Acta Orthop. Belg., 2020, **86 e-SUPPLEMENT** 1, 1-8

ORIGINAL STUDY

Internal fixation of displaced fractures of the proximal humerus with a locked intramedullary blade nail

Awaiz AHMED, Robert MIDDLETON, Aniruddha PENDSE, Geoffrey TAYLOR

From the Croydon University Hospital, United Kingdom

The optimum management of displaced proximal humerus fractures remains a contro-versial topic. The purpose of this study was to report 1 year functional and radiological outcomes after intramedullary nailing for displaced proximal humerus fractures using the Marquardt Locking Blade Nail (LBN) system.

Cases of displaced proximal humeral fractures treated with locking blade fixation under the care of a single surgeon from July 2011 to June 2015 were identified. The fracture pattern was classified according to Neer. The cases were predominantly 2 and 3 part fractures with only four 4 part fractures. The primary outcome measures were the Constant score and the Oxford Shoulder Score (OSS) at 1 year. Secondary measures assessed were the progression to bony union, evidence of avascular necrosis (AVN), loss of fracture alignment, humeral neck-shaft angle after fracture healing and implant related problems. Complication data and re-operations were also reviewed.

62 patients were identified, with 11 patients excluded from the analysis (8 cases lost to follow up, 3 died before 1 year). The mean Constant score at 1 year was 76.0±15.3 (range 44 - 100) and a mean OSS at 1 year of 41.6±5.1 (range 27 - 48). The mean post-operative humeral neck-shaft angle post-operatively was 130.6°±9.6° (range 101° - 145°). All patients achieved bony union. There were 4 cases (7.8%) of AVN. 7 cases (13.7%) underwent a secondary operative procedure during the 1 year follow-up period. Two cases (3.9%) demonstrated a varus loss of alignment post-operatively, and there was 1 case (2.0%) of screw penetration of the glenohumeral joint due to fracture impaction. There was no post-operative infection, axillary nerve injury or screw back out.

Fixation using the LBN achieved robust fixation and satisfactory clinical outcomes at one year follow up in 2 and 3 part fractures. Younger patients had better functional outcome compared to the elderly. The number of 4 part fractures is too small to draw any useful conclusion. AVN remains a difficult problem with these fractures.

Keywords: Proximal humerus fractures ; intramedullary blade nail ; Marquardt Locking Blade Nail.

■ Awaiz Ahmed[1].
■ Robert Middleton[2].
■ Aniruddha Pendse[2].
■ Geoffrey Taylor[2].

[1]Consultant Orthopaedic, Croydon University Hospital, United Kingdom; [2]Sho Trauma And Orthopaedics, Buckinghamshire Healthcare Nhs Trust, United Kingdom.

Correspondence: Awaiz Ahmed, Consultant Orthopaedic, Croydon University Hospital, United Kingdom

E-mail : orthofixer@hotmail.com

Conflict of interest: All authors declare that they have not received any funding or other benefits in support of this study. No relevant financial relationships to disclose.

INTRODUCTION

Proximal humerus fractures are the third most common fracture pattern in the elderly population, with a greater incidence in females, accounting for 5% of all fractures *(5,6,22,31)*. There has been a steady increase in the proportion of fractures managed surgically over the last two decades *(4)*. Neer defined criteria for displacement of greater than 1 cm or angulation greater than 45 degrees *(24)*. This definition of displacement and angulation is arbitrary and as in the PROPHER trial, was used in this series *(26)* Whilst the majority of stable, minimally displaced proximal humerus fractures can be satisfactorily managed with conservative treatment, unstable or displaced fractures treated conservatively are often associated with a poor outcome *(6,24)*. A variety of operative procedures have been reported in the literature. Less invasive nailing techniques have a number of potential benefits including the preservation of soft tissues, reduced disruption of the fracture site and shorter operating times. The Marquardt Locking Blade Nail (Medizintechnik, Spaichingen, Germany) *(17)*, has a number of favourable design features that assist in achieving good construct stability. It is a straight solid titanium alloy nail allowing an entry point medial to the rotator cuff foot print. Two head locking cancellous screws with large washers, lock into Polyaryletheretherketone (PEEK) inserts in the nail and compress the tuberosity fragments. A locking blade inserts through the nail to support the medial column. The peg extensions of the blade fixation screws insert into holes in the blade and the threaded portion locks into the PEEK inserts in the nail resulting in a stable triangular construct. The washers on the screws have suture holes to aid with rotator cuff repair if necessary (see figure 1). A single distal locking screw controls rotation and subsidence.

