recent publications investigated the relationship between PTFJ morphological parameters and knee OA severity. Zhao et al. [8] demonstrated that PTFJ might be associated with the occurrence and development of OA, especially with the height of fibula (HF) and the types of PTFJ. Lu et al. [9] reported that irregular PTFJ joint shapes were associated with osteoarthritic changes in the lateral knee compartment in older adults. Zhao et al. [10] showed how morphological changes in the PTFJ could be used to predict the risks of receiving total knee replacements (TKR). Chang et al. [11] found that changes in PTFJ surface area were associated with the presence of incident radiographic osteoarthritis, especially in the medial tibiofemoral compartment. Qi et al. [12] reported that PTFJ morphology in healthy people was significantly different from that in OA patients and that it was associated with the presence of knee OA. However, the factors considered in these studies were mostly related to cartilage structure and incidence of knee OA while the relationship between PTFJ morphology and knee alignment has not been investigated in detail. Neutral knee alignment is vital for balanced knee load-bearing. Malalignment causes the load-bearing axis to be biased to one side, resulting in a longer moment arm and greater load in one knee compartment. Such unbalanced loading presents a significant risk for the progression of OA [13].

The aim of this study was to evaluate the association between the morphology of PTFJ and knee alignment in OA patients. The morphology of PTFJ was measured in constructed bone models from CT scans. Knee alignment was measured by the femorotibial angle (FTA) on weight-bearing X rays. We hypothesized that the PTFJ morphology would be associated with knee alignment and that there would be a significant difference in PTFJ morphology between varus knees and valgus knees.

2. Materials and Methods

2.1. Participants

This was a cross-sectional statistical study that included 67 OA patients recruited from Chongqing Xinqiao Hospital. The patients who visited the hospital between Jan 2016 and Aug 2016 and were diagnosed with symptomatic radiographic knee OA according to the American College of Rheumatology classification criteria for knee OA [14] with a Kellgren–Lawrence (K–L) grade of K–L III or K–L IV [15] were asked to enroll in this study. In total, 70% of patients (70/100) gave positive responses. The exclusion criteria were as follows: (1) underlying diseases, such as hepatic or renal dysfunction; (2) total knee or hip replacement in either leg; (3) rheumatoid arthritis or traumatic arthritis; (4) nerve or muscle disease associated with walking difficulty; and (5) no full limb films and bilateral standing anteroposterior (AP) radiographs or intact CT scans from distal femur to ankle joint. Of positively responding participants, 1 was excluded due to having total knee arthroplasty (TKA) in the contralateral knee; 1 was excluded due to a lack of intact CT scans, which would be used for the reconstruction of PTFJ; and 1 patient was excluded due to a lack of radiographic images, which would be used to measure knee alignment. The characteristics of the subjects in this study were presented in Table 1. The study protocols were approved by the Biological Science and Medical Engineering review board in Beihang University (No. BM20200098) and informed consent forms were signed by all participants.

Table 1. Characteristics of the participant. Values are represented as a mean standard deviation (SD) unless otherwise indicated.

OA Participant (*n* = 67 Patients, 67 Knees)		
Gender	Male, N (%)/Female, N (%)	15 (22.3)/52 (77.7)
Side	Left, N (%)/Right, N (%)	30 (44.8)/37 (55.2)
	Age (years)	55.8 (4.6)
	Height (cm)	153.5 (6.3)
	Weight (kg)	62.2 (6.9)
	BMI (kg/m^2)	20.9 (2.1)

2.2. *Anatomical Measurement of PTFJ*

Patients were asked to lie in a supine position of relaxed lower limbs with fully extended knees. The lower limb of the patients was scanned by a CT machine (SOMATOM Spirit, Siemens, Germany) from approximately 20 cm superior to the knee joint line to ankle joint with a slice distance of 0.600 mm and a field of view (FOV) of 500 mm. Exterior cortical bone edges were segmented (threshold value: 400HU-1610HU) [16] and constructed using Mimics 21.0 (Materialise, Leuven, Belgium), and 3D models of the fibula and tibia were created. The PTFJ model included both the intact fibula and tibia. The morphology of the PTFJ was evaluated by shape type, PTFJ surface area, inclination angle of PTFJ, relative articular height, and declination angle of the PTFJ. According to the shape of the fibular articular facet, shape types were classified into three types: plane type, trochoid type, and double trochoid type [17]. The fibular contact surface with the tibia was regarded as the articular surface area [17]. The angle between the PTFJ surface and XY plane was calculated as the PTFJ inclination angle. In order to avoid individual differences caused by patient bone size [8], h was used to represent relative articular height, which was the ration of H (fibula articular surface height to tibia) divided by T (medial-lateral width of the tibial plateau) (shown in Equation (1)). The articular declination angle (β) was calculated as the angle between $O_T O_F{}'$ and the X axis (Equation (2)). A larger value of β indicated a more posterior positioning of the PTFJ (shown in Equation (2)) (Figure 1). Details of the measurement methods used are described in a previous study by the authors [12].

