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Dynamic contrast-enhanced ultrasound (CEUS) after open and minimally invasive locked plating of proximal humerus fractures

Christian Fischer[a,*], Marion Frank[a], Pierre Kunz[a], Michael Tanner[a], Marc-André Weber[b], Arash Moghaddam[a], Gerhard Schmidmaier[a], Andreas Hug[c]

[a] Center for Orthopedics, Trauma Surgery and Spinal Cord Injury, Heidelberg University Hospital, Heidelberg, Germany
[b] Diagnostic and Interventional Radiology, Heidelberg University Hospital, Heidelberg, Germany
[c] Spinal Cord Injury Center, Heidelberg University Hospital, Heidelberg, Germany

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ABSTRACT

Introduction: Closed reduction and locked plate fixation of proximal humerus fractures with the minimally invasive deltoid-splitting approach intends to minimize soft tissue damage although axillary nerve injury has been reported. The aim of this study was to assess the deltoid muscle perfusion with dynamic contrast-enhanced ultrasound (CEUS) as novel technique and evaluate its relation to the functional and neurologic outcome after open (ORIF) and minimally invasive (MIPO) fracture fixation.
Patients and methods: 50 patients, 30 with deltopectoral ORIF and 20 with deltoid-splitting MIPO approach were examined 6–49 months after surgery. Only patients with a healthy, contralateral shoulder were selected. Shoulder function, satisfaction as well as psychosocial outcome were assessed with established scores (Constant, DASH, Simple Shoulder Test, ASES, SF-12). Electromyography (EMG) of the deltoid muscle was performed to determine axillary nerve damage. Ultrasound of both shoulders included CEUS and Power Doppler after deltoid muscle activation via active abduction for two minutes.
Results: None of the examinations and scores showed significant differences between ORIF and MIPO patients, the psychosocial outcome was similar. The fracture types were equally distributed in both groups. The normalized Constant Score was 76.3 ± 18.6 in the ORIF and 81.6 ± 16.1 in the MIPO group ($p = 0.373$). Deltoid muscle perfusion in CEUS and Power Doppler revealed no differences between both approaches. EMG excluded functionally relevant axillary nerve injuries. Compared with the contralateral shoulder, Constant- and ASES-Scores ($p \leq 0.001$ for both ORIF and MIPO) as well as the deltoid CEUS perfusion (ORIF $p = 0.035$; MIPO $p = 0.030$) were significantly worse for both approaches.
Conclusions: Convincing consensus of functional, ultrasonographic and neurologic examinations demonstrated comparable outcomes after deltopectoral and deltoid-splitting approach. The quantification of the deltoid muscle perfusion with CEUS indicates that the proclaimed benefits of the MIPO approach on soft tissue might not be as great as expected.

Introduction

Proximal humerus fractures will become more common with increasing life expectancy of the population [1–3]. Whereas fractures without displacement can be treated conservatively with favorable outcome [4,5], the indication and ideal technique for a surgical intervention depend on several fracture and patient specific factors, e.g. localization and pattern of fracture, displacement, and comorbidities [6–12].

Common surgical techniques of open reduction and internal fixation (ORIF) with locked plates, e.g. Philos® (Synthes, Switzerland) via the standard deltopectoral approach are associated with complications such as impingement or avascular necrosis of the humeral head [13–15]. Hence, minimally invasive plate osteosynthesis (MIPO) via the deltoid-splitting approach was introduced with the intention of minimizing soft tissue injury, shortening inpatient stay and consequently improving shoulder function [16–19]. So far, only few studies directly compared the long term results of ORIF versus MIPO approaches and clear differences could not be established with respect to shoulder function, psychosocial outcomes, patient satisfaction, and complication rates [20–22]. Furthermore, these studies did not systematically analyze the impact of axillary nerve lesions, which are

* Corresponding author at: HTRG—Heidelberg Trauma Research Group, Center for Orthopedics, Trauma Surgery and Spinal Cord Injury, Heidelberg University Hospital, Schlierbacher Landstraße 200a, D-69118 Heidelberg, Germany.
E-mail address: Christian.Fischer@med.uni-heidelberg.de (C. Fischer).