This study reports the 1 year outcomes of proximal humerus fractures fixed with this implant. This is a single surgeon series with no conflict of interest in reporting the outcome with this implant.

MATERIALS AND METHODS

Records and radiographs for the patients who underwent internal fixation for displaced proximal humerus fractures with the Marquardt nail, were reviewed from July 2011 – June 2015, after approval from the Hospital Audit and clinical effectiveness department. The decision for surgery was based on fracture pattern, age, co-morbidities and mental state. There was usually a trial of non-operative management in a collar and cuff, particularly with two part fractures. All suitable patients were given the choice of non-operative management or surgery. In the same period 7 arthroplasties were preformed for acute fracture dislocations and no fracture dislocations were included in the study.

The primary outcome measures were Constant-Murley score and Oxford shoulder score at 1 year follow up. Secondary outcome measures were radiological analysis for union, loss of position, implant failure, avascular necrosis and neck shaft angle. Complications such as infection, nerve injury and secondary operative interventions were also recorded.

Surgery was carried out in a beach chair position under general anaesthesia with regional nerve block. Prophylactic antibiotics were administered as per local guidelines. The fracture was initially reduced closed under image intensifier control. A 5-8 cm anterolateral incision was made from the tip of the acromion and the deltoid muscle split at the junction of the raphe between the anterior and middle heads. Alternatively, a sabre incision has the versatility of creating additional delto-pectoral window if required. The anterior branch of the axillary nerve is located deep to the deltoid. The fractures are reduced with a combination of open and closed techniques, with temporary K wire fixation as needed. Reduction of the tuberosites is aided by temporary traction sutures placed in the insertion of the rotator cuff. The rotator cuff is incised longitudinally between stay sutures, after identification of the insertion point. The entry point for the nail is in-line with the centre of medullary canal, 1-2 mm lateral to the highest point of the humeral head, determined under image intensification. In three and four part fractures the entry was through the fracture site.

The guide wire is inserted under image intensifier control, ensuring a good position on antero-posterior and axillary views. The insertion point is then enlarged using the coring reamer which fits over the centring disc on the dedicated guide wire. A standard 150 mm nail was used in all cases (a longer nail is available for different fracture patterns, but is not reported in this series). The nail is mounted on a jig, which has an adjustable stop to aid in controlling the depth of insertion. The nail can be used to achieve indirect reduction of the shaft fragment. After insertion of the nail the 2 head screws are inserted into the greater and lesser tuberosities through the jig, taking care to avoid penetration of the articular surface. A blunt probe is often used instead of a drill to create the pilot hole in soft bone reducing the risk of a drill penetrating the joint. A curved chisel inserted through the jig is then used to cut a path for the blade, after which the blade is impacted in situ. The blade is then locked in position with up to two blade fixation screws inserted through the jig. For insertion of the distal blade fixation screw the axillary nerve is identified as described by Gardner et al *(14)*. A previous anatomical study by the senior author has demonstrated the proximity of the axillary nerve to the distal blade locking screw *(27)*. In first ten cases the axillary nerve was not routinely exposed. If it was deemed safe, the distal blade fixation screw was inserted followed by the proximal blade fixation screw and finally the distal locking screw to complete the construct.

A long blade with 2 blade locking screws configuration was used in 80% of the cases and distal blade locking screw was not used in 19% cases to avoid injury to the axillary nerve. Although a short blade is available, this was not used in this series. The simple nail and screw construct without the blade plate was used in a single case with a 2 part fracture where the bone quality was good and reduction of the fracture resulted in accurate and stable restoration of the calcar.

