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Research article

The importance of radiological parameters of proximal femoral morphology in recovery management of patients with avascular necrosis undergoing hip arthroplasty

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Abstract: *Background and Objectives*: Our study aimed to radiologically assess the morphology of the proximal femur in patients with avascular necrosis (AVN). We considered that the correct evaluation of the proximal femur morphology is essential and shows multiple clinical applications that can impact patient recovery and outcome. *Materials and Methods*: Our study included 177 patients (85 male and 92 female) with AVN regardless of the degree. The patients were assessed by bilateral hip X-ray in the supine position. We selected the most common radiographic parameters to evaluate for all patients: cortical thickness index (CTI), canal flare index (CFI), calcar-to-canal ratio (CCR), and morphological cortical index (MCI). *Results*: Average values for the parameters were: CTI = 0.5192 ± 0.07528, CFI= 3.5515 ± 0.5071, CCR = 0.4469 ± 0.05363 and MCI = 2.7572 ± 0.07704. We found no statistically significant differences between genders, except for CFI (p = 0.0325). *Conclusions*: The anatomical configuration of the proximal femur can play a major role in the process of planning the appropriate implant for total hip arthroplasty, as well as in the proper positioning of the implant during the surgical procedure. A thorough knowledge of the proximal femur morphology can be of great use to the orthopedic surgeon and may help decrease perioperative complications.

Keywords: Radiology; morphometry; anatomical variation; avascular necrosis; orthopedics; arthroplasty; rehabilitation.

Introduction

Avascular necrosis (AVN) of the femoral head, also known as osteonecrosis of the femoral head, avascular aseptic necrosis or ischemic bone necrosis is a result of disrupted blood flow to the bone cells within the femoral head [1,2]. The literature data presents different prevalence rates worldwide, with rates of 5,97% in the USA database of all total hip arthroplasty (THA) performed, while in India the prevalence was much higher, reaching 51,8% [3].

Femoral head AVN may be caused by trauma, metabolic, or other chronic conditions that cause vascular supply cut-off to the proximal femur [4,5]. AVN usually affects younger patients, and the most widely used treatment for AVN of the femoral head is THA [6].

THA is an increasingly common therapeutic surgical procedure that improves function, alleviates pain, and restores the patient's quality of life [7]. While multiple techniques and surgical approaches have been described, all procedures rely on a thorough understanding of patient anatomy, good visualization of the hip, and adequate preoperative planning [8-10]. Various studies have evaluated potential predictors of the long-term effects of THA and have concluded that, among other factors, good implant positioning is crucial in obtaining good implant survivability [11,12]. It was previously shown that properly assessing the morphologic features of the joint elements is essential in reducing perioperative complications and selecting the proper prosthetic [13,14]. Also, some anatomical variants may increase the risk of osteoarthritis and postoperative complications, as previously shown by other studies [15-18].

Variations in the morphology of the femur influence the choice of prosthetic for THA, especially in terms of implant size, but also in regard to neck length and alignment [19]. Multiple morphological parameters can be assessed preoperatively in order to conduct proper planning and choose the ideal prosthetic for each surgical case. Our study aims to assess the most commonly described radiographical morphological parameters of the proximal femur in a cohort of patients with AVN. In this regard, we evaluated the bone quality of patients planned to undergo THA using radiological markers such as CTI (cortical thickness index), CFI (canal flare index), CCR (calcar-to-canal ratio), MCI (morphological cortical index), since these are the most used parameters in the literature and we aimed to describe the correlation between radiological findings, implant prognosis and functional outcome.

2. Materials and Methods

Our retrospective study includes 177 patients with femoral avascular necrosis who were assessed in the "Foisor" Clinical Hospital of Orthopaedics, Traumatology, and Osteoarticular TB between April 2022 and April 2023. We included patients who reported to our ambulatory care unit for chronic hip pain and showed radiographic signs of AVN on the bilateral hip X-ray. We excluded patients with femoral fractures, hip dysplasia, bone tumors, or septic osteoarthritis. The patients agreed to participate in this study and signed an informed consent. The research was conducted in accordance with the Declaration of Helsinki from 1964 and its later amendments. The study was approved by the "Foisor" Clinical Hospital of Orthopaedics, Traumatology, and Osteoarticular TB Ethical Council with registration number no. 5207/29.05.2023.

Each patient was submitted to a bilateral hip X-ray using a DigitalDiagnost R3.1 system (Philips Medical Systems, Amsterdam, Netherlands). The patient was positioned supine in suspended respiration with approximately 15 degrees medial rotation of feet and approximately 20 cm between heels. All images were stored and accessed through the hospital picture archiving and communication system. The images were viewed on an imaging workstation using a dedicated radiology monitor and software.

