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Original article

Exploring the difficulties to improve minimally invasive application with long PHILOS plate in multifocal metadiaphyseal fractures of the proximal humerus: analysis of intraoperative procedure and clinical outcomes

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Summary. The MIPO (Minimally Invasive Plate Osteosynthesis) technique for treating metadiaphyseal fractures of the proximal humerus has gained great attention during the past years. The purpose of this retrospective study was to underline all the important difficulties when the MIPO technique is applied, to propose practical solutions and to evaluate the overall clinical outcome of our patients treated with this technique. A total of 14 patients had been operated in two different surgical units, at San Carlo Borromeo Hospital (Milan, Italy - 11 patients) and in Policlinico Umberto I Hospital (Rome, Italy - 3 patients), between June 2013 and November 2016. The humeral fractures were divided according to the Maresca et al. classification system. A lateral deltoid-split or an anterolateral deltopectoral approach was performed in the proximal humerus. In distal approach, an anterior or a lateral window was performed for plate fixation. After a follow-up of 17,4 (range 3-31) months all patients showed fracture healing and there were no non-unions or infected cases. MIPO of the humerus is a tissue sparing technique and in expert hands can improve healing rates and can also reduce complications like nerve damages and infections. In conclusion, we would like to highlight the importance of the MIPO technique as a possible alternative option to the traditional ORIF technique. (www.actabiomedica.it)

Key words: MIPO, PHILOS, helical plate, humeral fracture

Introduction

The MIPO (Minimally Invasive Plate Osteosynthesis) technique for treating metadiaphyseal fractures of the proximal humerus has gained great attention during the past years. Long PHILOS® plate (Synthes, Switzerland) can provide adequate stability for fracture healing and can also allow for an early rehabilitation program. A "biological" approach to fracture treatment of metadiaphyseal fracture can be achieved by taking advantage of different "windows" of soft tissue combining different approaches of proximal and distal types of exposure (1).

However, in clinical practice, the MIPO technique is correlated with technical difficulties throughout surgical procedures during a closed reduction. Danger zones should also be identified to avoid nerve injuries (2). Manipulation of the humerus for closed

reduction needs accurate knowledge of anatomy and deep understanding of the dynamic mechanism that actually induced the fracture.

Following unusual ideas of past surgical experience has contributed to improve minimally invasive plating (3).

The purpose of this retrospective study was to underline all the important difficulties when the MIPO technique is applied, to propose practical solutions and to evaluate the overall clinical outcome of our patients treated with this technique.

Materials and methods

Our retrospective study has been conducted in a group of subjects who had previously suffered from a unilaterally displaced multifocal metadiaphyseal fracture of the proximal humerus. A total of 14 patients had been operated in two different surgical units, at San Carlo Borromeo Hospital (Milan, Italy - 11 patients) and in Policlinico Umberto I Hospital (Rome, Italy - 3 patients), between June 2013 and November 2016.

The patients met the following inclusion criteria: 1) multifocal humerus fracture with involvement of the metadiaphyseal proximal site; 2) internal fixation with a Locking Proximal Humeral Plate PHILOS® (Synthes, Switzerland); 3) the use of a minimally invasive plate osteosynthesis (MIPO) technique.

The exclusion criteria included: 1) Comorbidity Severity Score (ASA) ≥4; 2) a post-operative follow-up shorter than 3 months.

The X-ray images of all the eligible patients were obtained from the Picture Archiving and Communication System (PACS) of our institutes and examined in at least 2 standard projections (anteroposterior and lateral radiographs view of the humerus). In addition, a CT-scan of the humerus was carried out in a few selected cases, when the fracture involved the neck or humeral head to enable the surgeon to study the injury features.

The humeral fractures were divided according to the Maresca et al. classification system (4). The average age of the patients was calculated and the side involvement was reported.

All patients were followed up as outpatients with X-rays according to our protocol (AP and lateral projection of the humerus) at 5 weeks, 3 months and thereafter at regular intervals depending on the progress of fracture healing. After each follow-up, a proof clinical examination was obtained. Bony union and complications as pseudoartrosis, infections and nerve lesions were examined in the immediate post-operative period.

The functional outcome was quantified using the Italian version of DASH 30-item to evaluate quality of life.