For all cases the shoulder is screened at the end of the procedure to check screw length, avoid screw penetration and test stability of the fixation. The rotator cuff is repaired, and the wound closed in layers. In 6 patients an incidental rotator cuff tear was found. These were repaired with sutures passing through the washer hole. The arm was supported in a poly-sling for 2 weeks and physiotherapy commenced immediately post-operatively under supervision, but active shoulder movements were avoided for 4 weeks post-operatively.

Patients were regularly followed up in the fracture clinic for clinical and radiological assessment. The Constant – Murley score *(9)* and Oxford Shoulder Score (OSS) *(10)* was recorded in the clinic at 12 months, by the senior author (GT). The Constant - Murley score was graded as poor (0-55 points), moderate (56 – 70 points), good (71 – 85 points) or excellent (86 – 100 points) *(7)*. The current version of the OSS was used with 48 points being the maximum. Radiographic analysis was performed retrospectively, using the Insignia Insight, picture archiving and communication system. Information on complications and re-operation was collected. The fractures were classified according to Neer's classification, based on trauma anteroposterior (AP), lateral scapular and trauma axillary views. The 12-month radiographic analysis was performed on standard AP, axillary and lateral scapular views. Analysis of the data was undertaken using IBM SPSS Statistics for Windows, version 20 (IBM Corp., Armonk, N.Y., USA). Where applicable non-parametric tests were used.

RESULTS

62 cases were identified during the 5-year period of investigation. 11 cases were excluded from the study analysis. (8 cases lost to follow up and 3 patients died prior to 1-year follow-up).

Of the 51 cases identified 40 (78.4%) were female and 11 (21.6%) male. The mean age was 67.4±11.9 years (range 33-96) (Table I & Fig. 2).

The majority of injuries were classified as low-energy (45 cases, 88.2%). These resulted in predominantly Neer's 2 or 3 fracture patterns (Table II). The small number of 4 part fractures is explained by the senior authors preference for arthroplasty in such cases, particularly in the presence of a dislocation.

The mean Constant score across all patients at 1 year was 76.0±15.3 (range 44 - 100) and a

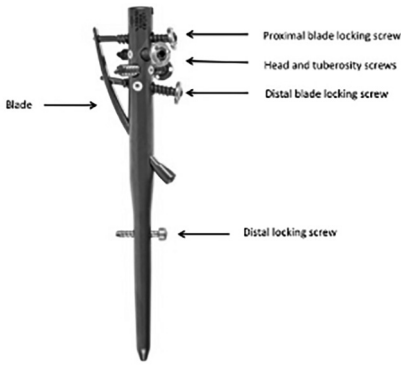

Fig.1. — Marquardt nail

Table I. — Demographics

Male		Sex	
		Female	
Age	30 - 39	0	1
	40 - 49	1	1
	50 - 59	2	7
	60 - 69	4	10
	70 - 79	4	13
	80 - 89	0	7
	90+	0	1

Of the 51 cases identified 40 (78.4%) were female and 11 (21.6%) male. The mean age was 67.4±11.9 years (range 33-96)

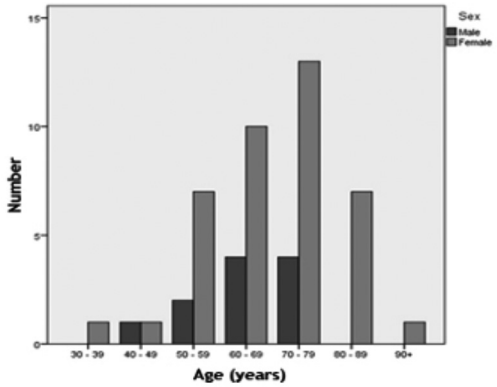

Fig.2. — Marquardt nail

mean OSS at 1 year of 41.6±5.1 (range 27 - 48). 38 cases of 51 (74.5%) achieved good or excellent Constant score outcomes (Table III). The OSS also demonstrated a predominance of good outcomes at 1 year (Table IV).

Patients aged <65 years scored significantly higher than those ≥65 years when assessed by the Constant score at 1 year, but there was no significant difference demonstrated between age groups for the OSS (Table V).

