

Evaluation of 3-Dimensional Profile of Asian Knee

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Abstract

Background: Maintaining proper size and rotation of components of total knee arthroplasty is mandatory for optimal longevity. Ethnic differences may affect fitness of the prostheses that were manufactured mainly based on Caucasian dimensions. This review aimed to evaluate 3-dimensional characteristics of distal femur and proximal tibia among Asian populations. Moreover rotational profile of distal femur was also assessed. **Methods:** Databases were searched and relevant studies were selected. Including criteria were: studies on Asian populations, studies on morphological and rotational characteristics of the knee joint and prostheses. Finally 21 studies were selected. **Results:** Based on the studies male subjects enjoy larger dimensions, while total configuration is proportionately similar to female at axial section. Some other studies in white populations or Asian populations found significant discrepancies among genders. Also it was indicated as anteroposterior size grows, aspect ratio shows downward inclination in both genders and in studied prostheses for Asian populations. In contrast to western Caucasian knees, there are some parameters in the Asian knees which decrease upon increasing the other parameters and the size of the knee. Finally females enjoyed greater value of these rotational values in majority of the studies. **Conclusion:** Generally, it can be said that assumption of smaller knee in Asian relative to white population is more accurate on femoral side while tibial dimensions share more homogenous profiles.

Keywords: Total Knee Arthroplasty; 3-dimensional Profile; Asian knee

Introduction

The knee joint is a modified hinge that can be arbitrarily divided into three compartments— medial, lateral, and patellofemoral. Osteoarthritis is one of the most common musculoskeletal conditions. The overall prevalence of osteoarthritis is 13.9% in adults aged 25 years and older and 33.6% in those 65 and older affecting approximately 18.7% of women and 13.5% of men in this age group.^[1,2] There are many treatment options available for osteoarthritis of the knee. The choice depends on the severity of symptoms and it is important to exclude other sources of knee pain, such as hip and spinal pathology^[1]. Operative and non-operative treatments are the effective methods of therapies that are dependent on the patients' situations and characteristics. Non-operative treatments include land-based aerobic and resistance exercise, as well as aquatic exercise and weight loss in the setting of overweight and obese patients. The options for surgical management will include joint preservation and joint-sacrificing procedures involving a partial or a total knee replacement or arthrodesis of the knee.

Although the joint-preserving surgeries are less predictable, when done with appropriate indications, they may afford long-term solutions with minimal need for activity restrictions. On the other hand, joint-sacrificing or replacement procedures are more predictable^[1]. Human body is a unique correlation between anatomy and physiology. It is mandatory to have adequate knowledge on this issue former to perform any kind of

surgery. There are several variations in human knee concerning middle-eastern and Asian ethnicity, which should be considered for performing total knee arthroplasty among these races. In this regard, total knee arthroplasty (TKA) has evolved to be a very successful and reliable procedure, with the ability to reduce pain and disability associated with osteoarthritis and other pathologic knee conditions.

Thus primarily the morphological characteristics of the knee joint are considered briefly as follows:

Distal femoral morphology

The architecture of the distal end of the femur is complex. Furthermore, this area serves as the attachment site of numerous ligaments and tendons. In shape and dimensions, the femoral condyles are asymmetrical; the larger medial condyle has a more symmetrical curvature. The lateral condyle viewed from the side has a sharply increasing radius of curvature posteriorly. The femoral condyles viewed from the surface, articulating with the tibia; show that the lateral condyle is slightly shorter than the medial.

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How to Cite this Article: Moghimi J, et al. Evaluation of 3-Dimensional Profile of Asian Knee. *Ann Med Health Sci Res.* 2017; 7: 61-66

Proximal tibial morphology

In a macerated skeleton, inspection of the tibial plateau suggests that the femoral and tibial surfaces do not conform at all. The larger medial tibial plateau is nearly flat and has a squared-off posterior aspect that is distinct on a lateral radiograph. In distinction, the articular surface of the narrower lateral plateau borders on convexity. Both surfaces have a posterior inclination of approximately 10 degrees with respect to the shaft of the tibia.

