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HUMAN PATELLA MORPHOMETRY AND VOLUMETRY, AN OSTEOLOGY-BASED STUDY IN THE JAPANESE ETHNICITY

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ABSTRACT

BACKGROUND Patella is the largest sesamoid bone in the body. It is of critical importance to the patellofemoral unit. Its morphology can be modified by several cultural-ethnic factors. Further, its morphometry is of prime value in anthropology, biometrics, evolutionary Biology, implant prosthesis and surgical orthopedic procedures. **AIM** To derive a statistical inference concerning the morphometry of the patella, in a specific ethnic sample. **MATERIALS AND METHODS** In a sample of 40 dry patellae of deceased member of the Japanese ethnicity, measurements were taken to derive statistical inferences concerning patellar morphometry. Specific morphometric parameters were studied: patellar heights (H1 and H2), maximal width (W), maximal thickness (T), volume, weight, and density. Patellar heights,width, and thickness. The volume was measured accurately using two methods: Archimedes fluid displacement principle (1st method), and the application of using an alginate impression cast material (2nd method). Patellar density was a derived function of both volume and weight. Citations of this paper were created via systematic review of literature with subsequent critical analysis. **RESULTS** The 95% confidence Interval were: 35.50 to 38.40 (H1), 26.46 to 28.40 (H2), 36.93 to 39.49 (W), 18.12 to 19.28 (T), 6.462 to 7.894 (volume), 8.991 to 10.677 (weight), and 0.696 to 0.765 (density). *Pearson's Correlation coefficient* (R), was positive for most of the tested parameters.The strongest correlation of Patellar weight versus volume, at R of 0.872, and patellar weight versus thickness at R of 0.779. All related p-values were significant at $p < 0.01$. Multiple Linear Regression of the tabulated parameters, revealed that the *Residual Sum of Squares* (*RSS*) was 0.913, and the *Coefficient of Determination* (R^2) was 0.981. **CONCLUSION** Data from this study is highly valuable and of vital applications in: anthropology, comparative Anatomy and evolutionary Biology, prosthesis synthesis, biomedical applications, orthopedic surgery, and degenerative Medicine.

KEYWORDS: Patella, Sesamoid Bones, Morphometry, Casting Technique, Humans, Japan.

LEVEL OF EVIDENCE: Level-5, according to the classification system by the Oxford Centre for Evidence-based Medicine (CEBM).

INTRODUCTION

The patella, also known as the kneecap or the kneepan, is the largest sesamoid bone in the body which develops within the tendon of the quadriceps femoris muscle. It is a flat bone with a shield-like architecture (Fig. 1), and it's located anteriorly in relation to the femoral condyles. It has two surfaces (anterior and posterior), three borders (superior, medial and lateral) and an apex. The posterior surface of the patella can be divided into two parts: superior (articular) and inferior (non-articulatar). The inferior part will form the apex, which serves as a site for patellar ligament attachment. The articular surface is further sub-divided into medial and lateral facets, separated by a vertical ridge.[1] Patella, as a bone, is significantly important in anthropometrics. It is involved in the various methods of sitting and squatting. Therefore, it will be modified by cultural and ethnic variables. It is to be assumed that the size of the patella, can be dependant on the strain generated by the quadriceps muscle. However, the absence of patella in some animals which have a very powerful action of knee extension, led to controversy concerning this concept.[2] Yoo et al. (2007), revealed that the geometry of the patella and patellar tendon was significantly larger in males. Other demographic factors including weight, height, body mass index correlates well patellar thickness, but poorly with the patellar tendon length.[3, 4] Qaudriceps tendon thickness, also showed significant correlation with patellar height.[5]

Koyuncu et. al (2011), interestingly studied the patellar development during the fetal life. It was found that there are no significant differences between genders or sides (right versus left patallae). However, a significant correlation was found between gestational age and all studied morphometric parameters of patella.[6]