$$h = \frac{H}{T} \tag{1}$$

$$\beta = arctan\left(\frac{Y}{X}\right) \tag{2}$$

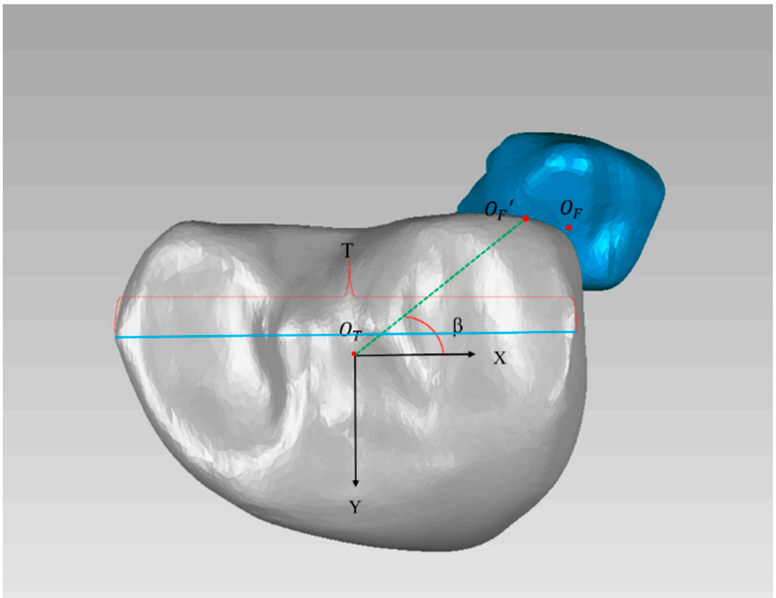

Figure 1. Measurement of the declination angle β. (O_T is the center of tibial plateau and was used as the origin of the tibial coordinate system. The Z axis was determined using a line connecting the center of the tibial plateau to the center of the distal tibial articular surface, with the positive direction running from proximal to distal. The Y axis ran from posterior to anterior, and the X axis ran from medial to lateral. O_F was designated as the centroid of the articular surface on the fibular side. T was the largest medial-lateral width of the tibial plateau. The articular declination angle β was the angle between $O_T O_F{}'$ and the X axis. $O_F{}'$ was the projection of O_F in the XY plane.)

2.3. Radiographic Assessment

Posterior-anterior weight-bearing knee radiographs were obtained by experienced radiology technicians with a film-focus distance of 130 cm, 60 kV, 200 Ma, and 50 ms. The patients were asked to assume a position with their knee fully extended and the patella in the center of the femoral condyle. The femorotibial angle (FTA), defined as the internal angle between the anatomical femoral and tibial axes (Figure 2), was used to classify the alignment of each knee as varus, normal, or valgus. The anatomical femoral axis was centered between two lines identified perpendicular to a tangent on the distal aspect of the femoral condyles [18]. The anatomical tibial axis was centered along the shaft of the tibia between medially and laterally placed points located 1 cm and 10 cm distal to the tibial plateau and was extended proximally up to the tibial plateau (Figure 2) [18]. If the femoral axis was located on the medial side of the tibial axis, the FTA was regarded as positive "+". If the femoral axis was located on the lateral side of the tibial axis, the FTA was regarded as negative "−". The normal FTA was sourced from the literature, being −5° to −1° for males and −7° to −3° for females [18]. Varus knees were determined as those with an FTA of less than −5° for males and less than −7° for females. Valgus knees were determined as those with an FTA of greater than −1° for males and greater than 3° for females. The radiographic measurement of each FTA was performed with measurement software (Digimizer, Beijing, China) with an accuracy of 0.001°. Each FTA was measured three times by two individuals, with the average being analyzed. Intra-reader reproducibility of the FTA measurements was 0.80, and inter-reader reproducibility was 0.83.