Distal femur rotational profile

As for proper sizing discussed earlier, rotational positioning of the components will largely affect the postoperative result. Any misplacement during total knee arthroplasty (TKA) may lead to abnormal patellofemoral kinematics, asymmetrical flexion gaps, and early failure. Most emphasis was put on the dangers of internally rotating the femoral component. Thus, information of ethnical variation in rotational profile is important in reconstructive surgery of the lower limb, in which longevity can depend on attention to detail planning.^[3,4]

Evolution of knee arthroplasty

A TKA procedure inevitably and irreparably alters the complex geometry and soft tissue interactions occurring at the knee joint. To date, most TKA procedures require resection of one or both cruciate ligaments and loosening of the collateral knee ligaments for proper balancing. Moreover, the removed bone and meniscus are replaced with metal and plastic, respectively, whose properties are significantly different.^[1,4]

The hypothesis of this study was to evaluate morphometrical dimensions of distal femur and proximal tibia in Asian population and whether current total knee prostheses were proportionally matching to anatomical profiles of their knees. Moreover, distal femur rotational profile was evaluated.

In order to evaluate our objective the recent two studies of ours were compared with other related studies in the literature. In this regard NCBI and ELSEVIER databases were searched and relevant studies were selected. Including criteria were: studies on Asian populations, studies on morphological and rotational characteristics of the knee joint and prosthesis. Finally 11 morphological and 10 rotational studies (21 totally) were selected.

Dimensional characteristics of the knee among Asian populations

Main triggers of the study

Briefly, in two of our previous studies^[5,6] morphological and rotational profiles of distal femur and proximal tibia were studied after simulation of pertinent cuts. The result were compared between genders and also compared with three current most available prostheses (i.e., Scorpio, NEXGEN, and GENESIS). Besides, GENESIS Gender Solution femoral component was also evaluated regarding amount of fitness in Iranian females.

Appraisal and interpretation of a work needs comparison with other ones to reveal similarities and discrepancies. That how much the works can be compared depends on awareness of

details of their study protocol. Thereby, it can help explaining the existing gaps. Unfortunately, this point is less noticed during study designing and result interpretation among Asian studies. Here some diversity among studies and their effect on results are discussed before turning to our findings:

- The specimens applied: Majority of the studied in this field involved imaging modality. However some were performed over cadavers. This can lead to differences which are mentioned during studies applying both of the sources.
- Type of imaging modality: tomography types imaging like CT scan.
- The criteria used during bone size measurement: although it is simply stated "AP or ML" sizes, there are several significant differences among studies while defining its actual values.

Resected or non-resected dimensions: some works were essentially designed for anthropometric aims while some other were conducted to evaluate prostheses fitness based on related bone cuts. Although there is some overlap, but it should be clearly defined which criteria is used. For example, for measuring femur ML size, some used the dimension at the level of condyles (for implication during TKA) and some used the anatomical transepicondylar axis. Obviously this gap can affect the results. Figure 1 shows some of this variation during measurement.

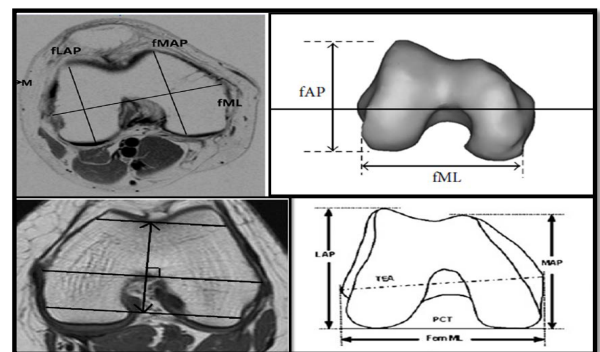


Figure 1: Variation in measurement of AP and ML dimension should be considered while interpreting the results.

- Method of calculating aspect ratio: this proportion is used to incorporate ML and AP values as the forms of ML/AP or AP/ML. This should be considered while comparison.

TKA necessities, gender to population

Properly shaped prostheses can provide the best coverage and avoid soft tissue impingement. Besides the surgical principle in TKA, proper sizing of the prosthesis is one of factors for a successful TKA. TKA requires an accurate soft tissue balancing and maximal coverage of components on the bone surface to minimize the stress applied to the bone-implant interface. Any mismatch in the form of overhanging or under sizing femoral components could lead to altered soft-tissue tensioning and altered patellofemoral stresses.^[1,7-9] Thus, it becomes important to obtain the anthropometric data to achieve the best stability and longevity for implant. Total knee prostheses based on the accurately morphologic data of knee, gender morphologic difference, and the morphologic correlations between tibia and femur may be expected to give better results.