Examination of a southern Chinese population, revealed that males have larger patellae, and there was no statistically significant difference between sides (i.e. right versus left patellae). Compared with Westerners, these patellae were smaller.[7]. In northern Indian population, a study used patellar morphometry for sex determination, with high accuracy up to 80.5% [8]. Olateju et al. (2013), studied a South African population of European ancestry, revealed high positive linear correlation (R=0.89) between the patellar thickness and width.[1] In this paper, *patellar facet angle* (PFA) was not measured. However, it is worthy to mention that other studies indicated that there is a relationship between the pre-operative PFA and the subsequent postoperative osteosclerosis. Therfore, both patellar morphmetry and implant design, affect patellofemoral contact stress following *total knee arthroplasty* (TKA).[9-14]

Many pathologies affect the patellofemoral compartment of the knee joint including: osteoarthritis, chondromalacia patellae, fractures and stress fractures, ideopathic patellofemoral pain syndrome, and others.[15] Patients undergoing TKA, are routinely subjected to a pre-determined amount of post-surgical loading of the knee, to preserve patellar articular cartilage and subchondral bone trophism.[16]. Other pathologies that may affect the patella during TKA include patellofemoral instability, and implant's failure.[17]. Biomechanical distrubances can also affect the patellofemoral compartment of the knee, for example when the Q-angle is high, there will be overpressure on the medial knee compartment during maneuvers that increase contact between patella and medial condylar facet.[18, 19]. Patellar fractures may be due to traumatic or nontraumatic causes. In patellar stess fractures, the absence of injury will further confirm the diagnosis.[19-21]

MATERIALS AND METHODS

Materials used included 40 dry specimens of human patellae. The patellae included 23 left patellae and 17 right patellae (Table 1 and Fig. 4). These patellae belonged to deceased members, of an unidentified age and gender, of the Japanese ethnicity. The patellar parameters that were measured included: two patellar heights measurement (H1, H2), the maximal width (W) measured perpendicularly to the mid-point of the main facetal vertical ridge (between medial and lateral facets), the maximal thickness (T) also measured at the level of the midpoint of the facetal ridge (Fig. 2). The morphometry measurement, was done by highlighting with a marker pen, the height of the facetal ridge, then measuring the two heights (H1 and H2), then marking the mid-point of the facetal ridge to measure the largest width (W) perpendicular to that point. Finally, the maximal thickness (T),was also measured.

Measurement were taken at the Anatomical specimens' unit at the department of Anatomy and Cellular Biology. Further, to prevent human-made error(s) and biases while measuring, the two researchers of this paper recorded each reading using a standard electronic Vernier Caliper (standard stainless steel electronic Vernier micrometer gauge tool, UPC number 814870023454). When the two measurements were different to the nearest 1/10th of a millimeter, a 3rd independent reading was taken to resolve the measurement dispute (numerical disparity). A fourth measurement was also taken, using an analogue Vernier, to confirm the accuracy of the electronic Vernier to the nearest millimeter. The final readings, as seen in table 1, represent the average readings for each measured parameter and as recorded accurately by the electronic Vernier. Statistical data were calculated using the *Statistical Package for Social Sciences* (SPSS version 20.0), Microsoft Excel 2016, and *Shodor-Interactivate* software.[23]

Other measured parameters are: patellar volume measured in cubic centimeters (cm^3), patellar weight measured in grams (gm), and the corresponding density (gm/cm^3). The volume was challenging to be calculated with high accuracy. Therefore, two methods were utilized. The 1st method (the least accurate) was an employment of Archimedes fluid displacement principle.[24] In which each kneecap bone, was taken and immersed in a 500-milliliters glass cylinder containing distilled water. The volume was measured with accuracy to the nearest centile of cubic centimeters. This method was done to double-check (confirm) the accuracy of the 2nd method, the casting technique (Fig. 3), which was the most accurate.

The 2nd method was very accurate, to the nearest 1/10th of a cubic centimeter. The method was an application of using an alginate impression cast material (Hydrogum, from The Zhermack Group).[25] The cast, seen in figure 3, was made to completely enclose each patella. Each cast after it was fully dried, was cut in accurately into two halves, and the patella was gently removed in order not to break the cast material. Later, the two halves were glued together using an epoxy resin, and water was injected into the cavity of the cast to estimate the volume of its cavity, which corresponds to the patellar volume. Gluing of the two-halves of the cast was done accurately, to seal the cast in a way to avoid leaking of the injected water from the cavity of the cast to the exterior. Whenever leaking happened, the entire cast was re-done for the specific patella. A syringe that was used to inject water, a standard 10-ml syringe. Later, the injected volume was accurately measured, by measuring the length of the injected water column.