Operating technique

All surgical procedures have been performed under general anesthesia. Patients were positioned supine with the upper limb on a radiolucent table or in a "beach-chair" position. A single shot of antibiotics (2 grams of cefazolin) was administered 30 minutes prior to skin incision. The image intensifier position had been checked preoperatively for adequate anteroposterior and lateral view of the humerus. The C-arm (X-ray tube) was positioned at the opposite side of the surgical site.

A lateral deltoid-split or an anterolateral deltopectoral approach was performed in the proximal humerus. When a lateral deltoid-split approach was used, finger dissection of the deep surface of the deltoid muscle allowed palpation and finger protection of the axillary nerve.

In distal approach, an anterior or a lateral window was performed for plate fixation. In such case, of distal lateral approach, the radial nerve was identified in the groove between brachialis and brachioradialis muscle and nerve exploration was performed in case of nerve disorder pathology. The plate was placed in the lateral border of the humerus and was carefully bended gently at the distal part to be adapted to distal humerus.

In an anterior distal approach, the biceps muscle was retracted medially to reveal the underlying brachialis. Special attention was paid to not disturb the musculocutaneous nerve under the brachialis muscle. After the biceps was retracted medially, the brachialis muscle was spitted in it midline so as to expose the anterior distal part of the humerus. In such cases the