In recent years, many studies have identified shape differences in the knee within the Caucasian population. Total knee replacement requires resection of bone thickness equal to the thickness of the implanted prosthetic component. Proper bone cuts for rotational alignment of the femur and tibia in the axial plane represents the key for a balanced flexion gap and proper patella tracking. Both represent important parameters for high flexion. [8,10,11].

The risk of component over sizing is especially present in Indians and other Asia subpopulations that are known to have a smaller build and stature as compared with their Western counterparts [4]. There has long been a belief among Indian and Asian-Pacific arthroplasty surgeons that the prosthetic components currently available on the market do not fulfill the requirements of these anthropometrically smaller ethnic groups, especially in the smaller sizes. Such anthropometrically smaller populations are vulnerable to the risk of technical errors in TKA, arising from the nonavailability of smaller sized prosthetic components, which may produce suboptimal postoperative results. [7,11,12].

Differences among males and females have been widely reported, with females having a smaller mediolateral to anteroposterior ratio and more narrow distal femurs and different proximal tibia geometry. [13-17]. Morphological measurements revealed female knee joints have anterior condyles that are less prominent and more diamond-shaped. Furthermore, women with the same anteroposterior (AP) length have been reported to have a narrower mediolateral (ML) width than men. [16,17]. However, ethnic differences have not received much focus given that most existing TKA implant designs are based on the Caucasian population. But, many studies have determined that the prostheses designed for Caucasian patients are not suitable for Asian patients. Anatomic differences have been identified between both sex and ethnicity. There are also a huge number of differences in the angular parameters between Asian and Caucasian knees. Distal femoral coronal angle, posterior femoral condylar angle, proximal tibial varus angle and posterior tibial slope have all been shown to be different in Asian from western Caucasian knees.

Several studies have found that the femoral aspect ratio (mediolateral [fML]/anteroposterior [fAP]) of the prostheses used in Asia were not suitable for Asian patients. For instance, Ho et al reported that 3 of 5 TKA systems used in China tended to cause mediolateral overhang of the component across the width of the resected femurs of Chinese patients.

Aspect ratio as the proportion of mediolateral to anteroposterior dimension was applied to consider total configuration of cut surfaces either in distal femur or proximal tibia. Different studies found a larger femoral aspect ratio in small knees and a proportionally smaller ratio in large knees. Surveys showed that the Japanese patients had a significantly less postoperative range of motion than white patients. Furthermore, Japanese patients are reported to require more revision after primary posterior cruciate-retaining TKA within an average follow-up of 6.6 years, whereas only 2.6% of their American cohort needed revision within an average follow-up of 9 years. The authors suggested that the racial morphologic differences might be a factor causing the differences in outcome. [12].

In order to enhance the quality of the fitness yielded by prostheses, anthropometric and morphometric studies from diverse ethnicities is mandatory. It is postulated that the smaller build and stature of the Asian-Pacific population requires a different component size. To best of our knowledge, anthropometric surveys from China, Korea, Japan, India, Indians, Malaysia and Thailand were conducted to support the hypothesis. [2,8,9,13,18-22]. Although all from Asian ethnicity, there were delicate discrepancies in their results that can affect the outcome of TKA in a different manner from Western population. In societies with smaller build, such as Indians, technical errors are more likely to occur in TKA with most of the commercially available prostheses because of shortage of availability of smaller-sized components. [18].

Morphological findings

In summary, our previous results indicated that on both sides, all morphological parameters showed difference between men and women except for aspect ratios. This indicates that male subjects enjoy larger dimensions, while total configuration is proportionately similar to female at axial section. Some other studies in white populations or Asian populations found significant discrepancies among genders. These findings are defined separately and detailed in following different parts.

Distal femur

In our previous study it was revealed that men have significantly larger dimensions than women for all measurements. To explain in detail, the females were found to have a narrower ML dimension compared with a male distal femur of the same AP dimension. These results are similar with those of Caucasian studies.