The density (gm/cm^3) was a derived parameter of weight and volume. The mean value for density was 0.730 gm/cm^3, which is evidently less than that of water. A scattered plot (Fig. 5), shows a correlation of three patellar parameters: weight, volume, and density. Density remains fairly constant for each patella, in contrast to patellar weight and volume, which exhibited a wider range of variability.

A systematic review of literature was done from 4th of March to the 20th of June 2016, to collect the most valid and up-to-date literature on the topic. The literature review was done across medical databases: PubMed, The Cochrane Library, Scopus, OpenGrey, and Google Scholar. Prespecified keywords were used, in combination with Boolean operators. The total number of papers of interest on the topic, after exclusion of duplicate articles, were 37 papers. These papers were scanned and filtered, following detailed inspection of paper's title, abstract, and main manuscript. The papers were also assessed for the level of evidence using critical appraisal. Total number of final references used in this paper's citation, is 28 including four invention patency papers from the United States.

The study was conducted in accordance with the Ethical approval no. 620-73, on the 15th of May 2016. The approval is under the authority of the dean office at the faculty of Medicine at the University of Baghdad.

RESULTS AND DISCUSSION

Data from the conducted statistical analyses (Table 2), were graphically presented as a box-whisker plot chart (Fig. 4). The mean values were: 36.95 mm (H1), 27.43 mm (H2), 38.21 mm (W), 18.70 mm (T), 7.178 cm^3 (volume), 9.834 gm (weight), and 0.730 gm/cm^3 (density). The standard deviation values were: 4.52 mm (H1), 3.03 mm (H2), 3.99 mm (W), 1.82 mm (T), 2.238 cm^3 (volume), 2.636 gm (weight), and 0.108 gm/cm^3 (density). The 95% confidence Interval (CI) were: 35.50 to 38.40 (H1), 26.46 to 28.40 (H2), 36.93 to 39.49 (W), 18.12 to 19.28 (T), 6.462 to 7.894 (volume), 8.991 to 10.677 (weight), and 0.696 to 0.765 (density).

It is important to point out that the tabulated density data, are of bones (belonging deceased Japanese people, roughly from the past 50). Therefore, it (the measured density) is not of an estimate of the density in live objects (i.e. in-vivo), and it is well known that bone degradation (decomposition) starts after death (post-mortem). However, bone is quite resistant to degradation, but it will eventually be broken down by physical breaking, decalcification, and dissolution. The rate at which bone is degraded, however, is highly dependent on its surrounding environment. When soil is present, its destruction is influenced by both abiotic (water, temperature, soil type, and pH) and biotic (fauna and flora) agents [26, 27].

It is also important to point out that the posterior orientation of the maximal patella thickness (TO), was frequently (82.5% of the sample) located in an area on the lateral facet, about few millimeters (up to 4 mm) laterally from the main facetal ridge, while 5% of this sample, it was located posteriorly in relation to the medial articular facet. Concerning the articular ridge (separating the medial and lateral facets), it was concave in about 50% of the sample, while being flat-to-convex in the rest of the sample.

Correlation coefficient (*R*), as seen in figure 6-10, was positive for most of the measured parameters (including H1 vs. H2, W vs. T, Wt. vs. Vol., H1 vs. W, H1 vs. T). The most evident correlations were: Patellar weight versus volume at *R* of 0.872, and patellar width versus thickness at *R* of 0.779. Further, all *p*-values were significant at $p < 0.01$. Multiple Linear Regression of all tabulated parameters, revealed that the Residual Sum of Squares (*RSS*) was 0.913, and the Coefficient of Determination (R^2) was 0.981.

The level of evidence of this paper is Level-5, according to the classification system by the *Oxford Centre for Evidence-based Medicine* (CEBM).[28]

TABLES

Table 1. Raw rata of the right (Rt.) and Left (Lt.) Patellae.

