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ORIGINAL ARTICLE

The medial cortical ratio as a risk factor for failure after surgical fixation of proximal humerus fractures in elderly patients

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ABSTRACT

Objectives: This study aims to investigate whether the medial cortical ratio (MCR) is associated with fixation failure in patients undergoing plate-screw fixation due to proximal humeral fracture.

Patients and methods: Between May 2011 and October 2020, a total of 93 patients (25 males, 68 females; mean age: 74.2±5.3 years; range, 65 to 92 years) who were operated for a proximal humeral fracture were retrospectively analyzed. The patients were divided into two groups during follow-up: patients with fixation failure (n=18) and patients with intact fixation (n=75). After radiological analysis, the MCR and fracture type were recorded. The effects of MCR and fracture type on the development of failure were evaluated.

Results: The mean follow-up was 41.3±4.7 (range, 18 to 66) months. There was no significant correlation between fixation failure and MCR in either group (p=0.535). However, the risk of fixation failure increased by seven-fold in patients with MCR greater than 0.09 compared to the other patients. In addition, the fracture type was significantly more severe in the failed fixation group than the intact fixation group (p<0.001).

Conclusion: Surgical treatment of proximal humeral fractures in elderly patients still remains a challenge for surgeons due to the high failure rate. In elderly patients scheduled for surgery to treat a proximal humerus fracture, a reverse shoulder arthroplasty may be a reasonable choice to avoid reoperation due to fixation failure in elderly with three-part or more fragmented fractures and high MCR.

Keywords: Elderly, failure, fixation, medial cortical ratio, proximal humerus.

Proximal humeral fractures are common fractures in the osteoporotic population over 65 years of age.[1] Although most of these patients are treated non-operatively, complex fractures, such as fracture-dislocations, head-split fractures, varus displacement, and complete head-shaft displacement, often have poor outcomes and require surgical fixation.[2]

Surgical treatment options include percutaneous nailing, locking plate-screw application, and arthroplasty, and the complexity of the fracture determines the surgical method.[3] Although the treatment of proximal humeral fractures has evolved in recent years toward preservation of the humeral head, osteoporosis-related bone loss in the humeral head causes complications, such as poor fixation and screw cut-out or screw penetration due to impaired fracture healing.[1] Despite the importance of bone density, patients often do not undergo whole-body or operative site-directed bone mineral densitometry prior to surgery. In addition, limited mobilization due to the fracture makes it difficult to measure bone mineral density (BMD) before surgery and prevents bone quality from guiding surgical decision-making.[4]

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Since Barnett and Nordin,[5] followed by Virtama and Telkka[6] reported that cortical thickness determination could be used as a predictor of bone mineralization, cortical thickness measurements have been used to estimate osteoporotic changes in the bone. Considering the high risk of insufficiency after fixation in osteoporotic patients, the medial cortical ratio (MCR) may be associated with insufficiency and indirectly affect the choice of surgical method.[7,8] However, to our current knowledge, there are few studies in the literature investigating this approach.

In the present study, we aimed to investigate whether MCR was associated with fixation failure in whom a plate-screw was used due to a proximal humeral fracture. By clarifying this relationship, we aimed to determine whether the MCR measured before surgery could be used to select the appropriate surgical method and to identify the relationship between the fracture type according to the Neer classification[2] and the development of fixation failure.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Başkent University Faculty of Medicine, Department of Orthopedics and Traumatology between May 2011 and October 2020. A total of 139 patients with a diagnosis of proximal humeral fracture during the study period were screened. Patients older than 65 years with an isolated traumatic proximal humeral fracture and subsequent plate-screw fixation with a proximal humeral internal locking system (PHILOS™; DePuy Synthes, Raynham, MA, USA) with at least two years of follow-up were included. Patients without displaced fractures (n=10), open fractures (n=1), pathological fractures (n=3), multiple trauma (n=7), patients who underwent shoulder arthroplasty (n=6), patients with missing data (n=7), and patients with poor reduction quality based on the intact measurements (e.g., varus malalignment, low head-shaft angle value, lack of medial cortical support after surgery) (n=12) were excluded from the study. Finally, a total of 93 patients (25 males, 68 females; mean age: 74.2±5.3 years; range, 65 to 92 years) who met the study criteria were recruited.