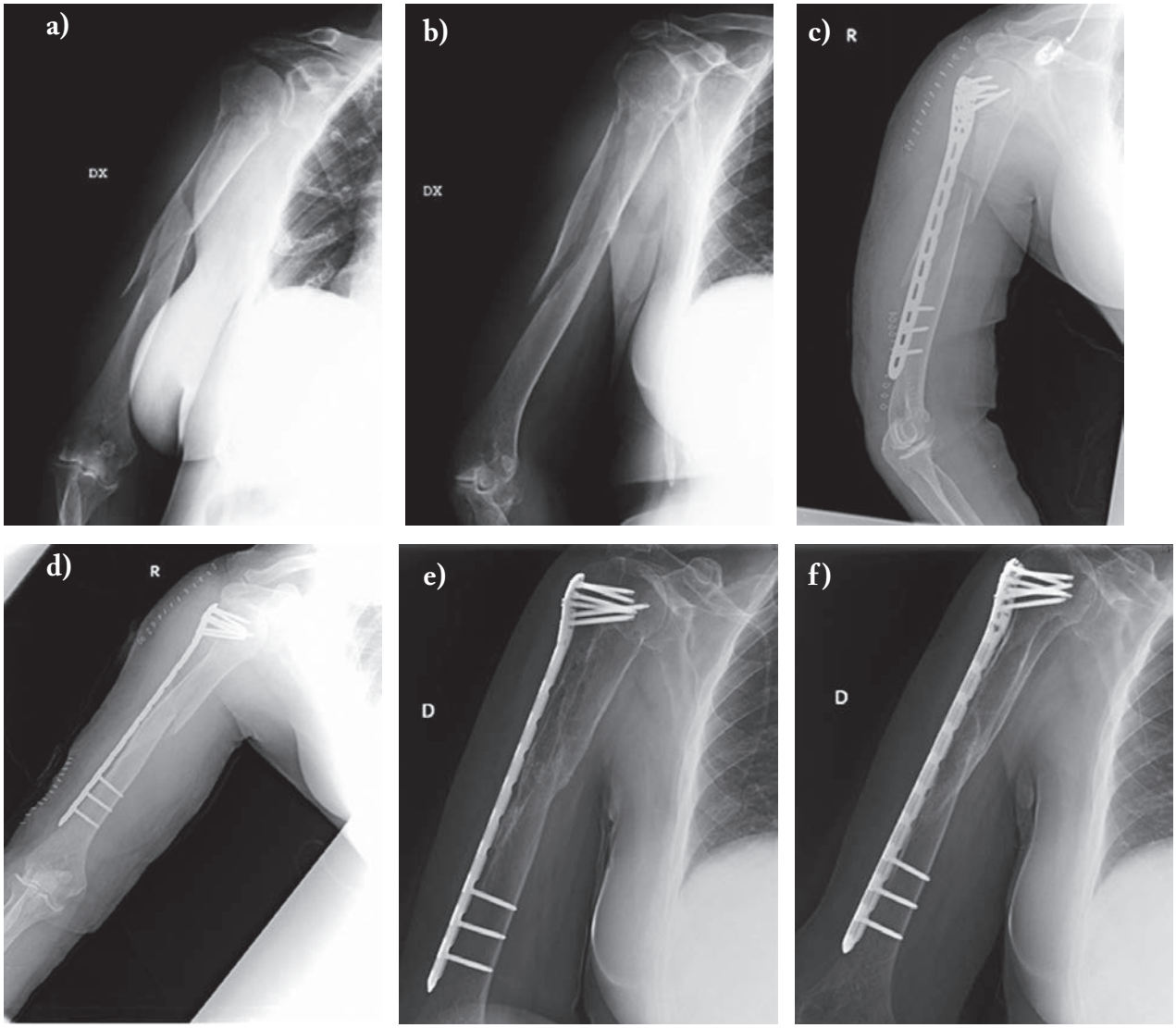

Figure 1 a, b, c, d, 1, 1. Radiographs of a 81-year-old woman with a multifocal humeral fracture (A3- Maresca et al. classification) with post-operative x-rays and 12-months follow-up

PHILOS® plate was twisted in an helical form to aid anterior distal fixation.

The plate was introduced into the sub-deltoid space or more anterior to the deltoid muscle and then through the subbrachial space and identified either anteriorly or laterally. The fracture was reduced by simple manipulation and traction to obtain a reasonable alignment that was immediately checked using an image intensifier. The plate was inserted from a proximal to distal direction on the lateral side of the humerus, always under the guidance of image intensifier. Screws were inserted through the incisions already made. When necessary, cortical interfragmentary screws were used to improve reduction and alignment, through an extension of the initial incisions. A final control view using the image intensifier was obtained to check the correct position of the implant. Standard skin closure was performed. A cast of the arm was applied in every patient at the end of the surgery. The patients were allowed to begin gentle active motion