*** Patella maximal *thickness orientation* (TO), in relation to lateral facetal area (L), medial facetal area (M), and facetal ridge (Mid).**

Specimen	Limb	H1	H2	W	T	TO*	Weight	Volume	Density
1.	Lt.	32.53	24.93	33.90	16.78	L	4.422	6.729	0.657
2.	Rt.	34.31	22.74	37.02	17.71	L	5.232	7.999	0.654
3.	Rt.	35.23	26.88	36.72	15.15	L	5.331	7.038	0.756
4.	Rt.	37.96	26.12	40.05	19.10	L	8.609	10.524	0.818
5.	Lt.	32.92	23.88	33.67	17.64	L	6.463	8.142	0.794
6.	Rt.	31.43	25.79	35.22	18.30	Mid.	4.418	7.124	0.620
7.	Rt.	36.68	25.41	34.13	16.78	L	5.695	9.112	0.625
8.	Rt.	28.53	24.94	35.02	16.03	L	4.281	6.048	0.708
9.	Rt.	43.89	26.26	42.16	19.17	L	8.564	12.270	0.698
10.	Lt.	33.19	26.30	33.54	18.18	Mid.	5.126	6.922	0.741

11.	Rt.	38.21	28.28	37.14	18.75	Mid.	6.958	10.012	0.695
12.	Lt.	24.50	27.24	36.46	19.31	L	5.311	9.018	0.589
13.	Lt.	36.26	25.58	35.96	18.01	L	6.481	10.022	0.647
14.	Lt.	42.84	32.17	46.45	20.53	L	12.092	13.620	0.888
15.	Rt.	43.02	33.21	42.13	17.84	L	9.611	11.942	0.805
16.	Rt.	41.28	33.10	39.85	20.23	L	6.089	11.944	0.510
17.	Lt.	37.35	25.40	36.29	17.99	L	5.517	9.744	0.566
18.	Rt.	43.18	29.24	44.42	20.22	L	8.957	14.628	0.612
19.	Lt.	36.44	28.76	37.94	19.17	L	6.657	10.974	0.607
20.	Rt.	37.41	31.69	39.99	19.00	Mid.	9.509	10.528	0.903
21.	Lt.	34.40	29.57	38.13	18.22	L	7.218	11.174	0.646
22.	Rt.	37.10	25.67	38.75	18.15	L	6.531	10.054	0.650
23.	Lt.	34.91	26.68	40.19	18.40	L	9.215	10.632	0.867
24.	Lt.	35.45	23.79	33.95	15.58	Mid.	4.990	6.858	0.728
25.	Rt.	33.34	26.89	32.51	17.61	L	5.637	6.314	0.893
26.	Lt.	36.02	26.54	39.71	20.04	L	5.019	7.404	0.678
27.	Lt.	36.82	25.94	39.63	20.29	L	7.270	8.312	0.875
28.	Rt.	42.85	27.69	39.76	20.89	L	7.738	11.428	0.677
29.	Lt.	37.27	28.58	37.07	19.72	L	6.835	10.044	0.681
30.	Lt.	42.52	27.06	49.83	23.40	L	11.130	15.546	0.716
31.	Lt.	37.82	25.51	38.02	17.71	L	6.130	8.610	0.712
32.	Lt.	31.62	23.50	32.91	16.12	L	4.879	6.720	0.726
33.	Rt.	41.43	30.18	38.09	20.32	L	10.832	13.646	0.794
34.	Lt.	39.15	27.40	38.98	18.55	M	7.004	8.524	0.822
35.	Rt.	38.44	30.47	38.92	17.71	L	7.564	9.124	0.829
36.	Lt.	40.54	27.42	44.13	21.71	L	8.656	12.178	0.711
37.	Lt.	38.21	30.97	35.91	17.95	L	9.755	11.488	0.849
38.	Lt.	32.93	21.38	32.45	18.08	L	4.240	6.626	0.640
39.	Lt.	32/96	28.45	35.90	18.18	M	7.971	7.890	1.010
40.	Lt.	47.18	35.62	45.67	23.52	L	13.195	16.464	0.802
Average	23 Lt. 17 Rt.	36.95	27.43	38.21	18.70	33 L 5 Mid 2 M	7.178	9.834	0.730

Table 2. Statistical analyses of Measured Parameters, including Weight (Wt.), Volume (Vol.), and Density (Dens.).