Data included demographic information, such as age and sex, follow-up period, fracture type according to Neer classification, and follow-up radiographs, which were retrieved from the computed tomography database and medical records. Radiological follow-up was performed at 1.5 months, three months, six months, and 12 months in the first year after surgery and annually thereafter. Radiographic examination was performed in patients who developed abnormal symptoms, such as sudden onset of increased pain and limitation of motion, during clinical follow-up after surgery, regardless of the pre-specified schedule.

Radiological analyses and determination of MCR

Radiological images of all patients were reviewed using the Picture Archiving Communications System (PACS). At least one set of follow-up radiographs was available for each patient. All radiographs were evaluated by two independent observers with at least 10 years of experience in orthopedic surgery.

First, the preoperative radiographs were evaluated, and the fracture type was recorded according to the Neer classification and the MCR according to Newton et al.[9] (Figure 1). The MCR was measured using the digital ruler available at PACS. The measurement was taken on the unaffected extremity, 20 mm distal to the most proximal level of the humeral diaphysis, where the endosteal borders of the lateral and medial cortices were parallel. The total diameter of the diaphysis and the thickness of the medial cortex were measured at this point and used to determine the MCR (Figure 2). The patients' follow-up radiographs were reviewed, and those in whom fracture fixation failed were identified. Radiological failure was defined according to the definition of Krappinger et al.[10] as any type of postoperative relative movement between the implant and the humeral head or shaft.



FIGURE 1. An anteroposterior radiograph of left shoulder of a patient (Neer type 3 fracture).

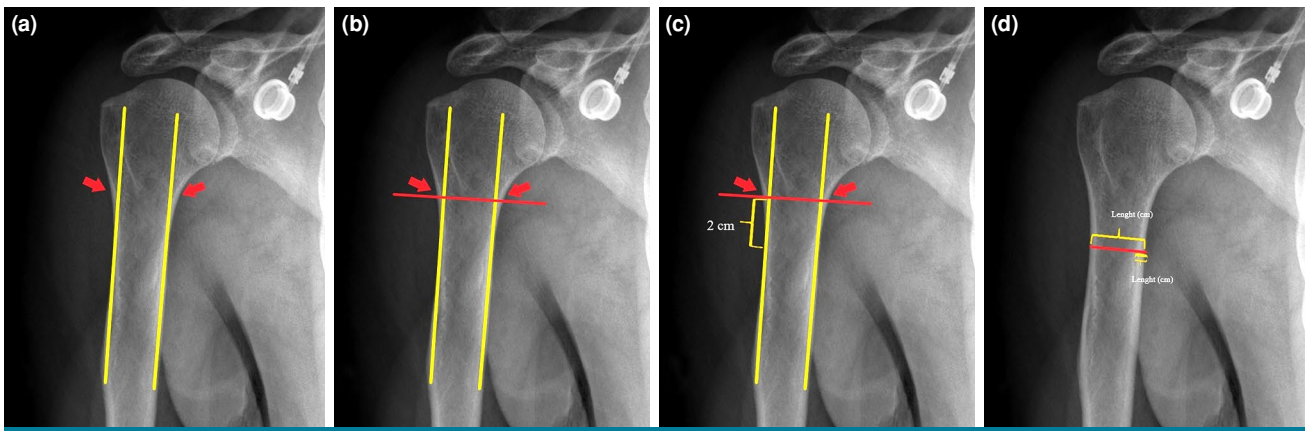


FIGURE 2. An anteroposterior radiograph of right shoulder of the same patient. **(a)** Yellow lines: Lines drawn parallel to the medial and lateral cortex. Red arrows: split points where the drawn lines end at the intersection of the cortical continuum. **(b)** Red Line: The line through the split points. **(c)** Determination of 2 cm distal of the line passing through the split points. **(d)** Red line: The line drawn perpendicular to the long axis and measuring the length of the outer diameter of the bone. Yellow line: The line measuring the length of the medial cortical thickness at the same level.