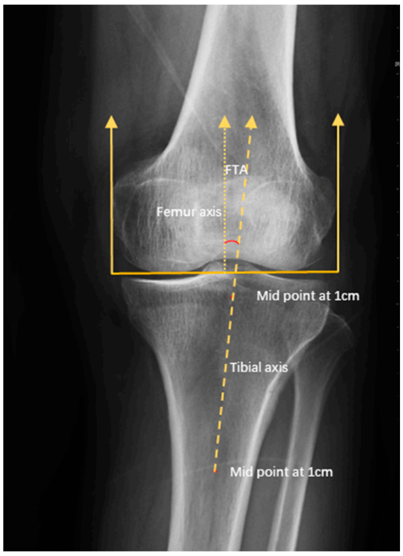

Figure 2. Measurement of the Femorotibial angle.

2.4. Statistical Analysis

To minimize bias produced by similarities between the right and left knees of the same subject [19], only one knee with knee OA per subject was analyzed. If both knees in the same subject were diagnosed with knee OA, the one with the higher K–L grade was selected [19].

The participants were divided into three groups according to FTA: varus FTA group (n = 43), valgus FTA group (n = 10), and normal FTA group (n = 14). The group differences of continuous variables (articular surface area, inclination of PTFJ, relative articular height, and declination of PTFJ) were assessed by ANOVA tests summarized as mean (standard deviation (SD)). Using Chi-square test, the group differences in categorical variable (shape type) were summarized as a number (%).

Multiple logistic regression analysis before and after adjustment for covariates was used to evaluate the association between PTFJ morphology and knee alignment. The independent variables were the morphological parameters of PTFJ including shape type, PTFJ surface area, inclination of PTFJ, relative articular height, and declination of PYFJ. The dependent variable was knee alignment grouping including the varus FTA group, the normal FTA group, and the valgus FTA group. The covariates were age, sex, and BMI in order to eliminate the influence of these factors on the results. The results were shown as proportional odds ratios (ORs) with a 95% confidence interval (CI). A p value of less than 0.05 was considered significant. All statistical analyses were performed in IBM SPSS 23.0 (IBM Corp., New York, NY, USA)

3. Results

The results obtained from all groups are summarized in Table 2. The varus FTA group had a significantly higher proportion of trochoid-type PTFJs (23 (53.5%)) than the other groups ($\chi2(3) = 15.305$, $p = 0.021$), whereas the predominant shape in the valgus FTA group (5 (50.0%)) and normal FTA group (7 (50.0%)) was a plane-type PTFJ. The inclination angle in the varus group was significantly more oblique (39.64 (SD: 3.21)) than the valgus group (36.32 (SD: 4.94)) and normal group (32.28 (SD: 5.92)) (p= 0.025). The PTFJ was significantly closer to the tibia in the valgus group (0.25 (SD: 0.01)) than in the varus group (0.28 (SD: 0.10)) and normal group (0.30 (SD: 0.03)) ($p = 0.019$). The PTFJ in the valgus group (22.82 (SD: 1.99)) was significantly more likely to be located anteriorly than the varus group (24.12 (SD: 5.62)) and normal group (24.93 (SD: 2.14)) ($p = 0.011$). There were no significant differences between the three groups in terms of articular surface area ($p = 0.688$).

Table 2. Characteristics of the proximal tibiofibular joint (PTFJ) in the three groups (normal femorotibial angle (FTA), varus FTA, and valgus FTA).

		Normal FTA ($n = 14$) (as Control Group)	**Varus FTA ($n = 43$)**	**Valgus FTA ($n = 10$)**	**P (Normal FTA, Varus FTA, and Valgus FTA)**
Shape type	Plane type, N (%)	7 (50.0%)	15 (34.5%)	5 (50.0%)	0.021 *
	Trochoid type, N (%)	4 (28.6%)	23 (53.5%)	4 (40.0%)	
	Double trochoid type, N (%)	3 (21.4%)	5 (11.6%)	1 (10.0%)	
Articular surface area of PTFJ (mm^2)		432.13 (31.26)	420.19 (28.40)	400.49 (32.50)	0.688
Inclination of PTFJ (°)		32.28 (5.92)	39.64 (3.21)	36.32 (4.94)	0.025 *
Relative articular height		0.30 (0.03)	0.28 (0.10)	0.25 (0.01)	0.019 *
Declination of PTFJ (°)		24.93 (2.14)	24.12 (5.62)	22.82 (1.99)	0.011 *

* $p < 0.05$ was considered statistically significant. Values for the categorical variables are presented as N (%) and for the continuous variables are presented as mean (SD).