Morphometric Parameters vs. Statistical Analyses		Age & Gender	H1	H2	W	T*	Wt.	Vol.	Dens.
Sample size		Unknown	40	40	40	40	40	40	40
Mean (x̄)			36.95	27.43	38.21	18.70	7.178	9.834	0.730
Median			36.96	26.89	37.98	18.26	6.746	9.878	0.712
Mode			38.21	None	None	17.71	None	None	0.794
Lowest value			24.50	21.38	32.45	15.15	4.240	6.048	0.510
Highest value			47.18	35.62	49.83	23.52	13.195	16.464	1.010
Range			22.68	14.24	17.38	8.37	8.955	10.416	0.500
Interquartile range			6.61	3.59	4.57	2.25	3.328	3.948	0.167
First quartile			33.58	25.53	35.39	17.71	5.316	7.526	0.647
Third quartile			40.19	29.12	39.96	19.96	8.644	11.473	0.815
Variance (s2)			20.45	9.17	15.94	3.31	5.007	6.946	0.012
Standard deviation			4.52	3.03	3.99	1.82	2.238	2.636	0.108
Quartile deviation			3.31	1.80	2.28	1.13	1.664	1.974	0.084
Mean absolute deviation (MAD)			3.43	2.33	3.05	1.37	1.793	2.122	0.088
Confidence Interval (CI)	90%		35.02 to 38.89	26.13 to 28.73	36.50 to 39.92	17.92 to 19.47	6.220 to 8.136	8.705 to 10.963	0.684 to 0.776
	95%		35.50 to 38.40	26.46 to 28.40	36.93 to 39.49	18.12 to 19.28	6.462 to 7.894	8.991 to 10.677	0.696 to 0.765

	99%	35.75 to 38.15	26.62 to 28.24	37.15 to 39.27	18.22 to 19.19	6.582 to 7.774	9.132 to 10.536	0.701 to 0.759
Statistical Correlation & Linear Regression		*R*	*p* value					
	H1 vs. H2	0.593	All *p*-values were significant at $p < 0.01$					
	W vs. T	0.779						
	Wt. vs. Vol.	0.872						
	H1 vs. W	0.748						
	H2 vs. T	0.614						
Multiple Linear Regression of All Measured Parameters	Residual Sum of Squares (*RSS*)	0.9132						
	Coefficient of Determination (R^2)	0.9819027949						

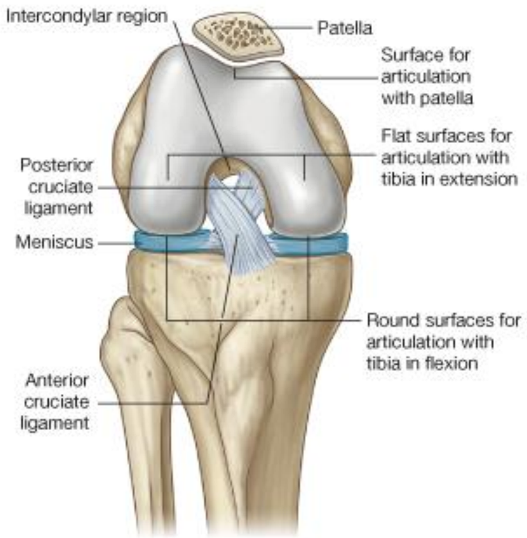

Figure 1. Schematic presentation of patellofemoral unit, an anterior view [22].

Figure 3. Some of the casts materials, used to accurately estimate the patellar volume.[25]