We found no significant difference between the outcome scores at 1 year follow up between the 2 part, 3 part and 4 part fractures. The p-values were 0.922 for 2 part vs 3part fractures, 0.707 for 2 part vs 4 part fractures and 0.792 for 3 part vs 4 part fractures respectively.

All cases progressed to bony union in this series (Fig. 3). The mean humeral neck-shaft angle achieved was 130.55°±9.6° (range 101° – 145°) across all cases. There were no significant

Table II. — Fracture classification of treated cases

		Number	Percent
Neer's Classification	2	21	41.2
	3	26	51.0
	4	4	7.8

Table III. — Constant scores at 1 year follow-up

		Number	Percent
Constant score groups	<= 55 (Poor)	7	13.7
	56 – 70 (Moderate)	6	11.8
	71 – 85 (Good)	25	49.0
	86+ (Excellent)	13	25.5

Table IV. — OSS at 1 year follow-up

		Number	Percent
OSS groups	25 - 32	4	7.8
	33 - 40	17	33.3
	40 - 48	30	58.8

Table V. — Breakdown of 1 year follow-up scores by retirement age

		<65 years (n = 19)	≥65 years (n = 32)
Constant score	Mean	81.6	72.7
	Standard deviation	16.6	13.7
	Range	44 - 100	44 - 96
	p - value†	0.015	
OSS	Mean	42.53	41.0
	Standard deviation	4.7	5.3
	Range	32 - 48	27 - 48
	p - value†	0.261	

†p-value of Mann-Whitney U test

differences between patients with a neck-shaft angle of <120° (6 patients) versus ≥120° (45 patients) when assessed by both the Constant score and OSS (Table VI).

Table VI. — Radiographic analysis. 1 year follow-up scores when assessed by neck-shaft angle

		Neck-shaft angle <120° (n = 6)	Neck-shaft angle ≥120° (n = 45)
Constant score	Mean	72.5	76.5
	Standard deviation	18.5	15.1
	Range	44 - 98	44 - 100
	p - value†	0.539	
OSS	Mean	41.67	41.58
	Standard deviation	5.6	5.1
	Range	32 - 48	27 - 48
	p - value†	0.943	

†p-value of Mann-Whitney U test

There were 4 cases (7.8%) of avascular necrosis, of which two were Neer type 4 fractures, one was Neer type 3 and one was Neer type 2. The Neer type 2 fracture had significant initial angular displacement of greater than 45°, the length of the metaphyseal head extension was 3mm and integrity of the medial hinge was lost. The Neer type 3 fracture had significant displacement and angulation of the fracture with medial metaphyseal head extension of 4 mm; this case was also administered high dose steroids for cryptogenic pneumonia during the follow up period a further risk factor for avascular necrosis. Both the type 4 fractures had significant initial displacement and angulation with medial metaphyseal head extension of less than 8mm. Predictably all the cases who developed AVN fared poorly and the mean Constant and OSS score for this sub-group was 55.5±15.2 and 34.0±7.4 respectively. Of these 4 cases, 3 patients underwent further surgical intervention. Two had arthrosplasty procedures and one had arthroscopic decompression and release. The remaining patient in the AVN group opted for conservative management.

Two cases (3.9%) had prominence of the nail at the insertion site. One of the cases developed later subsidence, also resulting in screw penetration into the glenohumeral joint. The second case had a tight canal, and in retrospect the humeral shaft could have been reamed to allow the nail to sit lower. Both these cases later underwent implant removal once the fracture had healed.

Two cases (3.9%) had fracture union with varus collapse and loss of neck shaft angle of more than 10°. The neck-shaft angle for these two patients was 101° and 115° post-operatively.

Seven cases required re-operation (13.7%) during the follow-up period, three cases (5.8%) for AVN. Two cases had arthroscopic release and decompression for stiffness and two patients underwent removal of metalwork. (See Table VII)

There were no cases of infection, axillary nerve palsy or implant failure. We omitted the distal blade fixation screw in 9 cases (18%) to avoid the axillary nerve.