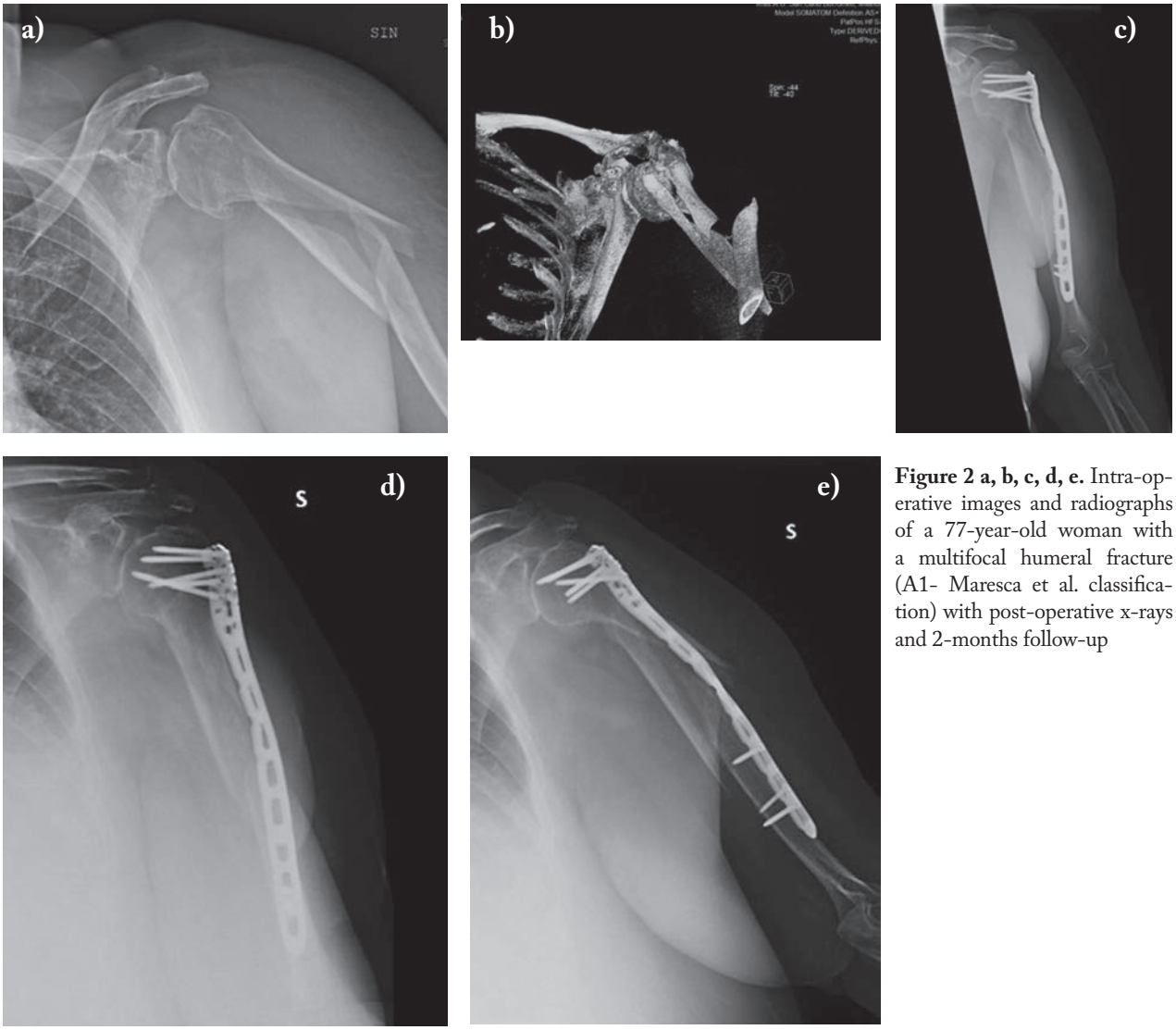

Figure 2 a, b, c, d, e. Intra-operative images and radiographs of a 77-year-old woman with a multifocal humeral fracture (A1- Maresca et al. classification) with post-operative x-rays and 2-months follow-up

and pendulum exercises of the shoulder the day after the surgery. Patients were instructed to clockwise and counterclockwise shoulder rotation, thumb to shoulder exercises, front and side-assisted lift movements of the arm. Physiotherapy was continued after the discharge of the patient on the outpatient department for all the necessary period.

Results

The final cohort of our patients that met the inclusion criteria was composed of 11 patients. There were 8 female and 3 male patients with a mean age of 70.4 years (range 43-85 years).

The Maresca et al. classification was used to categorize the fractures (Table 1).

After a follow-up of 17,4 (range 3-31) months all patients showed fracture healing and there were no non-unions or infected cases. In all these patients, entire fracture healing was documented by both X-rays and clinical evaluation at follow-up.

Three patients showed radial neuroapraxia on admission; after surgery and during the follow up a gradual improvement was seen, but one had ever recovered completely as evaluated during the last follow-up.