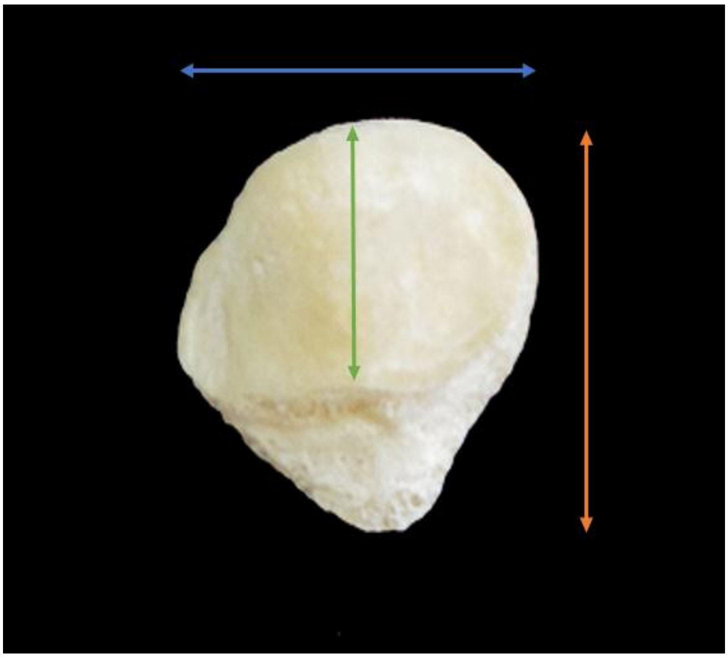

Figure 2. Posterior view of the articular patellar surface. H1 (vertical orange line), H2 (vertical green line), and W (horizontal blue line).

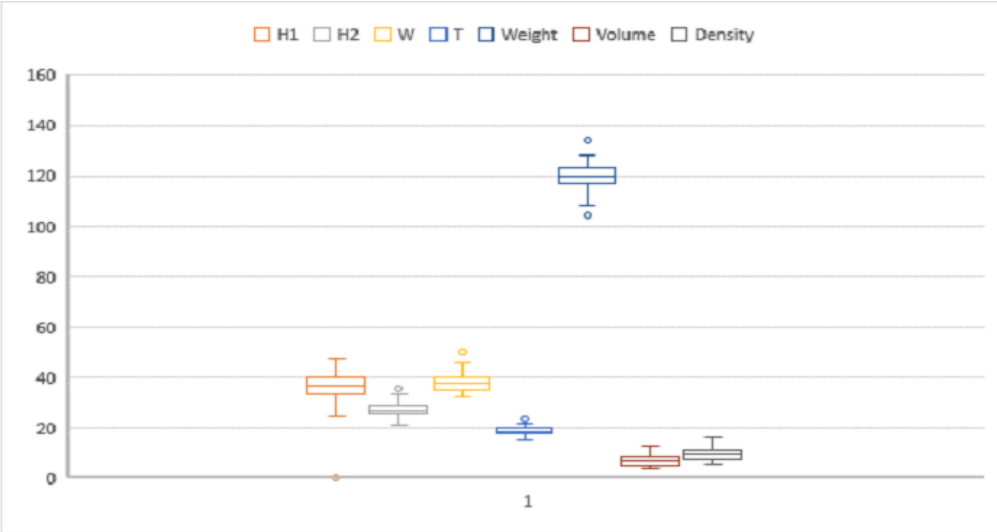

Figure 4. Box and Whisker Plot for the tabulated patellar parameters.