The results of the multiple logistic regression model suggest that some PTFJ morphological features were statistically related to knee alignment ($\chi^2(5) = 16.291$, $p = 0.029$ for the unadjusted model; χ^2 (5) = 20.817, $p = 0.020$ for the adjusted model). Correlations between each joint characteristic and the FTA groups are shown in Table 3. These results indicate that a higher relative articular height is related to a higher possibility of having a valgus knee (OR: 0.547, 95% CI: 0.129–0.831, $p = 0.034$) than a varus knee, even when adjusted for age, sex, and BMI (OR: 0.608, 95% CI: 0.205–0.998, $p = 0.017$). Similarly, a smaller declination angle was also significantly associated with a greater likelihood of exhibiting a valgus knee (unadjusted model: OR: 0.307, 95% CI: 0.095–0.759, $p = 0.020$; adjusted model: OR: 0.632, 95% CI: 0.601–0.887, $p = 0.019$) than a varus knee, which indicated that the more anterior the fibula head relative to tibia platform center, the more likely one had a valgus deformity. We also found that the shape type, PTFJ surface area, and inclination angle were not significantly correlated with different knee alignment groups. Furthermore, the PTFJ morphology was not significantly correlated with the presence of a varus knee or a normal knee. Compared with the varus FTA group, the normal FTA group regression value for shape type was OR: 1.327, 95% CI: 0.592–1.402, p = 0.336; the articular surface area was OR: 1.832, 95% CI: 1.781–1.923, p = 0.782; the inclination of PTFJ was OR: 0.317, 95% CI: 0.245–0.423, p = 0.019; the relative articular height was OR: 0.828, 95% CI: 0.681–0.952, p = 0.092; and the declination of PTFJ was OR: 1.506, 95% CI: 1.362–1.759, p = 0.083 in the unadjusted model. The results in the adjusted model were consistent with those from the unadjusted regression model.

Table 3. The association between PTFJ morphological parameters and knee alignment (the varus FTA group was chosen as the control group (n = 43)) for the valgus FTA group (n = 10), and the normal FTA group (n = 14).

Groups	Variables	Unadjusted Model			Adjusted Model *		
		OR	95% CI	p-Value	OR	95% CI	p-Value
Normal FTA Group	Shape Type	1.327	(0.592, 1.402)	0.336	1.620	(1.509, 1.902)	0.226
	Articular Surface Area	1.832	(1.781, 1.923)	0.782	1.891	(1.892, 1.923)	0.382
	Inclination of PTFJ	0.317	(0.245, 0.423)	0.019	0.463	(0.124, 0.582)	0.092
	Relative Articular Height	0.828	(0.681, 0.952)	0.092	0.305	(0.102, 0.491)	0.107
	Declination of PTFJ	1.506	(1.362, 1.759)	0.083	1.487	(1.273, 1.717)	0.061
Valgus FTA Group	Shape Type	1.201	(0.231, 1.927)	0.398	1.293	(1.018, 1.632)	0.527
	Articular Surface Area	1.832	(1.781, 1.923)	0.109	1.891	(1.892,1.923)	0.194
	Inclination of PTFJ	0.572	(0.230, 0.981)	0.820	0.326	(0.108, 0.796)	0.719
	Relative Articular Height	0.547	(0.129, 0.831)	0.034	0.608	(0.205,0.998)	0.017 *
	Declination of PTFJ	0.307	(0.095, 0.759)	0.020	0.632	(0.601,0.887)	0.019 *

* Adjustment for age, gender, and BMI.

4. Discussion

The aim of this study was to determine the association between PTFJ morphology and knee alignment. Abnormal knee alignment may induce OA symptoms [20]. Therefore, investigating association the between PTFJ morphology and knee alignment is important. The most important findings from the present study were as follows: (1) There were significant differences between the varus FTA group, the normal FTA group, and the valgus FTA group in terms of shape type, inclination of the PTFJ, declination of the PTFJ, and relative articular height. (2) The valgus group was associated with a higher relative articular height and a smaller declination angle of the PTFJ in comparison to the varus FTA group.

The varus FTA group had a significantly higher ratio of trochoid types, higher inclination angle, and higher relative articular height than both the valgus group and normal group. However, a study by Zhao et al. [8] reported no significant difference in relative articular height between varus knees and valgus knees. This difference could be due to the use of the hip–knee angle (HKA) to represent knee alignment in Zhao's study, thus having different criteria for determining varus and valgus knees.