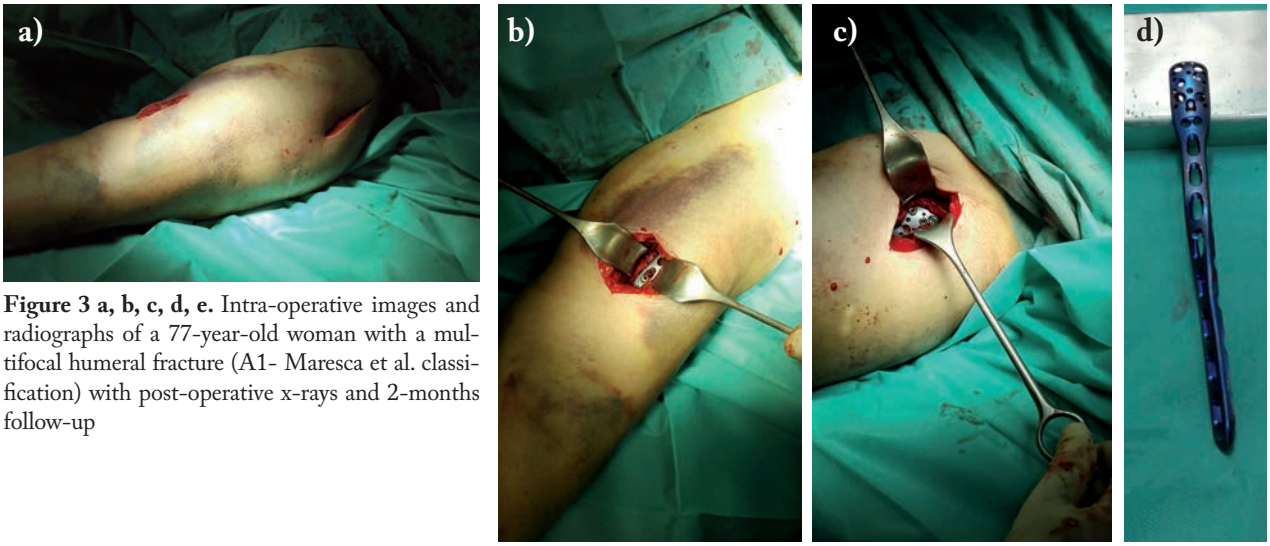

Figure 3 a, b, c, d, e. Intra-operative images and radiographs of a 77-year-old woman with a multifocal humeral fracture (A1- Maresca et al. classification) with post-operative x-rays and 2-months follow-up

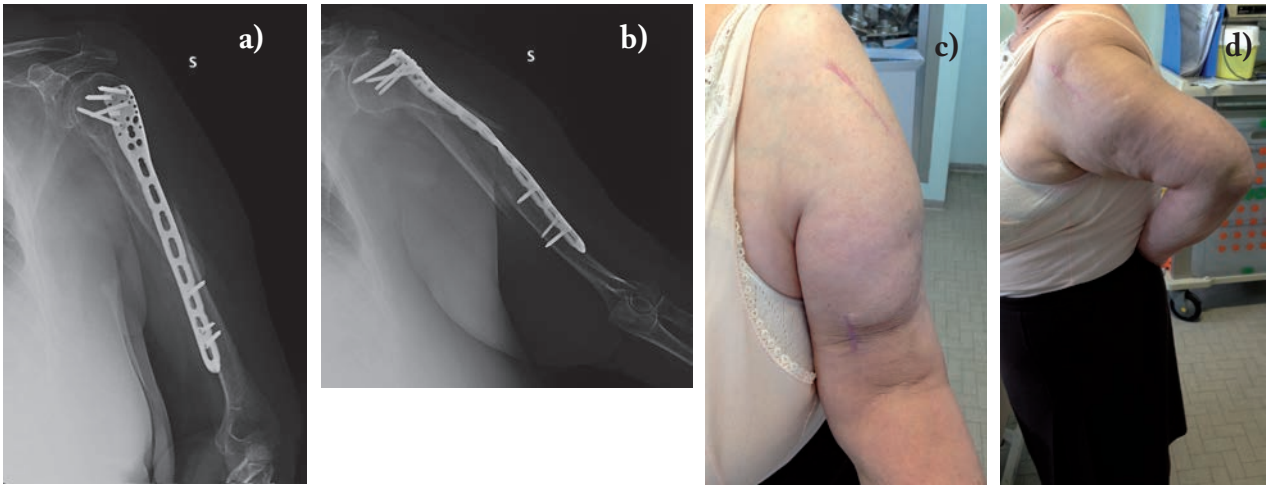

Figure 4 a, b, c, d. X-rays and clinical images of the 77-year-old woman at 3-months follow-up

The mean operation delay was 6.3 days (range 2-11 days).

There were 11 long PHILOS® plates used (8-hole: n=6; 10 hole: n=5).

A lateral deltoid – split proximal approach was performed in 10 cases; in the remaining one case, a deltoid-pectoral approach was used. A lateral distal approach between brachialis and brachioradialis muscles was performed in 9 cases, an anterior approach as described previously, in 2 cases.

The operating time was mean 98.6 min (range 60-125 min) (Table 2).

There were no intra-operative complications. Postoperatively, only one patient showed radial nerve palsy. No complications implant related occurred.

The mean values of the DASH scores determined at the last follow-up are reported in Table 1.