Table 1 shows comparison among findings of distal femur dimensions mainly from Asian countries. An average value of white population is also represented. Our results are depicted in two columns as either resected or non-resected measurement. Korean study reported AP and aspect ratio for both condyles.

Thai's results are based on resected cuts. [2]. Resected dimensions have, therefore, lesser AP values relative to others. Indian study that is from the earliest one of this kind of study, have based their AP measurement on medial condyle. [17]. Hence, the values may have been underestimated. As inferred from this study and previous reports, Indians have the least knee dimensions among Asians. On the other hand Chinese subjects seemed to have the longest AP dimension. [13]. Roughly, it can be stated that samples from Iranian, Malay and Thai population are placed in between.

Two major methods were applied for measuring ML sizes. Chinese, Korean and Caucasian studies assumed anatomical transcondylar axis length as this variable. Others along with us settle ML size at the level of condyls. As a result the latter reports (including ours) have resulted in smaller value. Although this amount is not quantified in any study, it seems to be approximately 10 millimeters. Based on these reports, our population like Thai and Indian subjects renders the lesser values of this variable among Asians. The variable is longer for Malay cases. [9].

Table 1: Distal femur dimensions reported from different studies.

		Thai (Resected)	Indian (non- resected Med. Condyle)	Korean ⁷ by Lim (Non- resected med. & lat condyles)	Malay (non- resected)	Iranian By Moghtadaei Resected and non-resected	Taiwanese by Ho Resected	Chinese by Cheng Resected	Chinese ¹¹ by Yue Non- resected	White's ¹¹ Non- resected
AP length (mm)	Total	45.43 ± 4.5		59.6 & 58.7		44.9 ± 4.1???	63.7 ± 5.1	64.1 ± 2.7		
	Male	48.55 ± 3.73	61.09 ± 3.74	62.7 & 59	63.93 ± 3.36	46.87 ± 3.3 & 63.35 ± 3.1		66.6 ± 2.4	65.0 ± 2.8	67.5 ± 3.6
	Female	43.32 ± 3.69	54.47 ± 1.91	56.8 & 58.4	57.39 ± 3.29	41.55 ± 3.1 & 56.53 ± 2.9		61.0 ± 2.7	58.8 ± 2.5	59.7 ± 2.6
ML width (mm)	Total	64.06 ± 6.31		78.6 ± 5.1		67.06 ± 6.39	70.2 ± 5.4	71.0 ± 3.0		
	Male	70.15 ± 3.87	69.64 ± 3.11	81.5 ± 5.70	74.88 ± 3.55	70.71 ± 4.1		74.4 ± 2.9	82.6 ± 3.6	86.0 ± 5.6
	Female	59.91 ± 3.75	61.06 ± 3.11	76.7 ± 3.71	64.53 ± 3.12	60.56 ± 4.2		66.8 ± 3.1	72.8 ± 2.6	76.4 ± 4.0
Aspect ratio (ML / AP)	Total	1.41		1.31 & 1.25		1.49 ± 0.11	1.09 ± 0.06	111.1 ± 2.7		
	Male	1.45		1.17 & 1.18	1.17 ± 0.05	1.51 ± 0.01 & 1.21 ± 0.1		111.7 ± 3.3	1.27 ± 0.03	1.28 ± 0.07
	Female	1.39		1.33 & 1.32	1.13 ± 0.05	1.46 ± 0.1 & 1.17 ± 0.07		109.6 ± 3.6	1.24 ± 0.04	1.28 ± 0.06

Table 2: Proximal tibia dimensions reported from different studies.

