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ORIGINAL ARTICLE

Plain Radiographic Measurement of the Knee Joint Line Among Sulaymaniyah City Population and their Implication on the Preoperative Evaluation for Revision Total Knee Arthroplasty

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ABSTRACT

Background: *In total knee arthroplasty (RTKA) there is challenging about the best reliable method for assessing the joint line level to achieve a successful outcome and reduce the postoperative complications*
Objective: *To estimate the plain radiographic measurement of the knee joint line and its implication in preoperative evaluation for revision total knee arthroplasty*
Patients and Methods: *A prospective quantitative study included 362 adult individuals of both genders who underwent supine antero-posterior radiograph for the measurement of the femoral width, with the distance to the knee joint line from the adductor tubercle and from the apex of the fibular head. The individual ratio of femoral width with the adductor tubercle joint line and fibula head joint line were calculated. The data analyzed by using Statistical Package for the Social Sciences (SPSS) version 22 software and a P-value of ≤ 0.05 considered statistically significant.*
Results: *The mean value of femoral width was (80.8 ± 6.8 mm), mean distance to the joint line from the adductor tubercle was (45.7 ± 3.7 mm) and to the joint line from the fibular head was (17.7 ± 3.1 mm). A significant positive correlation was found between the distance from the adductor tubercle to the joint line and femoral width (R = 0.91). The distance from the adductor tubercle to the joint line divided by the femoral width (the adductor tubercle ratio) was found to be (0.56 ± 0.02) with no inter-individual variation. A weak positive correlation was found between the distance from the fibular head to the joint line and femoral width (R = 0.24). The distance from the fibular head to the joint line divided by the femoral width (the fibular head ratio) was found to be (0.21 ± 0.04).*
Conclusion: *Among Sulaymaniyah city population, we documented the radiographic measurement of the knee joint line to the adductor tubercle (ATJL) and to the fibular head (FHJL) and the femoral width (FW) of the individuals. These values influenced by the individual variations in age, gender and height. The adductor tubercle can be used as a reliable and accurate bony landmark to identify and evaluate the position of the knee joint line restoration in revision TKA*

Keywords: *Total knee arthroplasty, knee radiograph., Joint line, measurement, implication*

1. INTRODUCTION

Total knee arthroplasty (TKA) has played a critical role in reducing and relieving the pain of patients with end-stage osteoarthritis and restoring knee function over the previous several decades. According to recent research by Gao Z et al., the average rate of primary and revision (combined) TKA was 175 procedures per 100,000 people, with the rate rising over time (1). One of the most difficult operations in knee surgery is revision total knee arthroplasty (RTKA). In the face of a massive increase in primary TKA indications around the world, RTKA will steadily increase its incidence over the next decade, nearly doubling by 2030. As a result, most orthopedic surgeons will have to deal with RTKA on a daily basis (2) . In fact, revision total knee procedures remain a surgical challenge for a variety of technical reasons , since the results are less predictable and satisfying than primary surgeries, and the 12-year survival rate is 82% (3). One of the most important requirements for a successful outcome is the restoration of the physiological joint line (JL) of the knee and it has been regarded as a watershed moment and the key goal in primary and revision TKA, which permits ligament balance and normal knee kinematics to be restored (4–6). This is simple to determine in primary TKA because all bony and ligamentous landmarks are intact (7).

However, in revision surgery, a portion of these markers is lost, making restoration of the joint line back to its original level much more difficult (8). Although complete restoration of original JL height following revision TKA is often difficult because to the existence of bone deficiency and joint deformity, there is still some controversy about the best approach for assessing the femorotibial JL position (9). The knee joint line restoration is necessary for proper knee function and the prevention of postoperative complications. Abnormal JL elevation has been identified as a cause of poor clinical outcome such as decrease range of motion as a result of Patella Baja (the patella sitting too low from its normal position) which is the most common complication, mid-flexion instability, decreased strength of the extensor mechanism, compression on the patella causing anterior knee pain,, component wear and a lower Knee Society Score (10,11). According to studies by Stienfeld B et al. and Fan A et al, coronal variations in JL position can influence patellar strain and patellofemoral contact forces even a 4–8 mm elevation or descent to the typical JL position may generate these complications (12,13) . Abnormal lowering of the