Discussion

During the past few years, clinical outcomes after MIPO technique applications to humeral fractures were generally been reported as satisfactory. Surgical

Table 1. Patient demographics, fracture type and outcome

Case	Sex	Age	Laterality	Maresca classification	Operation delay (days)	Follow up (months)	DASH score
1	F	85	Right	A1	2	31	22.4
2	F	81	Right	A3	11	26	62.9
3	M	73	Left	A3	10	20	6
4	F	82	Right	A1	7	19	22.5
5	F	70	Right	B	8	18	20.7
6	M	85	Right	A1	4	19	39.7
7	F	77	Left	A1	4	13	6
8	F	75	Right	A1	5	3	75
9	F	60	Right	A1	6	12	31.7
10	F	43	Right	A1	6	28	2.5
11	M	43	Right	A1	6	3	30
		Mean 70,4			Mean 6.3	Mean 17,4	Mean 29

Table 2. Surgical procedures and complications

Case	Operating time (min)	Proximal approach	Distal approach	Plate	Holes	Position	Complications
1	95	Lateral	Lateral	Normal	8	Supine	Radial neuroapraxia (preoperative - recovered)
2	75	Lateral	Lateral	Normal	10	Supine	Radial nerve postoperative palsy
3	115	Lateral	Lateral	normal	10	Supine	/
4	60	Lateral	Lateral	Normal	8	Supine	Radial neuroapraxia (preoperative incomplete recovery)
5	105	Lateral	Lateral	Normal	10	Supine	/
6	125	Lateral	Anterior	Helicoidal	8	Supine	/
7	60	Lateral	Anterior	Helicoidal	8	Supine	/
8	120	Deltopectoral	Lateral	Normal	8	Supine	Radial neuroapraxia (preoperative - recovered)
9	85	Lateral	Lateral	Normal	8	Beach-chair	/
10	125	Lateral	Lateral	Normal	10	Beach chair	/
11	120	Lateral	Lateral	Normal	10	Beach chair	/

experience, anatomy knowledge and adequate intraoperative imaging are mandatory to achieve promising results by a Mipo procedure.

MIPO of the humerus is a tissue sparing technique and in expert hands can improve healing rates and can also reduce complications like nerve damages and infections.

Compared to intramedullary nailing, Hohmann et al. found out that MIPO technique reduces rates of complications such as postoperative nerve injury, infection and nonunion. In their meta-analysis the authors described, in patients treated with MIPO, lower rates of shoulder problems related to the approach and the insertion site (i.e. shoulder pain and impingement). Furthermore, according to the authors, during intramedullary nailing there's more radiation exposure during the surgical procedure. They also found out that the rate of revision surgery is higher in patients treated with IM nailing (5).

Guo-dong Liu et al described no significant differences in terms of nonunion, postoperative infections and radial nerve paralysis. They report a higher

incidence of delayed union in patients treated with IM nailing (6).

MIPO technique can be performed in metadiaphyseal fractures of the proximal humerus, with many advantages compared to traditional plate fixation. Devascularization of the fracture fragments, when using extensive surgical approaches and dealing with an osteoporotic bone often result in significant rates of avascular necrosis and fixation failure (7).

Indications of MIPO include fractures of the proximal third of the humeral shaft or shaft fractures with extension into the humeral head with more than 20° angulation in the AP or lateral x-ray or with more than 3 cm axial shortening after closed reduction. Another indication can be delayed union after initial conservative treatment (8).

MIPO of the proximal humerus using PHILOS® plate is worth considering in the clinical practice. According to Fernandez Dell'Oca studies, helical plates can be used, as well as traditional straight ones, for MIPO of the proximal humerus (3). This kind of implants can be twisted DCP or LCP plates (like PHILOS®): a 90° twisted plate lies onto the lateral-proximal area of the humerus and on its anterior-distal part. A locking compression plate, which works as an internal fixator, does not need accurate contouring to fit the surface of the bone. A major concern is the damage to the locking thread caused by the twisting of the plate, but the latter lies over the fracture site where screws are not actually placed (9).