We defined failure based on radiographs, if any of the following was present: displacement of the fracture components, screw cut-out, or a change in the neck-shaft angle, as described by Newton et al.[9] Therefore, the patients were divided into two groups during follow-up: patients in whom fixation failed (Group F) and patients in whom fixation did not fail (Group N). After radiological analysis, the MCR and fracture type were assessed. The effects of MCR and fracture type on the development of failure were evaluated.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 23.0 software (IBM Corp., Armonk, NY, USA). Continuous variables were presented in mean ± standard deviation (SD), while categorical variables were presented in number and frequency. The Shapiro-Wilk test was used to determine the normality distribution of the data. As the numerical values of the study groups were normally distributed, comparison of numerical measurements was performed with a two-sample t-test (Student t-test) for two independent groups. The chi-square test was used to compare ratios between the groups. Univariate and multivariate analyses were also performed to examine risk factors for fixation failure; binary logistic regression analysis was used. Receiver operating characteristic (ROC) analysis was used to determine the cut-off values of

TABLE I
Demographic and radiological data of patients

	Group F			Group N			
	n	%	Mean±SD	n	%	Mean±SD	*p*
Age (year)			77.7±6.3			71.0±5.8	0.724†
Sex							0.924*
Male	5	27.8		20	26.7		
Female	13	72.2		55	73.3		
MCR			0.12±0.03378			0.15±0.03894	0.535†
Fracture type							**<0.001***
Type 1	0	0		2	2.9		
Type 2	0	0		42	60		
Type 3	14	78.8		24	34.3		
Type 4	4	22.2		2	2.9		

SD: Standard deviation; MCR: Medial cortical ratio.

TABLE II
Analysis of risk factors for development of failure

	Univariate			Multivariate		
	OR	95% CI	*p*	OR	95% CI	*p*
Age	1.173	1.073-1.282	**<0.001**			
Sex	0.945	0.299-2.990	0.924			
MCR >0.09	7	1.841-26.613	**0.004**	7.653	1.685-34.753	**0.008**
Age >73 (year)	0.143	0.043-0.479	**0.002**	0.135	0.037-0.492	**0.002**

OR: Odds ratio; CI: Confidence interval; MCR: Medial cortical ratio.

numeric scores. A *p* value of <0.05 was considered statistically significant.

RESULTS

The mean follow-up was 41.3±4.7 (range, 18 to 66) months. During follow-up, fixation failure occurred in 18 of 93 (19%) patients who underwent radiographic evaluation. There was no significant difference in the MCR of the patients with failed surgical fixation and those with intact fixation (p=0.535). The fracture type of patients in the fixation failure group was significantly more severe than in the group without fixation failure (p<0.001). Additionally, the relationship between the MCR and fracture type was evaluated between the groups. Although the fracture type worsened as the MCR value decreased in the groups, there was no statistically significant relationship (p=0.054) (Table I).

The univariate analysis revealed that the risk of fixation failure increased 0.1-fold per year in patients older than 73 years (r=0.238, p<0.001). In addition, fixation failure increased by seven-fold in patients with an MCR of >0.09 compared to other patients. In the multivariate analysis, both age and MCR were found to be significant risk factors for the development of fixation failure (r=0.232, p<0.001) (Table II).

DISCUSSION

In the present study, we investigated the relationship between the MCR and fixation failure in patients with proximal humerus fracture treated with a plate-screw fixation. The type of fracture was the most important factor in implant failure in elderly patients who underwent open reduction and internal fixation (ORIF) after proximal humerus fracture. After surgical fixation, age of the patient and MCR were significant risk factors for fixation failure.