knee joint line from its original level can cause Patella Alta (the patella located higher up than its normal position) which can lead to patella instability and dislocation, lack of full extension, flexion instability (14,15). There is no standard anatomical measuring technique for determining the level of the joint line on radiograph, and there is no agreement on which radiological view should be employed. The absolute distance between a reference bony landmarks and the tangent to the joint line is commonly used to determine the level of the joint line (15). Adductor tubercle (AT), The epicondyles (Medial and lateral epicondyles), the tip of the fibular head (FH), the inferior patellar pole (IPP) and the tibial tubercle (TT) are the most widely used bony landmarks (16). The distances between these landmarks and the joint line were previously expressed as absolute values. These values, on the other hand, are less informative due to the large variation that exists between the gender and the different knee sizes (17). Although absolute distances were measured from bony landmarks to JL, the distances may be affected due to differences in gender, height, or ethnicity (18). Depending on using the ratios of the absolute distances between the adductor tubercle, medial or lateral epicondyles, fibular head and the joint line tangent to the femoral width in order to avoid these problems. There was no statistical difference in the ratios of different genders and heights, according to studies (19,20). However, they need pre-operative radiograph that are calibrated, as well as extra measurements and calculations during surgery (21).

The intra-operative accuracy of locating the landmarks used for the ratios has been shown to be extremely low (22). Plain radiography is a regular procedure in preoperative surgery and most widely used for determination of the JL level (23). It has been hypothesized that the adductor tubercle (AT) is one of the most dependable landmarks for establishing the knee joint line (JL). The AT was an accurate and reliable landmark for estimating the JL, which can be determined by calculating the femoral width (FW) and femoral diameter (FD), and adopting the fixed ratio formulas (15,24,25). Furthermore, AT is close enough to the JL to allow for comfortable measurements, and it is unaffected by bone abnormalities that are typical in knee OA patients It also has the benefit of being less prone to be damaged during knee arthroplasty, which is associated with significant bone loss (16) . So Adductor Tubercle (AT) could be employed as a reliable pre-operative (could be identified easily in standard plain radiography) and intra-operative landmark for restoring JL height appropriately (9) . While, recognizing the

epicondyles (Medial and Lateral epicondyles) on a plain radiograph is not always easy and obvious (15). The rationale of using the adductor tubercle as a reliable landmark to assess the joint line in RTKA has then been described by a number of authors, particularly considering the correlation with the trans-epicondylar femoral width, leading to the introduction of the concept of AT ratio the (ATJL distance)/FW (9,26) . The present study aimed to assess the radiographic measurement of the femoral width (FW), adductor tubercle to the joint line (ATJL) and fibular head to the joint line (FHJL) among Sulaymaniyah city population by plain radiography. Evaluate the effects of the individual variation in age, gender and height on these values and to find if there is a correlation between the adductor tubercle to the joint line and fibular head to the joint line with the femoral width and determine which one is most suitable for surgical practice and to find a comprehensible formula applicable during revision procedures.

2. METHODOLOGY

Study design

A prospective quantitative case series study on 362 individuals with or without knee pain of Sulaymaniyah city population who presented to the outpatient clinic in Sulaymaniyah and Shar teaching hospitals from March 2021 till December 2021 underwent plain radiography of the knee joint.

Inclusion Criteria

• Both genders (males and females).

• Age group is (18-60) years old with normal knee to kellegren and Lawrence grade 2 osteoarthritis.

Exclusion Criteria

• Kellegren and Lawrence grade 3 and grade 4 osteoarthritis.

• Pediatric and adolescent age groups.

• Any recent fractures or prior fractures to the bony landmarks of the knee joint (femoral condyles fracture, tibial condyles fracture, patella fracture).

• Posttraumatic osteoarthritis change of the knee joint.

• Any injuries to the ligaments of the knee joint (ACL, PCL, MCL, LCL).

• Previous knee surgery (open or arthroscopic).

• Inflammatory disorders (Rheumatoid arthritis, Gout)

• Hormonal disorders (Acromegaly, Hyperparathyroidism)

Data Collection

Individuals were interviewed personally and their data were documented in a special form which contains before knee radiograph part (the individual's demographic data and exclusion criteria) of our questionnaire was filled to help in recruitment and selection of the individuals to be included in this study, the other part of knee x-ray measurements were filled after taking the knee radiograph,.