In this study, knee alignment (varus, neutral, or valgus) was related to PTFJ morphology in declination angle and relative articular height in the logistic regression model. However, the results were inconsistent with Zhao et al. [8], in which no significant correlation was found between the relative articular height and knee alignment. This inconsistency may be explained by differences in the regression methods. In our study, a multinomial logistic regression analysis was used, while Zhao et al. used linear regression. The different group criterion mentioned previously may also have contributed.

Figure 3 shows the relative position of a fibula to a tibia. This construct is used to explain the biomechanical relationship between these bones and their importance to knee alignment. The weight-bearing force on the fibula (F_f) generates a valgus moment (M) on the knee joint which, depending on the magnitude of the moment, could induce a valgus deformation. The more proximally a fibula is positioned (higher relative articular height), the larger the moment arm of the fibula (l) is. This can increase the valgus moment, subsequently leading to valgus deformation. However, if the fibula is located posteriorly relative to the tibia (larger declination angle), the moment arm of the fibula is shorter, as that anteroposterior region of tibial platform is smaller than mediolateral size [21]. This can decrease the valgus moment, subsequently decreasing the risk of developing a valgus knee. Thus, a higher relative articular height and lower declination angle were found to be associated with an increased likelihood of having a valgus knee.

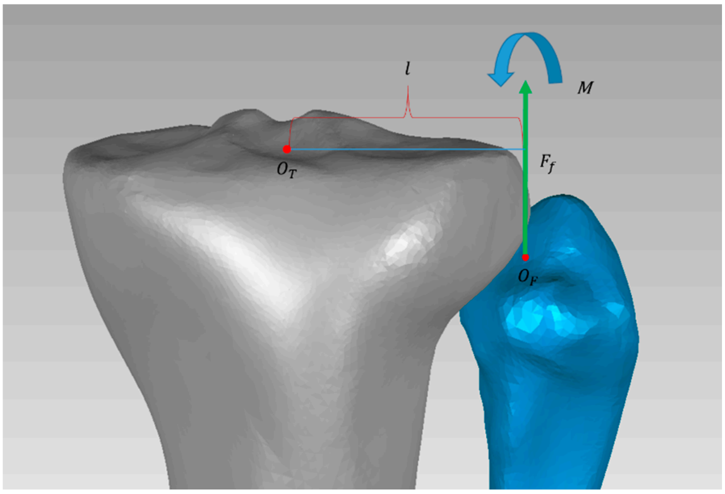

Figure 3. Illustration of fibula function to the tibia.

From our study, The fibula was used to be considered less critical for joint functionality than the other long bones of the lower limb. It has been freely used as a source for grafts and as a vascularized transplant to bridge large bony defects [22,23]. As proximal fibulectomy was applied to treat knee OA, the biomechanical influence of a fibula on the knee joint has been considered. According to Zhang et al.'s study [24], proximal fibulectomy weakened the lateral fibular support and led to the correction of varus deformity, which can subsequently shift the loading force from the medial compartment more laterally, leading to decreased pain and a satisfactory functional recovery. A cadaver study showed that, after fibular osteotomy, the peak force, contact area, and pressure in a medial tibial compartment decreased with significant differences at 15° of flexion ($p < 0.05$) [25]. Qin et al. found that the range of motion (ROM) of the PTFJ increases and that the fibula head shifts posteriorly and downward due to rebalancing of the lateral soft tissues after fibulectomy [5]. These findings not only explain the mechanism of proximal fibulectomy to treat knee OA but also prove the biomechanical function of the fibula in the knee joint. It is important to further explore the association between the fibula and knee joint for a better understanding and treatment of knee OA in the future.

This study had several limitations. Firstly, the sample size in this study was small. To improve reliability of the logistic regression model, a greater sample size should be enrolled to further explore the association between PTFJ morphology and knee alignment in future studies. Secondly, due to a lack of weight-bearing knee radiographs for healthy people, only participants with severe knee OA were included in this study. To further evaluate the relationship between PTFJ morphology and knee alignment, future studies should also incorporate healthy knees and knees with medial OA.

5. Conclusions

In conclusion, this study indicated that the PTFJ morphological parameters were significantly different between different knee alignment groups. The PTFJ morphology was found to be significantly correlated with knee alignment, particularly in the declination angle and relative articular height for the varus FTA group and the valgus FTA group.

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C.-K.C.; supervision, C.-K.C. and M.W. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author. Data are not publicly available due to privacy or ethical restrictions.

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Conflicts of Interest: The authors declare no conflict of interest.

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