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Computed Tomography vs Computer Modeling for Comparison and Evaluation of Anatomical Features of the Radial Head

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Abstract

Background. The generally accepted method of treating complex radial head fractures is arthroplasty. At the present stage, there is a variety of prosthetic designs, in production of which statistically averaged morphometric parameters are used. The anthropometric features of patients are not taken into account.

The aim of the study — to compare the morphometric parameters of the proximal radius obtained using computed tomography and computer modeling.

Methods. The study used the radiological method of examination and the computer modeling method. The study material was a database of DICOM format computer tomograms of the right and left elbow joints of 137 people (66 males, 71 females). Their age ranged from 40 to 70 years, without signs of musculoskeletal system pathology. Computer tomograms were analyzed using the RadiAnt DICOM Viewer program. Computer modeling was carried out through the ITK-SNAP program (GNU General Public License version 3.0 — GPLv3), with further processing of the obtained model using the developed software method.

Results. Comparison of the morphometric parameters of the radial head obtained using the developed computer modeling program and the morphometric parameters of a standard computed tomogram showed their identity.

Conclusion. The presented software program "Automated determination of bone morphometric parameters" will enable to model the radial head prosthesis on the basis of indicators of computer tomograms, taking into account the individual structural features of the patient's radius.

Keywords: radius, radial head, radial neck, arthroplasty, modeling.

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Сравнение и оценка анатомических особенностей строения головки лучевой кости человека при компьютерной томографии и компьютерном моделировании

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Реферат

Актуальность. Общепринятым методом лечения сложных переломов головки лучевой кости является эндопротезирование. При производстве современных конструкций протезов используются статистически усредненные морфометрические параметры без учета конституциональных антропометрических особенностей пациентов.

Цель исследования — сравнить морфометрические показатели проксимального отдела лучевой кости человека, полученные при помощи компьютерной томографии и компьютерного моделирования.

Материал и методы. В исследовании использовали лучевой метод и метод компьютерного моделирования. Материалом исследования послужила база компьютерных томограмм формата DICOM правых и левых локтевых суставов 137 человек (66 мужчин, 71 женщины), возраст которых составил от 40 до 70 лет, у них отсутствовали признаки патологии опорно-двигательного аппарата. Компьютерные томограммы анализировались с помощью программы RadiAnt DICOM Viewer. Компьютерное моделирование проводилось в программе ITK-SNAP (GNU General Public License version 3.0 — GPLv3) с дальнейшей обработкой полученной модели при помощи разработанного программного метода.

Результаты. Сравнение морфометрических показателей головки лучевой кости, полученных при помощи разработанной программы компьютерного моделирования, и параметров морфометрии стандартной компьютерной томограммы показало их тождественность.

Заключение. Представленный программный продукт «Автоматизированное определение морфометрических параметров кости» в дальнейшем позволит моделировать протез головки лучевой кости, опираясь на показатели компьютерных томограмм с учетом индивидуальных особенностей строения лучевой кости пациента.

Ключевые слова: лучевая кость, головка лучевой кости, шейка лучевой кости, эндопротезирование, моделирование.

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INTRODUCTION

The fractures of the radial head account for 30 to 50% of all elbow joint injuries in adults and are often accompanied by ligament tears and valgus instability in the elbow joint [1, 2, 3]. Total elbow arthroplasty using metal and pyrocarbon radial head implants has become a common surgical procedure in modern orthopedic practice [4, 5, 6]. The objective of elbow arthroplasty is to reduce pain and restore joint mobility [7, 8]. According to the literature, this method demonstrates satisfactory clinical outcomes and is the method of choice for managing comminuted fractures [9, 10, 11]. To avoid postoperative complications, such as degenerative bone changes and the loss of elbow motion, the implant size should correspond to the normal anatomy of the radial head [10, 12]. For this purpose, various prosthetic designs differing in the diameter and height of the radial head are used in the practice of orthopedic surgeons [13, 14]. These prostheses are manufactured using statistically averaged morphometric parameters obtained through meta-comparison and summation of research results, without considering the constitutional anthropometric characteristics of patients. The analysis of currently available implants shows that all radial head prostheses have a limited size range, which, in turn, excludes the possibility of personalized selection [15].

Given this, the issue of modeling and manufacturing individualized radial head prostheses based on the anthropometric parameters of specific patients is highly relevant. Furthermore, the priority task today is the design and production of domestically manufactured radial head prostheses.

The aim of the study is to compare the morphometric parameters of the proximal radius obtained using computed tomography and computer modeling.