Plain Radiographs were taken with the individual in supine position, the knee in full extension, the patella in neutral position and the x-ray tube centered on the knee joint. The distance between the tube of the x ray device and the radiographic table was 100 cm. The system used in the hospital radiology department is General Electric (GE) healthcare system

By using antero-posterior (AP) plain radiograph, the following measurements were performed:

1. The joint line (JL): defined as the line that connects the most distal points of medial and lateral femoral condyles.

2. The femoral width (FW): defined as the line that connected the most prominent points of the medial and lateral epicondyles.

3. The adductor tubercle to the joint line (ATJL): defined as the perpendicular distance between the adductor tubercle as the distal point on the medial supracondylar slope of the femur and the joint line.

4. The fibular head to the joint line (FHJL): defined as the perpendicular distance between the superior pole of fibula and the joint line.

5. The adductor tubercle ratio (ATJL/FW): defined as the distance from the adductor tubercle to the joint line divided by the femoral width.

6. The fibular head ratio (FHJL/FW): defined as the distance from the fibular head to the joint line divided by the femoral width.

All the measurements were performed on the digital radiographic image by using Radiant Digital Imaging and Communication in Medicine (DICOM) viewer (version 2021) which calculate the magnification factor (MF) automatically and electronically.

Although the radiological magnification factor of the knee radiographs was automatically and electronically coordinated by the Radiant DICOM and since the x-rays are diverging in nature, the radiological magnification has been periodically calculated to confirm that the Radiant DICOM viewer is dependable and accurate to calculate the magnification factor in order to not affecting the measurement's results of our study.

The most widely used method of calculating radiological magnification is to place a radio-opaque marker (for example a disc or sphere) of a known dimensions near the individual knee joint at the time the radiograph is performed then we measured this marker on the resulting image. From 362 knee x-rays obtained 120 knee x-rays were randomly selected for calculating the radiological magnification. The radio-opaque marker that have been used was a stainless-steel ball placed on the medial side of the individual knee joint. The true size of the marker measured by a vernier caliper, (20 mm) in diameter.

The size of the marker on the digital image measured by the Radiant DICOM viewer was also (20mm). So, the Radiant viewer is dependable and accurate to calculate the MF automatically and electronically as the marker size on the image is identical to the true object size and therefore not affecting the measurement's results of our study,

Data Analysis

Statistical analysis done by SPSS version 22 software, frequency and percentage used for categorical data, mean and SD for continuous data. Person correlation (R value) show and measures the correlation between continuous data. Values always range between -1 (strong negative correlation) and +1 (strong positive correlation). T test used for evaluation differences between mean and median of continues variables. P-value less or equal to 0.05 is consider significant.

3. RESULTS

In this study we included 362 individuals, 200 (55.25%) males and 162 (44.75%) females, 190 (52.49%) have left and 172 (47.51%) have right knee joint plain radiographs,(**Table 1**). The mean age of the individuals was (38.7 ± 11.19) years, the mean height of individuals was (168.9

± 8.98) cm, the mean FW was (80.8 ± 6.8) mm, the mean ATJL was (45.7 ± 3.7) mm and the mean FHJL was (17.7 ± 3.1) mm. The mean ATJL / FW ratio and FHJL / FW ratio were (0.56 ± 0.02) and (0.21 ± 0.04), respectively, (**Table 2**).

There was a significant negative correlation between age of the individuals and (FW, ATJL, FHJL). There was significant positive correlation between the height of the individuals and (FW, ATJL, FHJL). The mean values of FW, ATJL and FHJL were significantly higher in males than females, (P<0.001). This means that these absolute values (FW, ATJL and FHJL) have been affected by the individual variations in physical dimensions of age, height and gender as seen according to the results in (**Table 3 & 4**), so these absolute values are of limited utility and less informative. Therefore, in our study we want to find if there is correlation between the adductor tubercle and fibular head to the joint line with the FW and to evaluate the effects of the individual variations (age, height, gender) on their ratios. We found a significant strong positive linear correlation between FW and ATJL with (R value= 0.91, P<0.001) while there was a significant weak positive correlation between FW and FHJL with (R value=0.24 , P<0.001), (**Table 5**). No significant correlation was found between age and height of the individuals from one side against ATJL/FW and FHJL/FW ratios on the other side, (P>0.05), (**Table 6**). No significant difference was found in the mean ATJL/FW and FHJL/FW ratios between both genders, (P>0.05), (**Table 7**).