Table VII. — For patients who had re-operation

Age	Gender	Neers	Complication	Constant score	OSS	Procedure
75	Female	3	AVN	76	44	Arthroscopic release and decompression
81	Female	4	AVN	44	27	Arthroplasty
71	Female	4	AVN	44	30	Arthroplasty
65	Female	3	Nail prominence + screw penetration	69	40	Removal of metalwork
57	Female	4	Nail prominence and impingement	76	44	Removal of metalwork
55	Female	2	Stiffness	44	32	Arthroscopic release and decompression
51	Female	2	Stiffness	85	32	Arthroscopic release and decompression

Fig.3a. — Trauma radiograph of case 1, showing Neer type II fracture pre-operatively.

Fig.3a. — Post operative radiography axillary view of case 1.

DISCUSSION

Proximal humerus fractures are the third commonest fracture in elderly population with three and four part fractures accounting for over half

Fig.3b. — Post operative AP radiograph of case 1, with implant in situ and fracture healed satisfactorily.

of these injuries *(19)*. Optimum treatment remains debatable, however good results have been reported in the elderly patient population with complex 3 and 4 part fractures with reverse shoulder replacement procedures *(3,8)*. Locked proximal humerus plates offers anatomical reduction and rigid fixation and higher loads to failure *(29)*, unfortunately the complication and re-operation rates are high *(11,23,28)*. The PROFHER study has cast doubt on the place of surgery in such fractures *(26)*.

The biomechanical stability of intramedullary devices is superior to extra-medullary devices *(13)*. However, there is insufficient evidence from RCTs to inform the choices between different surgical interventions, for these fractures *(16)*. The main disadvantages of humeral nails are inadequate medial calcar support (and hence primary stability); as well as potential damage to the rotator cuff. The locking blade nail implant aids in providing medial calcar support by the distally inserted blade which achieves hold in in the medial head. The blade locking screws aims to create a triangular

metaphyseal construct counteracting the deforming forces from the rotator cuff and deltoid to prevent rotational and varus mal-alignment of fracture construct. The straight nail design facilitates entry of the nail, either through a reamed entry point or intrafocally through the fracture site in 3 and 4 part fractures. The entry point is medial to the supraspinatus foot print facilitating good repair at the end of procedure.

The outcomes in our series are comparable to those reported for other intra-medullary devices *(15,25,30)* and the complication rate is lower than those reported for extramedullary devices *(11)*. Patients under 65 years of age had a significantly better outcome than those over 65. These findings are consistent with the existing literature *(12,15)*. Pre-exiting shoulder pathology, osteoporosis and comorbidities are more prevalent in the older patient, whereas the younger patient often has a greater rehabilitation potential. There was no correlation between a reduced neck shaft angle and the outcome which is in agreement with prior work *(15)*.

There were no cases of proximal screw loosening or backing out. The published rates of screws backing out following antegrade nails for proximal humerus fractures is up to 15% *(1,2,20,21,25)* The secure grip of the PEEK insert on the proximal screw, as well as the compression achieved by the washer on the screw head, may explain the absence of backed out screws in our series.

The stability of the construct achieved was very good and we encountered varus loss of position in only 3.9% cases. This is comparable to that achieved with locking proximal humeral plates *(11)*.

The observed AVN rate compares favourably to extra-medullary devices *(11)* and was similar to studies reporting other intra-medullary implants *(1,20,25)*. All the cases that developed AVN had poor prognostic predictors for ischaemia of the humeral head *(18)*.

We had a re-operation rate of 13.7% overall, similar to that reported by Wong et al. *(30)* in their systematic review, however we did not encounter the significant complication rates of 33.6% for two part fractures and 57.8% for three part fracture reported in their study. We did not encounter any complication with screw back out, infections or axillary nerve palsy. We believe the reason for avoiding axillary nerve complications was the modification and adaptation of surgical technique based on earlier study *(27)*.

We believe that the majority of the improvement, occurs in the first 12 months following the operative intervention of a proximal humerus fractures *(15)* and the 12 month functional outcome is a reliable reflection of the final functional outcome. Our primary aim was to assess the impact of proximal humeral fracture fixation using the Marquadt LBN on functional and patient reported outcomes. In our series 75% of patients had a good to excellent outcome as assessed by the Constant score, which is comparable to the reported outcomes of other intra-medullary implants *(12,15)*. These outcomes are also superior to those reported for extra-medullary devices *(11)*. Patient reported outcome measures (OSS) also demonstrated a good result.