The following parameters were recorded for each patient. Cortical thickness index, defined as the ratio between the difference of the cortical and endosteal diameters and the cortical diameter at 10 cm below the tip of the lesser trochanter. Canal flare index, defined as the ratio between the endosteal diameter at the level of the isthmus (10 cm below the tip of the lesser trochanter) and the femur diameter 2 cm above the lesser trochanter. Calcar-to-canal ratio, defined as the ratio between the endosteal diameter 10 cm below the tip of the lesser trochanter and the endosteal diameter at the tip of the lesser trochanter. Morphological cortical index, defined as the ratio between the total width of the femur at the tip of the lesser trochanter and the endosteal diameter 7 cm below the tip of the lesser trochanter (**Figure 1**). The score of hip osteonecrosis was assessed in each patient using the Steinberg classification [20].

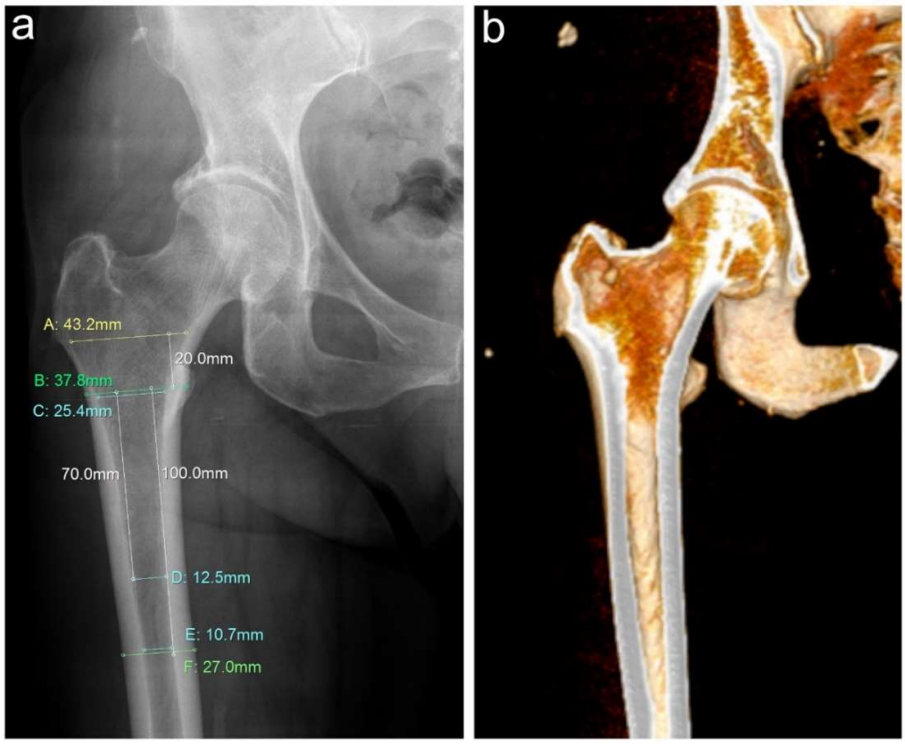

Figure 1 Demonstration of measurements for cortical thickness index (CTI), canal flare index (CFI), calcar-to-canal ratio (CCR) and morphological cortical index (MCI) on an X-ray, for the right hip (a) in a patient with avascular necrosis stage 3 according to Steinberg. A: Width of canal 2 cm proximal to the lesser trochanter, B: External width at the level of the tip of the lesser trochanter (reference line), C: Internal width at the level of the lesser trochanter, D: Internal width at 7 cm below the reference line B, E: External width at 10 cm below the reference line B, F: Internal width at 10 cm below the reference line B, CTI=F/E, CFI=A/F, CCR=F/C, MCI=B/D. For the same patient, a computed-tomography (CT) virtual rendering reconstruction of the same hip is presented to depict the main bony features for demonstrative purposes (b); note that the patient underwent the CT scan for distinct medical reasons related to the contralateral hip.

The statistical analysis was performed using MedCalc Version 14.8.1 64-bit medical statistics software. The distribution of data was tested for normality using the Shapiro-Wilk test and the comparison between means was performed using independent samples two-sided t-test after performing an F-test. If the F-test showed unequal variances, a Welch test was used instead.

3. Results

The study lot included 85 male and 92 female patients aged between 31 and 82 years old. The average age was 64.30 ± 9.84 years. Further demographic data, as well as a gender comparison, is presented in **Table 1**.

Table 1. Demographic data of the patients included in the study lot.

Parameter	Male (n=85)	Female (n=92)	P value
Age	64.80 ± 9.71	63.75 ± 10.02	0.4793
Body mass index	28.78 ± 3.19	29.17 ± 4.65	0.5099

The four radiographic parameters, namely CTI, CFI, CCR, and MCI, were assessed in the study lot for each patient, and the results are displayed in **Table 2**. There were no significant differences between sublots for any of the parameters regarding the degree of AVN.

Table 2. Analysis of radiographic parameters in the study lot according to AVN degree.