The following structures are at risk while performing MIPO of the proximal humerus, and most of them are avoided if a helical implant is used for fixation:

- Axillary nerve: it's a major concern when using a deltoid-splitting approach. It has to be identified and protected or a minimal anterolateral approach has to be performed to avoid damaging it (9). Gonç et al. found out that the nerve runs at average 60 mm distance from the lateral aspect of the acromion. It means that the proximal incision should not be longer than 50 mm and the risk of axillary nerve damage increases whan infero-medial calcar screws are inserted (10);
- The long head of the biceps tendon: it can be injured only with anterior plating when screws are inserted from anterior to posterior.
- Musculocutaneous nerve: it can be at risk during placement of percutaneous screws from anterior to posterior, as it crosses from medial to lateral and runs in the distal parts between biceps brachia and brachialis muscles. According to Gardner et al., it's not recommended to insert screws in the danger zone (12.2-14.8 cm distal from the great tuberosity) (7).
- Distal extent of the deltoid muscle: it sets a limit for a longer plate insertion. A 90° twisted plate lies medial and distal to this structure and can preserve insertion of deltoid muscle (11).
- Radial nerve: Apivatthakakul et al. described a cadaveric study about MIPO of humeral shaft fractures (12). According to the Authors, this procedure is recommended to be done with the arm in 90° abduction and the forearm in full supination. The radial nerve runs posteriorly close to the humerus in its middle third (from 20.7±2 cm proximal to the medial epicondyle to 14.2±0.6 cm proximal to the lateral epicondyle). No bicortical screw has to be inserted from anterior to posterior through this danger zone. With a traditional 10 holes LCP plate, screw holes n. 6 and 7 must be avoided. After piercing the lateral intermuscular septum, Apivatthakakul et al. found that radial nerve runs approximately 3.2 mm far from the lateral border of the plate. With pronation of the forearm, radial nerve moves medially closer to the distal end of the plate.

Primary limitations of our study was the restricted number of cases. In addition, for some patients discussion of long-term functional outcome is lacking. Furthermore, only the DASH score was used as outcome measure for functional evaluation.

MIPO technique with PHILOS® plate is a safe and valid choice for the treatment of metadiaphyseal fractures of the proximal humerus, with good functional outcome. Bridging plating allows an elastic osteosynthesis that results in a very low rate of failure of the construct. In our series we don't report any rupture of the plate. Callus formation was visible even in x-rays of patients evaluated 12 weeks after surgery and we didn't have, in our series, complications like nonunion, AVN, and infection, due to less soft tissue damage and blood supply impairment.

The surgical approaches described are user-friendly and can be performed by young surgeons: the lateral approach to the proximal humerus can be easily done; for the distal humerus surgeons may consider an anterior approach (to place screws in the safe zone for radial nerve), instead of a traditional lateral one (more at risk of radial nerve lesion) (13). An accurate preoperative planning, together with an efficient teamwork, can reduce the duration of the procedure and ease the surgeon's job. For example, it's our practice to do intraoperative x-rays with the C-arm positioned at the opposite side of the patient.

One of the most technically difficult points of MIPO is obtaining adequate fracture reduction. Indirect reduction under c-arm imaging should be obtained. Exposure of the great tuberosity by the deltoid-pectoral approach could be demanding in the cases of multifocal humeral interest, as internal rotation of the proximal part of the humerus could cause mal-reduction or displacement of the meta-diaphyseal fragments. In the transdeltoid lateral approach attention should be paid not to damage the axillary nerve by choosing the appropriate holes of the plate to be utilized.

The deltoid insertion in the lateral approach of the humerus is long and broad and could be challenging to bypass by the plate.

In the distal part of the approach of the lateral exposure, the radial nerve could become sensitized. Careful manipulation of the nerve is crucial to reduce the risk of iatrogenic lesions. Anterior exposure of the distal part of the humerus is less invasive; the only nerve at risk is the muscolocutaneous. The bending of the PHILOS® plate is hard as this plate is resistant to helicoidally deformation

A major concern is how to twist the plate if a helical implant is required. Basically, we suggest to twist the plate according to the fracture site, and not in a standard way. In our every day practice, we still don't have commercially available pre-contoured plates.

Complications such as screw cut-out, nerve injuries and bad reduction are usually technique-dependent. We had just one radial nerve injury, probably caused by excessive retraction during the procedure. Two of the three patients with radial nerve impairment before the procedure recovered at the last follow-up.

Conclusions

We would like to highlight the importance of the MIPO technique as a possible alternative option to the traditional ORIF technique and underline the ability and flexibility required by surgeons for practicing not common techniques such as helicoidal plating to selected cases.

Furthermore, the MIPO technique can be used instead of IM nailing, as there's no evidence of higher rates of infection, nonunion and nerve injury. This technique avoids problems related to the insertion site of both antegrade and retrograde IM nail.

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