METHODS

Study design

Type of study: retrospective cohort study.

The study material consisted of a database of computed tomography (CT) scans in DICOM format of the right and left elbow joints of 137 individuals (66 men, 71 women).

The study included patients aged 40 to 70 years without signs of musculoskeletal pathology. CT scans were analyzed using the RadiAnt DICOM Viewer software, as it is a universal and most frequently used computer program available for public access. When the CT scans are loaded into the program, it is possible to switch to the Multiplanar Reconstructions mode which allows for the visualization of the segment in three planes and the manual measurement of each parameter one by one.

In computer modeling, the first step involves the fragmentation of the bone on the CT scan and converting it into a more convenient three-dimensional format. For this purpose, the open-source ITK-SNAP (GNU General Public License version 3.0 — GPLv3) software was used. After opening the file, the program displays the image in three planes. The fragmentation process consists of the following steps:

1) selecting the fragmentation area — at this stage, it is necessary to choose the area of the image where fragmentation will occur;

2) adjusting fragmentation parameters — the most important aspect at this stage is highlighting the silhouettes of the bones by modifying the color filter parameters, which is essential for accurate bone fragmentation;

3) placing "bubbles" — at this stage, initial fragmentation points need to be marked, which will then propagate throughout the entire bone volume (the more "bubbles" placed, the more precise the fragmentation will be);

4) running the fragmentation algorithm — at this stage, the program begins automatic fragmentation, the results of which can be observed in real time. The result of fragmentation is a finished model. Next, the model needs to be exported into the vtk (Visualization Toolkit) format for 3D modeling and graphics (Figure 1).

The further processing of the computer model of the radius was carried out using a software method developed by us, tentatively named "Automated Determination of Bone Morphometric Parameters".

Upon launching the program, a window opens displaying the bone model (Figure 2). The bone model can be rotated by moving the mouse while holding the left button. To move the model parallel to the screen, the user should hold the shift key. The scroll wheel is used to scale.

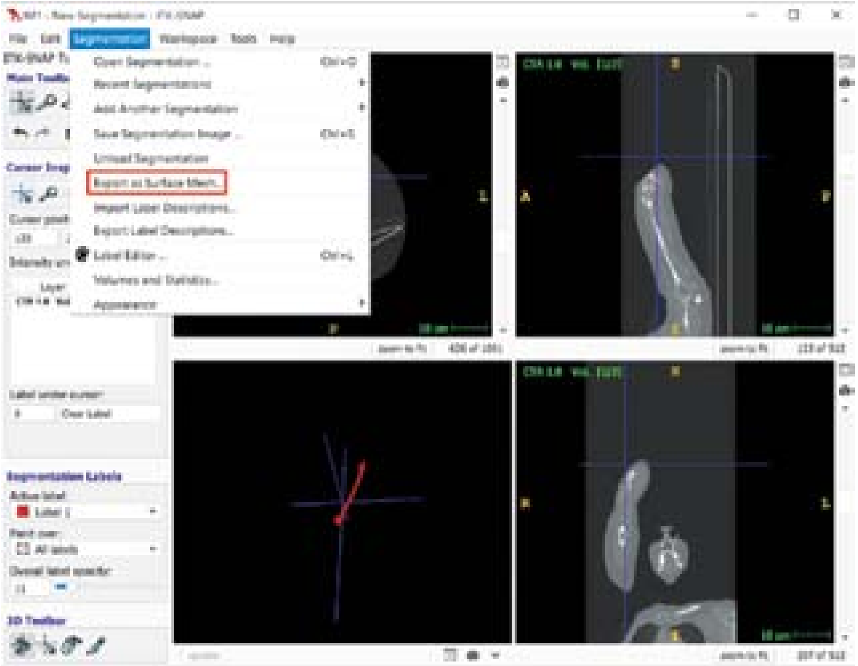

Figure 1. Export of radial head 3D model into vtk format

Figure 2. The appearance of the program window "Automated determination of bone morphometric parameters"

Fixed reference points automatically appear on the computer model and can be manually adjusted if necessary. After selecting all the required points, the morphometric parameters will be displayed in the console, and the user will be given the option to save the parameters to a file.

Statistical analysis

The statistical analysis of the study results was performed using the Microsoft Excel and Statistica 13 for Windows software packages. The Lilliefors test was used to check for normality of distribution. The arithmetic mean and standard deviation (M±SD), as well as the minimum and maximum values, were considered for all groups. The significance of differences was assessed using the t-test for independent variables. Differences were considered statistically significant at $p<0.05$. To evaluate statistically significant differences between the mean values in the male and female groups, the confidence interval (CI) of the difference in mean values was used.