It has been well documented that individuals aged 65 years and older are at a higher risk of proximal humerus fractures due to osteoporosis. The fracture rate in women is up to 2.5 times higher than in men.[11,12] Several factors have been identified in the literature that are associated with implant failure after fixation of proximal humeral fractures with locking plates. Among 48 patients with a mean age of 61±15 years Adıyeke et al.[3] found that 33 patients were 53 years or older and 52% of them (n=11) who developed insufficiency were aged between 56 and 75 years. Krappinger et al.[10] also reported that 6 of 34 patients who had proximal humerus fracture were treated with locking plate-screw, and the risk of failure increased after age 63 years. In contrast, Hepp et al.[13] analyzed data from 113 patients with an average age of 66 years to examine factors associated with reoperation after fracture fixation. Twenty-two (50%) of 44 patients with an average age of 60 years required reoperation due to implant failure or insufficiency at the implant-bone interface. The failure rates reported in these studies after fixation with a locking plate-screw were 22.4%, 17.6%, and 19.4%.[3,10,13] In this study, the majority of participants were female, consistent with the literature. However, the mean age of our patients was higher than in other studies. Fixation failure occurred in only 19.3% of patients, despite their older age. This may be due to the fact that we did not include patients who had poor reduction after surgery. Considering age as a risk factor for the development of failure, we also found that in patients older than 73 years, the risk of developing a fracture increased by 0.1-fold. Our results support the findings of Krappinger et al.[10] reporting that advanced age increased the fracture risk.

Although the gold-standard method in the diagnosis of osteoporosis is dual-energy X-ray absorptiometry (DXA), the device is not available in every center, and it is costly to use. In addition, in acute situations such as osteoporotic fractures, access to devices is limited and local assessment of BMD

TABLE III
Literature studies showing the relationship between cortical thickness measured in different anatomical regions and bone mineral densitometry

Study	Year	Anatomic region	Measurement type	Critical value for low BMI
Tingart et al.[21]	2003	Proximal humerus	CCT	CI <4 mm
Sah et al.[18]	2007	Femur diaphysis	CTI	CTI ≤0.40
Rodríguez-Soto et al.[17]	2010	Femoral neck	CTI	Unspecified
Spross et al.[20]	2015	Proximal humerus	DTI	DTI ≤1.4
Webber et al.[22]	2015	Distal radius	BCT	BCT ≤5 mm
Baumgärtner et al.[14]	2015	Proximal femur	CTI	Unspecified
Patterson et al.[16]	2016	Distal tibia	CBT (AP and Lat)	CT (AP) ≤3.5 mm
He et al.[15]	2018	Distal femur	CBT and DFCI	CBT ≤4.4 mm and DFCI ≤1.10 mm
Schmidutz et al.[19]	2021	Distal radius	CI	Unspecified
Yoshii et al.[23]	2021	3rd metacarpal bone	CTR	Unspecified

BMI: Body mass index; CCT: Combine cortical thickness; CI: Cortical index; CTI: Cortical thickness index; DTI: Deltoid tuberosity index; BCT: Bicortical thickness; CBT: Cortical bone thickness; AP: Anterior posterior; Lat: Lateral; DFCI: Distal femoral cortical index; CT: Cortical thickness; CTR: Cortical thickness ratio.

is almost impossible. The use of cortical thicknesses in different anatomical regions to predict BMD was first described by Barnett and Nordin[5] and this result was supported by the study of Virtama et al.[6] in the following years. As a result, the researchers thought that this method could be an easily accessible, low-cost, simple, and effective complementary method for estimating BMD. The interest in studies measuring BMD with the measurement of cortical thickness and the ratios formulated from it until today is increasing day by day (Table III).[14-23] One of these ratios that has been revealed is the MCR. The MCR was first introduced by Newton et al.[9] in 2016. In the study conducted by Skedros et al.,[24] the MCR significantly decreased ($p<0.001$) in patients older than 60 years (0.12) compared to patients younger than 60 years old (0.16). In addition, a correlation between the MCR and DXA-based BMD measurements was also observed.