Table 1. Distribution of the studied group according to the gender and side of Knee plain radiographs

Variable		No.	%
Gender	Male	200	55.2
	Female	162	44.8
Knee plain radiographic side	Left	190	52.5
	Right	172	47.5

Table 2. Mean and Standard Deviation of the studied scale variables (n=362)

Variable	Mean	SD
Age	38.7	11.19
Height	168.9	8.98
FW (mm)	80.8	6.8
ATJL (mm)	45.7	3.7
FHJL (mm)	17.7	3.1
ATJL / FW ratio	0.56	0.02
FHJL / FW ratio	0.21	0.04

SD: standard deviation

Table 3. Correlations between age and height with FW, ATJL, FHJL (n=362)

Variable		FW	ATJL	FHJL
Age	R	-0.170	-0.200	-0.110
	P. value	0.002 sig	0.0001 hs	0.040 sig
Height	R	0.330	0.310	0.110
	P. value	0.0001 hs	0.0001 hs	0.040 sig

hs: highly significant (P<0.001), sig: significant (P<0.05)

Table 4. Differences between mean of FW, ATJL, FHJL according to gender

Variable	Gender	No.	Mean	SD	P. value
FW (mm)	Female	162	75.9	5.0	0.0001 hs
	Male	200	84.9	5.0	
ATJL (mm)	Female	162	43.1	3.0	0.0001 hs
	Male	200	47.8	3.0	
FHJL (mm)	Female	162	16.9	3.0	0.0001 hs
	Male	200	18.5	3.0	

SD: standard deviation, hs: highly significant (P<0.001)

Table 5. Correlations between FW and ATJL, FHJL respectively

Variable		ATJL	FHJL
FW	R	0.91	0.240
	P. value	0.0001 hs	0.0001 hs

hs: highly significant (P<0.001)

Table 6. Correlations between age, height and ATJL/FW, FHJL/FW.

Variable		ATJL/FW	FHJL/FW
Age	R	-0.060	-0.020
	P. value	0.270 ns	0.600 ns
Height	R	-0.060	-0.050
	P. value	0.230 ns	0.390 ns

R: correlation coefficient (Pearson's correlation), ns: not significant. P>0.05

Table 7. Differences between mean of ATJL/FW, FHJL/FW according to gender.

Variable	Gender	No.	Mean	SD	P. value
ATJL /FW	Female	162	0.56	0.023	1.00
	Male	200	0.56	0.021	ns
FHJL /FW	Female	162	0.21	0.039	1.00
	Male	200	0.21	0.037	ns

ns: not significant, P>0.05

4. DISCUSSION

Plain radiographic measurements of the normal value for the knee joint line among Sulaymaniyah city population is important when planning knee arthroplasty, especially revision surgery, because any change in the JL may affect the biomechanics of the knee, resulting in problems such as diminished extensor mechanism strength, patella compression, anterior knee discomfort, and limited knee joint range of motion (4,27). Many researches have focused on measuring different anatomical sites to determine the position of the knee joint line (19). The inferior end of the patella, the superior end of the tibia, the tibial tuberosity, fibular head, femoral epicondyles, and the adductor tubercle are all utilized as reference points. Because these distances can be influenced by many factors such as age, gender, and height, the ratios between the JL and these points have recently become more popular (9,15,28)(,). Joint line level is usually determined by measuring the distance from one of above mentioned anatomical landmarks and the joint line tangent (15). Plain radiography is the most often utilized method for determining the JL level because it is a regular procedure in preoperative surgery, MRI and CT scans are more costly, the inserted implant may cause