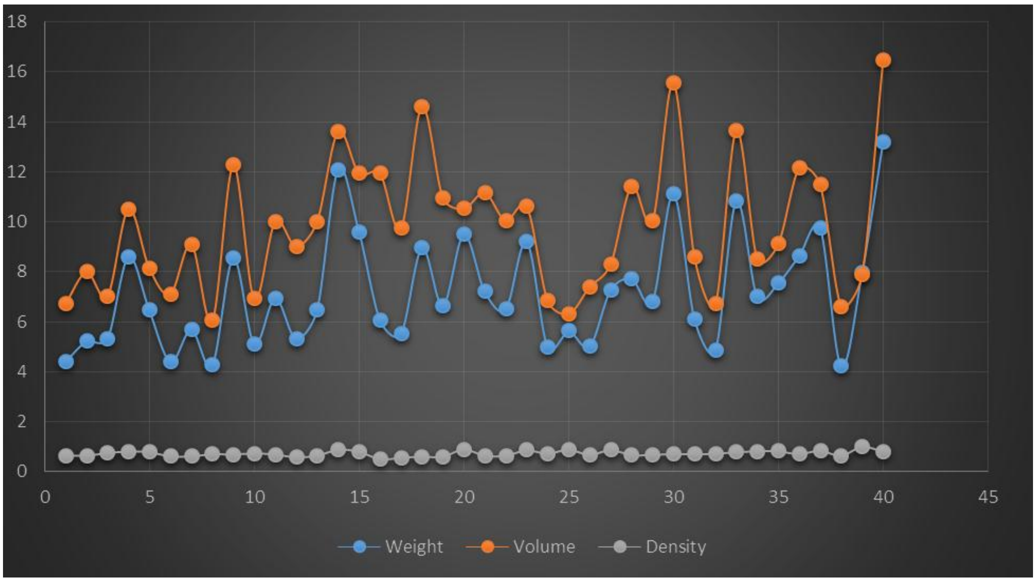

Figure 5. Scattered plot of three patellar parameters (weight, volume, density). Density remains fairly constant at 0.730 gm/cm^3 +/- 0.108 (SD), despite patellar variations of weight and volume.

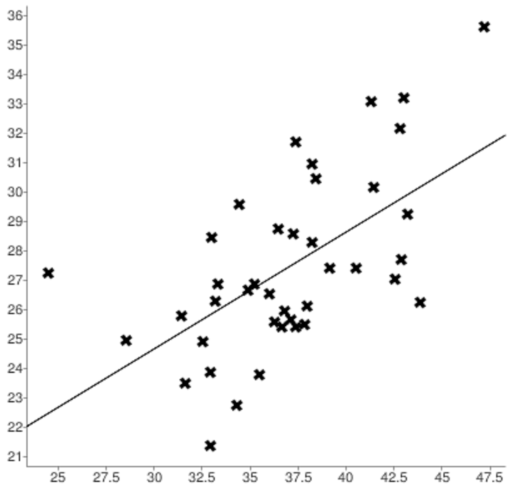

Figure 6. Linear regression and a scattered plot, H1 (X coordinate) vs. H2 (Y coordinate). Correlation coefficient (*R*): 0.593, and the slope is 0.397

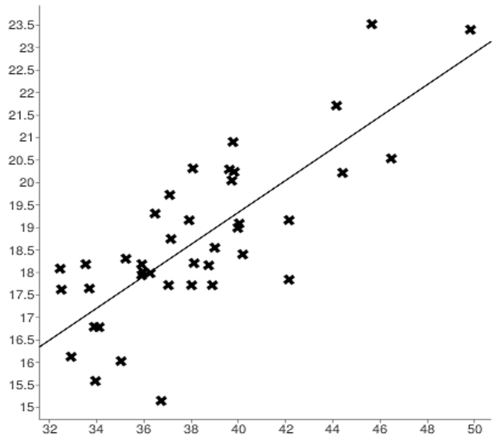

Figure 7. Linear regression and a scattered plot, Width (X coordinate) vs. Thickness (Y coordinate). Correlation coefficient (*R*): 0.779, and the slope is 0.355

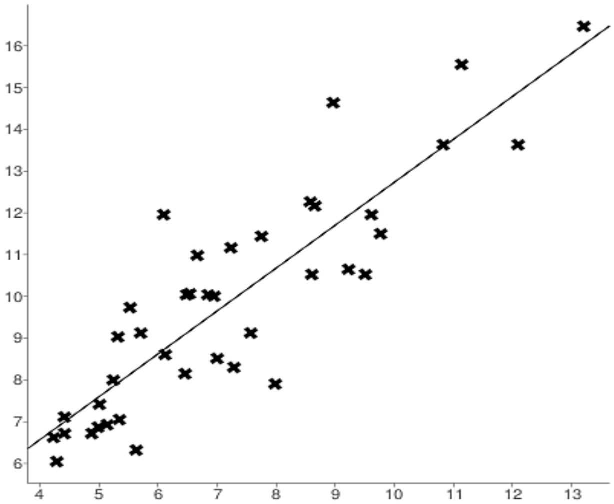

Figure 8. Linear regression and a scattered plot, weight (X coordinate) vs. volume (Y coordinate). Correlation coefficient (*R*): 0.872, and the slope is 1.028