RESULTS

To obtain the values of the radial head diameters, the distance between the most distant points of the head in the frontal and sagittal planes, oriented relative to the radial tuberosity, was used. Anthropometry using classical computed tomography in men showed that the selected parameters were 26.81±1.58 mm in the frontal plane and 26.4±1.30 mm in the sagittal plane. The use of the developed computer modeling program revealed similar values for the studied parameters of the radial head model, which were 26.78±1.61 mm and 26.44±1.3 mm, respectively. In women, the average radial head diameter values in the frontal plane measured on CT scans were 21.62±1.46 mm, while those obtained using computer modeling were 21.68±1.43 mm. The corresponding values in the sagittal plane were 21.92±1.38 mm and 21.96±1.4 mm, respectively.

The height of the radial head was determined as the distance between the smallest and largest base of the radial head at four mutually perpendicular points in the frontal (F1; F2) and sagittal (S1; S2) planes, oriented relative to the radial tuberosity. Notable differences in the height of the head in the studied planes were observed, indicating that the radial head is not an ideal cylinder but rather has the shape of a truncated cone with highly variable and often elliptical bases. This underscores the necessity of considering these parameters during modeling. The results obtained using CT were also nearly identical to those obtained through computer modeling.

The studied morphometric parameters and their values are presented in Tables 1-3.

Table 1

Morphometric parameters of the radius in men, mm

Parameter		Computed tomography			Computer modeling			p
		M±SD	max	min	M±SD	max	min	
Diameter of the radial head in the frontal plane		26.81±1.58	30.00	22.80	26.78±1.61	30.00	22.80	0.94
Diameter of the radial head in the sagittal plane		26.4±1.30	28.60	24.10	26.44±1.30	28.70	24.20	0.90
Height of the radial head in the frontal plane	F1	11.75±2.04	16.20	6.71	11.79±2.05	16.50	6.71	0.94
	F2	10.04±1.88	15.30	7.77	10.05±1.87	15.10	7.77	0.98
Height of the radial head in the sagittal plane	S1	9.56±1.33	12.00	7.17	9.58±1.36	12.00	7.27	0.96
	S2	10.23±1.58	14.10	7.78	10.30±1.61	14.30	7.78	0.86
Depth of the articular fossa		3.52±0.82	5.63	2.21	3.54±0.80	5.63	2.31	0.93
Length of the radial tuberosity		25.16±2.49	30.80	21.20	25.16±2.49	30.90	21.30	1.00
Width of the radial tuberosity		14.47±2.91	21.20	9.40	14.45±2.92	21.10	9.30	0.98

The p-values indicate no statistically significant differences between the computed tomography and computer modeling groups ($p>0.05$).

Table 2

Morphometric parameters of the radius in women, mm

Parameter		Computed tomography			Computer modeling			p
		M±SD	max	min	M±SD	max	min	
Diameter of the radial head in the frontal plane		21.62±1.46	25.10	18.40	21.68±1.43	25.2	18.30	0.99
Diameter of the radial head in the sagittal plane		21.92±1.38	25.10	18.60	21.96±1.40	25.2	18.40	0.95
Height of the radial head in the frontal plane	F1	9.46±1.71	15.00	6.37	9.59±1.63	15.00	6.38	0.99
	F2	8.04±1.16	9.65	5.71	8.05±1.11	9.75	5.81	0.99
Height of the radial head in the sagittal plane	S1	7.85±1.06	11.00	5.93	8.03±1.18	11.00	5.95	0.87
	S2	8.41±1.23	11.00	5.77	8.26±1.27	11.00	5.67	0.82
Depth of the articular fossa		2.84±0.45	4.06	2.03	2.90±0.45	4.06	2.13	0.89
Length of the radial tuberosity		23.26±3.86	31.30	15.4	23.03±3.72	31.20	15.30	0.99
Width of the radial tuberosity		11.97±1.93	15.70	8.3	12.13±1.89	15.80	8.20	0.64

The p-values indicate no statistically significant differences between the computed tomography and computer modeling groups ($p>0.05$).