artefacts in the images particularly when planning revision surgery. Herzog et al. (29) and Sarmah et al. (23) found no difference between direct radiographic and MRI and CT measurements. Before any primary total knee arthroplasty, reference points can be easily measured on a normal radiograph; however, they may not be seen following a revision operation because of bone deficiencies. As a result, it would be more practical to employ a reference point that could be calculated before and even during the revision surgeries. Because it may be easily seen and measured both on preoperative plain radiographs and during surgery, the adductor tubercle (AT) is a useful marker for determining the JL (30). This bony protrusion is located on the medial surface of the medial condyle of the femur and represents the insertion of the vertical fibers of the adductor magnus tendon (31,32). Because the adductor tubercle is situated away from the distal tibiofemoral joint, it is less likely to be influenced by significant bone loss following knee arthroplasty (33). The present study showed the value for the average FW which is the line that connected the most prominent points of the medial and lateral epicondyles was (80.8 ±6.8) mm.

The average of ATJL which is the perpendicular distance measured from the adductor tubercle to the joint line was (45.7 ±3.7) mm. The average FHJL which is the Perpendicular distance between the superior pole of the fibula and the joint line was (17.7 ±3.1) mm. In comparison to the femoral width (FW) value found in this study among Kurdish population on 362 individuals was (80.8 ±6.8) mm, Iacono et al have found the FW to (89.7 ± 8.4) mm among Italian population on 110 individuals in 2013 (15), by Gürbüz et al. it was (87.2 ±10.8) mm among Turkish population on 108 individuals in 2015 (30), (85.4 ±7.1) mm by Luyckx et al. among Belgium population on 100 individuals in 2014 (8) and (89.44 ± 8.77) mm by Gao Z. et al. among Chinese population on 451 individuals in 2021 (1). While our average adductor tubercle to the joint line (ATJL) was 45.7 ± 3.7) mm, Iacono et al. found it to be 48.7 ± 4.8) mm (15), by Gürbüz et al. it was (47.9 ±6.2) mm (30), (44.6 ±4.3) mm by Luyckx et al.(8) and (49.43 ±4.97) mm by Gao Z. et al. (1). In the present study, the fibular head to the joint line (FHJL) was found to be (17.7 ±3.1) mm in average, by Gürbüz et al. it was (20.5 ±4.0) mm (30). On the other hand, the FHJL by Iacono et al. was found to be 16.7 ± 4.0) mm (15), by Luyckx et al. the FHJL was found to be (15.1 ±3.7) mm (8), by Gao Z. et al. the FHJL was (19.95 ± 3.98) mm (1). There are some differences in the measurement results of the FW, ATJL and FHJL of our study

in comparison to the above-mentioned studies. This could be due to differences in the age and heights of the individuals, the race of the population, the number of the sample size according to their population but these results are significant as all the measurements in these studies done on standard (AP view) plain radiography in supine position. Such absolute values according to the results of our study and the other studies are of limited utility because measurement results may vary due to large individual variations in physical dimensions such as gender, age and height (3,17,21) In order to account for these individual variations, a ratio of these distances to the joint line, to the femoral width had been described. By dividing the absolute values of these distances by the femoral width, the ratio becomes relative individual variations independent while calculating the joint line position (8,21,28,34). The Pearson's correlation coefficient between these distances (ATJL, FHJL) and FW was calculated. The present study found a significant strong positive linear correlation between ATJL and FW gives the best result which was found to be (R = 0.91) and the ratio between them found to be 0.56 ±0.02). While the correlation between FHJL and FW found to be weak positive correlation (R=0.24), although it is statistically significant, with a ratio of (0.21 ±0.04). Iacono et al. found an excellent correlation between ATJL and FW (R=0.83) with a ratio of 0.54 while he found the FHJL and FW had a weak correlation (R = 0.21) and due to this weak correlation no ratio was identified between FHJL and FW (15). Luyckx et al. found a strong positive correlation between ATJL and FW (R= 0.82) with a ratio of 0.52 while the correlation between the FHJL and the FW was found to be weaker (R=0.13) with a ratio of 0.19 (8). Gao Z. et al. found an excellent linear correlation between ATJL and FW (R=0.83) with a ratio of 0.55 but he found weak positive correlation between FHJL and FW and no ratio was identified between them due to this weak correlation (1). Gürbüz et al. found a strong positive correlation between the ATJL and FW with a ratio of 0.55 while there was a weak correlation between the FHJL and FW and no ratio was identified between them (30), (**Table 8**). So, the adductor tubercle is an accurate and dependable bony landmark for the joint line reconstruction in revision TKA because there is a strong positive linear correlation with the femoral width (R=0.91) with a ratio (0.56) stronger, more constant and precise than the correlation between the fibular head to the joint line with the femoral width (R=0.24) which was weaker with a ratio (0.21) and not affected by any individual factors such as gender, age or height. Practically we can locate the knee Joint line