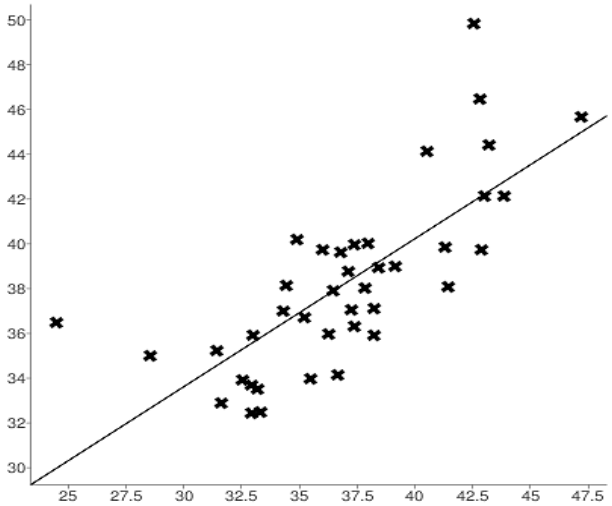

Figure 9. Linear regression and a scattered plot, H1 (X coordinate) vs. Width (Y coordinate). Correlation coefficient (*R*): 0.748, and the slope is 0.661

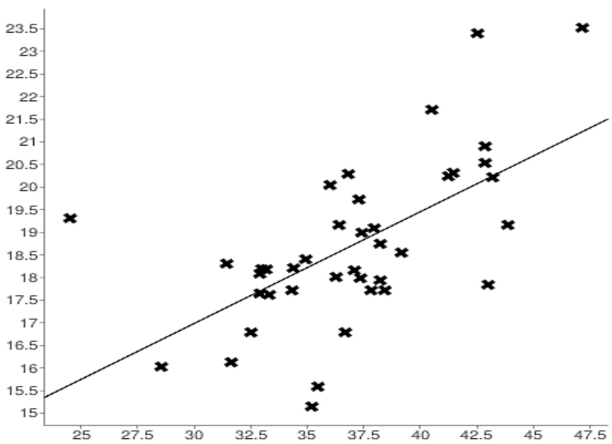

Figure 10. Linear regression and a scattered plot, H1 (X coordinate) vs. Thickness (Y coordinate). Correlation coefficient (*R*): 0.614, and the slope is 0.247

DISCUSSION AND CONCLUSION

It is important to pay the reader's attention to the evident positive linear correlation of patellar width versus thickness, as these two parameters are vital for contribution in knee join biomechanics, quadriceps muscle insertion and patellar ligament attachment, and contractile force generation across the patella and in relation to the patellofemoral unit.

This study in relation to morphometry of the kneecap are obviously and critically important from a biomechanical perspective. The concluded parameters and their relevant statistical analyses, can be variably used for application in many disciplines: Anthropology and anthropometrics, comparative Anatomy and evolutionary Biology, patellofemoral unit prosthesis synthesis, patellar implants, arthroplasty, biomedical and biomechanical applications, Surgical and radiological indices, orthopedics and arthroscopy, rheumatology, and forensic sciences.

LIST OF ABBREVIATIONS

Not applicable

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted in accordance with the Ethical approval no. 620-73, on the 15th of May 2016. The approval is under the authority of the dean office at the faculty of Medicine at the University of Baghdad.

CONSENT FOR PUBLICATION

we, the co-authors of this paper, give our full consent for publication of this paper, in accordance with the guidelines of the Journal of Biomedical Science.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

COMPETING INTERESTS

None.

FUNDING

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AUTHORS' CONTRIBUTIONS

Al-Imam A. was responsible for:

1. Literature review
2. Acquisition of bony specimens
3. Measurement of the tabulated parameter, with exception of the patellar volume
4. Creation of figures and tables
5. Double checking the mathematical analyses
6. Statistical analyses

Al-Imam M was responsible for:

1. Literature review
2. Measurement of the tabulated patellar parameters
3. Choice of the appropriate casting material

4. Application of the casting technique to measure the patellar volume
5. Mathematical and statistical analyses
6. Drafting the paper

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Professor Nawfal Al-Hadithi, a professor of Human Anatomy and an ENT surgeon at the faculty of Medicine, University of Baghdad. His orientation concerning paper structure was precious.

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