It is usually accepted that osteopenia of the humeral head increases with age and that a decrease in BMD is a major cause of fixation failure after osteosynthesis for proximal humerus fractures.[13] A relationship between medial cortical thickness and BMD was first described by Tingart et al.[21] in the proximal humerus. Further studies confirmed this finding and even suggested that median cortical thickness and, thus, MCR could be used to clinically exclude osteoporosis.[7,24] However, the results of our study showed no statistically significant correlation between MCR and the development of fixation failure. This result may be due to the small sample size with disabilities in the patient group compared to the control group. In addition, this result may be related to the fact that our study population included only patients older than 65 years with osteopenia or osteoporosis. When we examined whether MCR was a risk factor for the development of fixation failure, an MCR greater than 0.09 was found to be significantly associated with a seven-fold increased risk of fixation failure.[25] This finding indicates that the MCR cut-off value of 0.09 can be used in future studies in evaluating the association between MCR and fixation failure.[25]

Currently, ORIF is the preferred surgical method of treating proximal humerus fractures. However, recent studies have shown that the preferred surgical treatment method in elderly patients has tended to shift toward reverse shoulder replacement surgery over the past decade. The most likely reason for this trend is that patients undergoing ORIF are at a higher risk for reoperation, primarily due to fracture fixation failure and complications, than patients undergoing reverse shoulder arthroplasty (RSA).[26] One of the most important reasons for the high rate of fixation failure (19.4% in our study and 17.6 to 22.4% in the literature) after fixation of proximal humerus fracture with locking-plate is the decreased bone quality with increasing age. Decreased bone quality with age causes complex fractures even with low-energy trauma and, therefore, Neer type 3 and type 4 fractures are more common in these patients. In their study, Barlow et al.[27] evaluated 131 proximal humerus fractures in patients over 60 years of age, and they found the rate of failure development in Neer 3-part fractures to be 39%, while this rate

increased to 45% in 4-part fractures. The most common cause of failure in these patients was collapse due to humeral head avascular necrosis, followed by intra-articular screw penetration, implant failure, post-traumatic arthritis, and rotator cuff insufficiency, respectively. Solberg et al.[28] also examined surgical results in Neer 3 and 4 fragment fractures in elderly patients. The two most common causes of failure development were avascular necrosis and screw penetration. In this study, varus malalignment developed during or after surgery. In another study by Schumaier and Grawe,[11] approximately 20% of proximal humeral fractures were Neer 3-4-part fractures. In the surgical treatment of comminuted fractures in elderly osteoporotic patients, bone quality is often insufficient for fixation. In a study by Adıyeke et al.,[3] 84% of patients who experienced failure after fixation with a plate-screw had 3-4-part fractures, while in the study of Newton et al.,[9] this rate was 93%. All patients who developed fixation failure in our study had Neer 3-4-part fractures, consistent with the literature. These findings indicate that locking plate-screw systems may be inadequate in the presence of poor bone quality, despite adequate fracture reduction and further developments in implant technology. In this study, we showed that MCR and age, which are the main indicators of bone quality, could predict the risk of fixation failure. Therefore, we suggest that shoulder arthroplasty is the preferred option for surgical treatment of patients with advanced age and high MCR.

Nonetheless, this study has several limitations. First, the study has a single-center, retrospective design. Second, and more importantly, BMD measurements were unable to be obtained in all patients included in the study. Therefore, we could not assess whether there was a correlation between MCR and BMD. In addition, the sample size of the group in which fixation failure occurred is small.

In conclusion, surgical treatment of proximal humerus fractures due to osteopenia and osteoporosis in elderly patients still remains a challenge for surgeons, despite ongoing developments in the implant technology. Reverse shoulder arthroplasty may be a viable alternative to avoid repeated surgeries due to fixation failure in elderly patients with three-part or more fragmented fractures and high MCR who are scheduled for surgery to treat proximal humerus fractures. However, further studies are needed to draw more reliable conclusions on this subject.

Ethics Committee Approval: The study protocol was approved by the Başkent University Medical and Health Sciences Research Board (date: 30.11.2021, no: KA21/466). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea and concept, data collection and processing, literature review, writing the article: A.M.; Study design, data collection, writing the article, materials: E.K.Ş.; Control and supervision, critical review, references and fundings: B.H.

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