from the adductor tubercle precisely through a formula by multiplying the femoral width of the patient that can be measured on the standard plain radiograph preoperatively after calculating the radiological magnification factor by the constant adductor tubercle ratio of Sulaymaniyah city population which was (0.56) according to the result of our study. Also, on comparing the adductor ratio to the epicondyle's ratio (medial and lateral epicondyles), finding of the adductor tubercle is easier either by plain radiograph or intraoperatively making it a valuable landmark for joint line reconstruction in revision TKA. Even in difficult revision cases where the epicondyles can no longer be found, the adductor ratio remains an identifiable landmark as it is located away from the distal tibiofemoral joint, so it is less likely to be influenced by significant bone loss after knee arthroplasty (8,15). It's worth mentioning that Iacono et al. measured the ATJL/FW ratio both preoperatively and intraoperatively. The ratios measured were (0.53 ± 0.03) and (0.54 ± 0.03) for intra-operative measurements and radiographic measurements respectively so there was no difference (0.01 ± 0.03) between the calculated ratios ATJL/FW (35).

Table 8. The results of the different measured distances expressed as mean absolute values (mm) with the standard deviations

Distances	Present Study	Iacono et al. (15)	Gürbüz et al. (30)	Luyckx et al. (8))	Gao Z. et al. (1)
FW	80.8 ± 6.8	89.7 ± 8.4	87.2 ±10.8	85.4 ±7.1	89.44 ± 8.77
ATJL	45.7 ± 3.7	48.7 ± 4.8	47.9 ±6.2	44.6 ±4.3	49.43 ± 4.97
FHJL	17.7 ± 3.1	16.7 ± 4.0	20.5 ±4.0	15.1 ±3.7	19.95 ± 3.98
ATJL/FW	0.56	0.54	0.55	0.52	0.553
FHJL/FW	0.21	-	-	0.19	-

5. CONCLUSIONS

Among Sulaymaniyah city population, we found the radiographic measurement results of the knee joint line to the adductor tubercle (ATJL) and to the fibular head (FHJL) and the femoral width (FW) of the individuals. These absolute values according to the results of our study have been influenced by the individual variations in age, gender and height. We found there is a significant strong positive linear correlation between the adductor tubercle to the joint line with the femoral width with a ratio (0.56) stronger, more constant and precise than the

correlation between the fibular head to the joint line with the femoral width and which was weaker irrespective of any factors such as age, gender and height. So, the adductor tubercle can be used as a reliable and accurate bony landmark to identify and evaluate the position of the knee joint line restoration in revision TKA through the following formula: (ATJL = AT ratio × FW). Therefore we recommend conducting further studies on national level at other centers to compare the results and to establish standard measurement for Iraqi population. Performing intraoperative measurement in order to make a better comparison. Measring of other anatomical points such as medial epicondyle to the joint line (MEJL), lateral epicondyle to the joint line (LEJL) together with their ratios that may help to make a true comparison between these ratios and the adductor tubercle ratio.

Limitations:

The study is not free of limitations, firstly we did not performed intraoperative measurements, secondly, preoperative MRI and CT-scan measurements were not assessed, however previous studies found no significant differences between intraoperative and preoperative measurement in the present study and no differences were found between direct radiographic and MRI and CT measurements (23,29,35,36)

Ethical Approval:

All ethical issues were approved by the authors and documented at the Scientific Council for Orthopedic Surgery of the Arab Board of Health Specializations. Data collection and patients' enrollment were in accordance with Declaration of Helsinki of World Medical Association, 2013 for the ethical principles of researches involving human. Signed informed consent was obtained from each participant and data were kept confidentially.

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