Radiographic parameter	AVN degree				P value	Overall
	2 (n=7)	3 (n=30)	4 (n=61)	5 (n=79)		
CTI	0.5157 ± 0.08715	0.5273 ± 0.07732	0.5138 ± 0.08238	0.5206 ± 0.06860	0.873	0.5192 ± 0.07528
CFI	3.3757 ± 0.4949	3.5513 ± 0.4705	3.5921 ± 0.5501	3.5358 ± 0.4920	0.730	3.5515 ± 0.5071
CCR	0.4243 ± 0.06925	0.4480 ± 0.05346	0.4464 ± 0.05401	0.4489 ± 0.05257	0.716	0.4469 ± 0.05363
MCI	2.6600 ± 0.2102	2.8587 ± 0.2486	2.7472 ± 0.2540	2.7349 ± 0.3040	0.141	2.7572 ± 0.07704

We further assessed the radiographic parameters comparatively between genders, and the results are detailed in **Table 3**.

Table 3. Comparative analysis of radiographic parameters between genders.

Radiographic parameter	Male (n=85)	Female (n=92)	P value
CTI	0.5251 ± 0.07141	0.5138 ± 0.07868	0.3217
CFI	3.6361 ± 0.5496	3.4734 ± 0.4536	0.0325
CCR	0.4399 ± 0.04689	0.4534 ± 0.05869	0.0919*
MCI	2.7818 ± 0.3204	2.7345 ± 0.2305	0.2647*

* Welch-test (assuming unequal variances)

4. Discussion

The anatomical configuration of the proximal femur can play a major role in the process of planning the appropriate implant for total hip arthroplasty as well as in the proper positioning of the implant during the surgical procedure [21]. In our study, we have thoroughly described the femoral morphology in patients with AVN by assessing four of the most common radiographic measurements. The morphological parameters that we assessed were shown to play an essential role in the prediction of periprosthetic fractures after THA [22]. It is widely accepted that particular features of patient anatomy can have significant clinical implications and may influence the selection of an adequate therapeutic method [23-28]. Furthermore, concurrent conditions such as local or systemic inflammation, malignancy, adjacent benign lesions, or altered immune responses may aggravate patient recovery and the healing process [29-33]. Consequently, these categories of patients were excluded from our study.

The outcome and patient satisfaction of the THA surgical procedure can be significantly influenced by osteoporosis, bone mineral density and proximal femoral morphology, serving as prognostic factors for aseptic loosening and periprosthetic fracture [34,35]. Liu et al. concluded in their 2022 study that CTI is a great indicator of femoral osteopenia [36], while Pothong et al. demonstrated that CTI is the strongest radiological predictor for subsequent contralateral fragility hip fracture, followed by CFI, MCI and CCR [37].

It is noteworthy that the surgical result and patient evolution may be worse in patients with AVN due to their younger age and more frequent concurrent ailments compared to patients with osteoarthritis [38]. However, it was shown that the long-term outcome is not significantly different between these two groups [6]. This consideration is important in patients undergoing rehabilitation after arthroplasty, where different programs and approaches can significantly influence the patient outcome, especially in cases of physical or psychological comorbidities [39-42].

The CTI has been successfully used in predicting the rate of perioperative complications after THA, and it was shown that patients with higher values had fewer postoperative dislocations and intra-operative fractures [43]. Moreover, higher values of CFI were shown to increase the risk of postoperative leg length discrepancy [44]. Additionally, CCR has been used as a predictor of the canal fill ratio, a parameter with a direct impact on

osseointegration [45]. It was previously demonstrated that MCI can be used as a predictor of bone quality, alongside CFI and CTI [46].

One parameter widely used in clinical practice is the Dorr classification of the femur. However, we considered that the CTI, also known as the Noble classification, is more accurate as it offers a quantitative index compared to the qualitative assessment provided by the Dorr score [47].

We identified a statistically significant distinction in the values of CFI between male and female patients. No significant variance was detected in the other measured parameters. Other literature reports cite no difference between genders regarding CFI [48,49].

While some of the morphological parameters were described in other populations and diseases, in patients with AVN the literature data is scarce [50,51]. We consider this criterion as one of the strong points of our study.

Among the study limitations, we mention that our monocentric study can predispose to patient selection bias and can restrict the statistical significance of the data. Also, we consider that a more significant number of subjects would be beneficial in obtaining more accurate values of the measured parameters. Further studies that include computed tomography or magnetic resonance imaging investigations might reveal further antropological details and consolidate the role of proximal femoral morphometry in the management of patients with AVN.

5. Conclusions

Strong knowledge of the proximal femur morphology is essential in the preoperative planning and surgical management of patients with avascular necrosis undergoing total hip arthroplasty. Recent literature reports showed that the radiographic parameters used in the morphometry of the femur are important predictors of implant prognosis and functional outcome. Moreover, morphometric data of the proximal femur may be useful in the future design and development of better and more suitable prosthetics.

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