		Thai	Korean (by Kwak)	Korean (by Lim)	Japanese	Iranian By Moghtadaei	Chinese By Cheng	Chinese (by Yue)	White's
AP length (mm)	Total	46.04 ± 4.4	45.7 ± 3.8	53.4 & 49.2	48.3 ± 5.4	48.6 ± 4.5	48.8 ± 3.4		
	Male	50.15 ± 3.09	48.2 ± 3.3	59.5 & 52.7	53.8 ± 6.6	51 ± 2.77	51.3 ± 2.0	41.5 ± 2.1	45.0 ± 2.8
	Female	43.23 ± 2.57	43.2 ± 2.3	47.7 & 45.7	46.6 ± 3.6	44.18 ± 3.51	45.7 ± 1.9	37.3 ± 2.8	39.3 ± 2.6
ML width (mm)	Total	68.8 ± 5.8	71.9 ± 5.6	75.1 ± 7.01	74.3 ± 6.6	74.6 ± 5.9	73.0 ± 4.6		
	Male	74.44 ± 3.44	76.1 ± 4.0	80.6 ± 6.31	83.0 ± 6.2	78 ± 3.81	76.4 ± 2.8	75.2 ± 3.6	78.7 ± 5.4
	Female	64.95 ± 3.45	67.6 ± 3.1	70.0 ± 3.45	71.7 ± 4.0	68.5 ± 3.83	68.8 ± 4.6	66.2 ± 2.1	69.0 ± 4.2
Aspect ratio (ML / AP)	Total	1.47		1.4 & 1.51		1.53 ± 0.07	1.49		
	Male	1.48		1.35 & 1.52		1.53 ± 0.07	1.49	1.82 ± 0.07	1.75 ± 0.11
	Female	1.47		1.47 & 1.52		1.55 ± 0.07	1.5	1.78 ± 0.10	1.76 ± 0.08

If one considers aspect ratio as somehow an indicator of shape configuration, evaluation of its changes with knee enlargement will be valuable while designing prosthesis. As AP size grows, aspect ratio shows downward inclination in both genders and in studied prostheses for Asian populations. Of note is that the trend is more remarkable in Iranian men implying that smaller knees benefit more from larger mediolateral dimension.

Proximal tibia

In the morphological study of proximal tibia, we found minor differences between Asian studies [Table 2]. This is especially true on ML dimension. In our previous study, tibia ML lengths were found to be greater in men. This is supported by other studies except for Japanese that stated a higher tibia ML for females.^[16] The gap between two Korean studies seemed to be for overestimation resulted from MR imaging.^[11,12]

For AP values, the Korean study by Lim reported a significantly higher amount relative to others.^[12] This may be attributed to the application of MRI as they reported similarly higher values for femur dimensions. On the other hand another study from Korea represented more acceptable results similar to Asian ethnicity.^[11] Chinese along with white population studies seems to have significantly lower AP values.^[13] This also can explain higher aspect ratio for them.

As our review of literature shows, in Chinese, Japanese, Korean and Indian population, the mediolateral diameter of the distal

femur is smaller than their counterpart in western population with the same AP diameter.^[2,4,8,9,11-13,16,17,21] There is also a more important aspect of difference between these two groups of knees, which is great disparity among changes in these parameters. In other words, in contrast to western Caucasian knees, there are some parameters in the Asian knees which decrease upon increasing the other parameters and the size of the knee. As it has been shown in Chinese knees, the femoral aspect ratio was higher for smaller knees and proportionally lower for larger knees and female subjects had a smaller aspect ratio with the same anteroposterior dimension. On the tibial side, the aspect ratio (tML/tAP %) showed a definitely negative correlation with tAP, which means that there were large values in the aspect ratio with the smaller tAP, and that males have larger values in the aspect ratio than females having the same values for anteroposterior dimension. Although, there are some prostheses that consider this negative correlation between tibial aspect ratio and tAP, however, the rate of change did not match that of the Asian population.

Rotational profile findings

As for proper sizing discussed earlier, rotational positioning of the components will largely affect the postoperative result.^[11,23,24] Any misplacement during total knee arthroplasty (TKA) may lead to abnormal patellofemoral kinematics, asymmetrical flexion gaps, and early failure.^[3,4,25] Most emphasis was put on the dangers of internally rotating the femoral component. Thus, information of ethnical variation in rotational profile is

Table 3: Distal femoral rotational axes reported in various studies.