Table 3

Confidence interval of the difference in mean values between men and women

Parameter		Confidence interval of the difference in mean values	
		Computed tomography	Computer modeling
Diameter of the radial head in the frontal plane		[4.41; 5.87]	[0.57; 3.69]
Diameter of the radial head in the sagittal plane		[3.77; 5.11]	[1.16; 3.48]
Height of the radial head in the frontal plane	F1	[1.33; 3.13]	[3.81; 5.15]
	F2	[1.32; 2.78]	[4.35; 5.85]
Height of the radial head in the sagittal plane	S1	[0.95; 2.19]	[1.29; 3.11]
	S2	[1.26; 2.68]	[1.27; 2.73]
Depth of the articular fossa		[0.36; 0.98]	[0.92; 2.18]
Length of the radial tuberosity		[0.56; 3.68]	[1.42; 2.68]
Width of the radial tuberosity		[1.70; 3.02]	[0.01; 1.27]

With a 95% probability, the true difference in means for all parameters between the male and female groups falls within an interval that does not include 0, indicating a statistically significant difference between the mean values.

Thus, the morphometry of the radial head on CT demonstrated statistically significant gender differences in the studied parameters. The morphometric parameters in men were 1.1-1.3 times larger than in women. The numerical values measured on patient CT scans using the RadiAnt DICOM Viewer software were almost identical to those of the computer model created using the new software product.

DISCUSSION

B. Pasli et al. studied the dimensions of the head, neck, and tuberosity of 80 radii. Parameters important for prosthesis design were analyzed, and their correlations were examined. The authors found that the shape of the radial head was oval in 36% of cases and round in 64%. According to the authors, the average height of the radial head from the anterior, posterior, medial, and lateral sides was 8.52±1.32 mm, 9.02±1.23 mm, 9.20±1.59 mm, and 8.05±1.13 mm, respectively. The average depth of the articular fossa was 1.85±0.37 mm [16]. These data differ from the results obtained in our study. In our research, these parameters in men were 11.75±2.04 mm, 10.04±1.88 mm, 9.56±1.33 mm, and 10.23±1.58 mm, while in women, they were 9.46±1.71 mm, 8.04±1.16 mm, 7.85±1.06 mm, and 8.41±1.23 mm, respectively. The difference in results is likely due to the fact that the study was conducted without considering gender differences. The authors did not identify a high degree of correlation between the studied parameters influencing prosthesis design. In their opinion, the frequency of complications after radial head arthroplasty depends on age-related osteoporosis, which is often caused by a mismatch between the prosthesis size and the true radial head dimensions [16].

E.A. Lalone et al. studied CT scans of 50 upper extremities from cadavers (34 men and 16 women) and compared their morphometric parameters with available radial head prostheses. The general design of three different types of prostheses was quantitatively compared with the radial head. The authors noted a discrepancy between the radial head dimensions on CT images and the parameters of existing commercially available implants, averaging (0.4±0.2)–(0.5±0.1) mm. They concluded that the mismatch between the radial head and implant surfaces could be reduced through reverse engineering methods to determine the required parameters for individualized prosthetics [17]. In our study, we compared the parameters obtained from CT morphometry with the numerical values of the radial head modeled using the developed software method. Statistical analysis of the results confirmed the equivalence of the compared parameters.

The computer modeling method has several drawbacks. Firstly, the process of creating and exporting the radial bone model must be supervised by a physician to ensure that the bone is fragmented without surrounding tissues. Secondly, time is required for the formation and correction of the model (approximately 1 hour). Thirdly, this method requires specific skills in using the equipment and software.

The advantage of this method lies in the fact that, in addition to providing a list of osteometric parameters and their values, the result of the study is the creation of a computer model of the radius, which is not possible when using the standard software of a CT scanner.

In the future, the developed method could facilitate the selection of a prosthesis from existing ready-made implants for patients with elbow joint pathology, based on computer morphometry and modeling of the contralateral radius. The computer model of the proximal radius could also serve as the foundation for the personalized fabrication of a radial head prosthesis.

CONCLUSION

The comparison of the morphometric parameters of the radial head obtained using the developed computer modeling program with those derived from standard CT showed their equivalence, as confirmed by the statistical analysis of the compared parameters. The advantage of the computer modeling method is the rapid creation of a 3D bone model with minimal errors. Moreover, the further development of this computer-based approach can allow for the modeling of the radial head prosthesis based on the measurements acquired from CT scans, considering the patients' individual anatomical characteristics of the radius.

DISCLAIMERS

Author contribution

Samokhina A.O. — study concept and design, data acquisition, statistical data processing, literature search and review, drafting the manuscript.

Shemyakov S.E. — data acquisition, editing the manuscript.

Ratiev A.P. — study concept and design, editing the manuscript.

Egiazaryan K.A. — scientific guidance, editing the manuscript.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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Ethics approval. Not applicable.

Consent for publication. The authors obtained written consent from patients to participate in the study and publish the results.

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