The limitations of the study were, it was a retrospective study and the sample size was small. The Constant scores recorded in our series have not been age adjusted and we believe that the results would translate into even better scores if they were. The subgroup of patients with 4 part fracture was even smaller hence we cannot derive any safe conclusions for this cohort of patients for this implant, however there was a high rate of avascular necrosis in this group.

Our findings support the only previously published work regarding outcomes after proximal humeral fracture fixation using the Marquadt LBN *(17)*. We feel this is a useful implant for proximal humerus fractures. The LBN provides robust construct stability as with an extramedullary device while at the same time retaining the procedural ease and benefits of a nail. The high rate of AVN in 4 part proximal humerus fractures is a recognised complication, however there may be a place for internal fixation in the younger patient in an attempt to avoid shoulder arthroplasty.

REFERENCES

1. **Adedapo AO, Ikpeme JO.** The results of internal fixation of three and four-part proximal humeral fractures with the Polarus nail. *Injury.* 2001 , 32 : 115-121.
2. **Agel J, Jones CB, Sanzone AG, Camuso M, Henley MB.** Treatment of proximal humeral fractures with Polarus nail fixation. *J Shoulder Elbow Surg.* 2004 , 13 : 191-195.

3. **Anakwenze OA, Zoller S, Ahmad CS, Levine WN.** Reverse shoulder arthroplasty for acute proximal humerus fractures: a systematic review. *J Shoulder Elbow Surg.* 2014 ; 23 : e73–e80.
4. **Bell JE, Leung BC, Spratt KF, Koval KJ, Weinstein JD, Goodman DC** *et al.* Trends and variation in incidence, surgical treatment, and repeat surgery of proximal humeral fractures in the elderly. *J Bone Joint Surg Am.* 2011 ; 93 : 121-131.
5. **Benger U, Johnell O, Redlund-Johnell I.** Changes in the incidence of fracture of the upper end of the humerus during a 30- year period: a study of 2125 fractures. *Clin Orthop Relat Res.* 1988 , 231 : 179-182.
6. **Bigliani LU, Flatow EL, Pollock RG.** *Fractures of the proximal humerus. Rockwood and Green's fractures in adults.* Edited by: Rockwood CA Jr, Green DP, Bucholz RW, Heckman JD. 1996, Philadelphia: Lippincott-Raven, 1055-1107.
7. **Bjorkenheim J.M., Pajarinen J., Savolainen V.** Internal fixation of proximal humeral fractures with a locking compression plate: a retrospective evaluation of 72 patients followed for a minimum of 1 year. *Acta Orthop Scand.* 2004 ;75 : 741-745.
8. **Bufquin T, Hersan A, Hubert L, Massin P.** Reverse shoulder arthroplasty for the treatment of three- and four-part fractures of the proximal humerus in the elderly: a prospective review of 43 cases with a short-term follow-up. *J Bone Joint Surg Br.* 2007 ; 89 : 516-520.
9. **Constant CR, Murley AHG.** A clinical method of functional assessment of the shoulder. *Clin Orthop Rel Res.* 1987 ; 214 : 160-4.
10. **Dawson J, Fitzpatrick R, Carr A.** Questionnaire on the perceptions of patients about shoulder surgery. *J Bone Joint Surg Br.* 1996 ; 78 : 593-600.
11. **Erasmo R, Guera G, Guerra L.** Fractures and fracture-dislocations of the proximal humerus: A retrospective analysis of 82 cases treated with the Philos locking plate. *Injury.* 2014 ; 45 : S43-S48.
12. **Fazal MA, Baloch I, Ashwood N.** Polarus nail fixation for proximal humeral fractures. *J Orthop Surg.* 2014 ; 22 : 195-8.