	Posterior Condylar Angle (°)			Condylar Twist Angle (°)			Age
	Total	Male	Female	Total	Male	Female	
CT study							
Present study	2.35	2.45	2.12	5.77	5.86	5.85	43.02 (17-80)
Jabalameili ³⁰ (Iran)	1.90 (1.85)	2.60 (1.67)	1.00 (1.69)	5.68 (1.89)	6.23 (1.95)	4.97 (1.55)	38.8 (16-75)
Mullaji ²⁷ (Indian)				5 (1.7)			31.3 (26-40)
Yoshino ¹⁸ (Japanese)	2.9 (1.8)			6.4 (1.7)			75.5 (49-89)
Griffin ²⁵	3.11 (1.75)	2.75 (1.61)	3.33 (1.82)				
Arima ¹⁹				5.7 (1.7)			
Cadaveric study							
Berger ³¹		3.5 (1.2)	0.3 (1.2)		4.7 (3.5)	5.2 (4.1)	
Yip ¹⁶ (Chinese)		5.1(1.9)	5.8(1.8)				78 (18-94)
Griffin ²⁵		3.6 (1.8)	3.7(2.6)				
Arima ¹⁹				4.4 (2.9)			

important in reconstructive surgery of the lower limb, in which longevity can depend on attention to detail planning.

Despite everyone being convinced of the clinical importance of correct rotational alignment, there is no widely accepted surgical technique leading to superior results.^[20] It is yet unclear the best rotational reference to which all other parameters can be compared. The rotation of the femoral component can be described, relative to landmarks on the distal femur or relative to its relation with the tibia. Distal femoral references include the posterior condylar line (PCL),^[26] the anatomical transepicondylar axis (TEA), the surgical TEA, the trochlear anteroposterior (AP) axis, and the femoral transverse axis.

Berger was the first to use CT scans to evaluate the rotational alignment of the components.^[11] Posterior condyle-epicondylar angle (“posterior condylar angle”) was originally defined by him. There after numerous similar studies were performed to evaluate posterior condylar angle and condylar twist angle and their validity and reliability. There are geographic and racial differences between these axes and these have been studied using cadaveric bones intra-operative measurements, or computer tomography (CT). Most CT studies were performed on arthritic knees; only a small number involved normal knees.

The results our previous studies along with similar ones from Asian and Caucasian population are depicted in Table 3.

Rotational measurements based on transepicondylar axes suggest similar profile among Iranian and Indian subjects. On the other hand, Japanese and Chinese cases are reported to have relatively higher values.^[22,25,27] Older age and more osteoarthritic knees may be responsible for such discrepancy. Interestingly, a review article by Victor also stated that younger patients seemed to have a smaller angle than older patients.^[13] It was hypothesized that this might be due to posterolateral cartilage wear, increasing with age. However, some authors^[17] are against this. During total knee arthroplasty, a common recommendation is to allow 4° of external rotation. The clinical indication of Chinese study revealed that this needs to be modified to 6° for Chinese women and 5° for Chinese men.^[3]

Females enjoyed greater value of these rotational values in majority of the studies. However, our findings accompanying with Berger and some other reports showed that males’ distal

femur is more externally rotated. The difference between genders was not statistically significant. This is supported by most of current studies, although a few authors report significant gap.^[3,25,27] In addition, according to recent studies, CT imaging is a the suitable method.^[28-34]

Limitations of the study

First, the limitation of our analysis is relatively white population of the selected sample.

A second limitation is that this is an observational study of asymptomatic patients, and thus conclusions regarding alignment cannot be drawn for patients with degenerative joint disease who are candidates for total knee arthroplasty.

Third, this study only focused on the anatomical parameters of the femoral and tibial obtained from 3D-CT images, to provide some explanations with clinical implications.

Conclusion

The efforts are continuing to complete ethnical and racial information for altering the needed prostheses that can represent better coverage and fitness. Among Asian area desired studies were conducted over Chinese, Japanese, Thai, Korean, Indian and Malay population. There was paucity of data about Iranian population. Some significant methodological differences were observed among these studies design that make their comparability disturbed. Generally, it can be said that assumption of smaller knee in Asian relative to white population is more accurate on femoral side while tibial dimensions share more homogenous profiles. On the femoral side, along with white populations, Asian studies are on agreement that females have lesser dimensions specially mediolaterally. This may made “gender solution” subtype prostheses more suitable not only for females but also for the males of this ethnicities who believed to have lesser mediaolateral dimensions than White’s ones with same AP. Future implant designs may wish to incorporate this finding so as to be able to provide better implant fittings for use in the Asian population at a larger scale. Distal femur rotational profile based on transepicondylar axes seemed to be essentially similar among Asian and Caucasian population. Although there are some differences, we are more convinced to explain it as consequence of discrepancy in age distribution of samples.

Conflict of Interest

All authors disclose that there was no conflict of interest.

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