13. **Fuchtmeier B, May R, Hente R, Maghsudi M, Volk M, Hammer J** *et al.* Proximal humerus fractures: a comparative biomechanical analysis of intra and extramedullary implants. *Arch Orthop Trauma Surg.* 2007 ; 127 : 441-7.
14. **Gardner MJ, Griffith MH, Dines JS, Briggs SM, Weiland AJ, Lorich DG.** The extended anterolateral acromial approach allows minimally invasive access to the proximal humerus. *Clin Orthop Relat Res.*2005 ; 434 : 123-9.
15. **Giannoudis PV, Xypnitos FN, Dimitriou R, Manidakis N, Hackney R.** Internal fixation of proximal humeral fractures using the Polarus intramedullary nail: our institutional experience and review of the literature. *J Orthop Surg Res.* 2012 ; 7 : 39.
16. **Handoll HH, Brorson S.** Interventions for treating proximal humeral fractures in adults. *Cochrane Database Syst Rev.* 2015 ; CD000434.
17. **Hashmi FR, Mayr E.** A new nail with a locking blade for complex proximal humeral fractures. *Eur J Orthop Surg Traumatol.* 2016.
18. **Hertel R, Hempfing A, Stiehler M, Leunig M.** Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. *J Shoulder Elbow Surg* 2004 ; 13 : 427-433.
19. **Kannus P, Palvanen M, Niemi S, Parkkari J, Jarvinen M, Vuori I**. Increasing number and incidence of osteoporotic fractures of the proximal humerus in elderly people. *BMJ.* 1996 ; 313 : 1051-1052.
20. **Kazakos K, Lyras DN, Galanis V, Verettas D, Psillakis I, Chatzipappas C, Xarchas K.** Internal fixation of proximal humerus fractures using the Polarus intramedullary nail. *Arch Orthop Trauma Surg.* 2007 , 127 : 503-508.
21. **Koike Y, Komatsuda T, Sato K.** Internal fixation of proximal humeral fractures with a Polarus humeral nail. *J Orthop Traumatol.* 2008 , 9 : 135-139.
22. **Lauritzen JB, Schwarz P, Lund B, McNair P, Transbold I.** Changing incidence and residual lifetime risk of common osteoporosis-related fractures. *Osteoporos Int.* 1993 , 3 : 127-132.
23. **Moonot P, Ashwood N, Hamlet M.** Early results for treatment of three and four part fractures of the proximal humerus using the PHILOS plate system. *J Bone Joint Surg Br.* 2007 ; 89 : 1206-9.
24. **Neer CS**. Displaced proximal humeral fractures Part II: treatment of three-part and four-part displacement. *J Bone Joint Surg Am.* 1970 , 52 : 1090-1103.
25. **Rajasekhar C, Ray PS, Bhamra MS.** Fixation of proximal humeral fractures with the Polarus nail. *J Shoulder Elbow Surg.* 2001 , 10 : 7-10.
26. **Rangan A, Handoll H, Brealey S** *et al.* Surgical vs Nonsurgical Treatment of Adults With Displaced Fractures of the Proximal Humerus. The PROFHER Randomized Clinical Trial. *JAMA.* 2015 ; 313 : 1037-1047.
27. **Spiegelberg BG, Riley ND, Taylor GJ.** Risk of injury to the axillary nerve during antegrade proximal humeral blade nail fixation – an anatomical study. *Injury.* 2014 ; 45 : 1185-1189.
28. **Sproul RC, Iyengar JJ, Devcic Z, Feeley BT.** A systematic review of locking plate fixation of proximal humerus fractures. *Injury.* 2011 ; 42 : 308-413.
29. **Weinstein DM, Bratton DR, Ciccone WJ** *et al.* Locking plate improve torsional resistance in the stabilization of three-part proximal humerus fractures. *J Shoulder Elbow Surg* 2006 ; 15 : 239-243.
30. **Wong J, Newman JM, Gruson KI.** Outcomes of intramedullary nailing for acute proximal humerus fractures: a systematic review. *J Orthop Trauma.* 2016 ; 17 : 113-122.
31. **Zyto K, Wallace WA, Frostick SP, Preston BJ.** Outcome after hemiarthroplasty for three and four part fractures of the proximal humerus. *J Shoulder Elbow Surg.* 1998 , 7 : 85-89.