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suspected to occur more frequently in minimally invasive deltoid-splitting approaches [23,24].

Our study was designed to investigate the impact of ORIF versus MIPO approaches on soft tissue injury (i.e. deltoid muscle) with novel ultrasound techniques. Therefore, dynamic contrast-enhanced ultrasound (CEUS) [25,26] was implemented as part of an ultrasound-based perfusion assessment. Compared to standard Power Doppler sonography, CEUS allows the imaging of small microvessel perfusion (2–7 nm) and is therefore more accurate. Since muscular perfusion and recruitment are well correlated [27,28], muscle tissue vitality can be estimated by the CEUS method. It has not been used for the perfusion assessment of the deltoid muscle yet. Its musculoskeletal applications are still rare although CEUS is easily accessible, cost-efficient and quick-to-use with very low complication rates [29,30].

Thus, the aim of this study was to compare ORIF versus MIPO approaches with respect to deltoid muscle integrity assessed by CEUS, needle electromyography (i.e. assessment of axillary nerve injury) and long-term clinical outcome.

Patients and methods

Patient population and study protocol

This study was conducted in accordance with the declaration of Helsinki in its present form and was approved by the local ethics committee (S-438/2012). 50 patients who received open or minimally invasive Philos®-plate fixation after proximal humerus fractures between 2011 and 2014 were prospectively enrolled for CEUS, EMG and clinical testing. All participants accorded with the study protocol and gave their written informed consent prior to any study relevant intervention.

Patients were excluded if there was a history of recent myocardial infarction, cardiac insufficiency NYHA III and IV, uncontrollable hypertension, severe respiratory disease, galactosemia, known allergic reaction to SonoVue®, pregnancy resp. lactation, age under 18 years and impairment of the contralateral shoulder.

Surgical techniques

Surgery was performed by four trauma consultants at our hospital. Both ORIF and MIPO were performed in beach chair position. For the ORIF approach the skin was incised between the coracoid process and the deltopectoral groove over about 10 cm. Dissection of the deltopectoral interval medial of the cephalic vein and blunt preparation of the subdeltoid space were performed. The plate was positioned under direct visualization. For the MIPO approach, the skin was incised from the lateral tip of the acromion 5 cm distally parallel to the delta fibers. The deltoid muscle was bluntly dissected to approach the major tubercle and to protect the axillary nerve. The plate was inserted along the humeral shaft with the designated mounting device. Postoperative management was standardized and equal for both groups. Range of motion was enabled immediately and for 12 weeks axial stress was limited to a minimum.

Functional, psychosocial and radiologic evaluation

We assessed the range of motion (ROM) for both shoulders and used the following questionnaires to determine functional and psychosocial outcomes:

- the patients' outcome satisfaction which was classified on a discrete ordinal scale from 1 (very satisfied) to 5 points (not satisfied at all).
- Visual analogue scale (VAS; 0 [extreme pain] to 15 [no pain at all]).
- The normalized "Constant score (CS)" according to Angst et al. [31] with shoulder-specific objective and subjective criteria on a scale of 0–100 (with 100 representing the best function).
- The "American Shoulder and Elbow Surgeons (ASES) Society standardized shoulder assessment form" that focuses on the activities of daily living (ADL) on a scale of 0–100 (with 100 representing the best quality of ADL) [31].
- "Disabilities of the Arm, Shoulder and Hand (DASH)", that measures the symptoms and function of the upper extremity on a scale of 0–100 (with 100 being no function resp. maximal symptoms) [31,32]
- "Simple Shoulder Test (SST)" for assessment of the functional disability of the shoulder on a scale of 0–100 (with 100 representing the best function) [31].
- SF-12 questionnaire to determine both physical and mental health outcome on a scale of 0–100 (with 100 representing the highest level of health) [31].
- CS sub tests (activities of daily living, strength and pain) and SF-12 subtests (Physical and Mental Health Composite Score [PCS and MCS]) were evaluated as well.

X-rays were performed to rule out complications in fracture healing like avascular necrosis, material failure, screw perforation, malposition or non-union.

B-mode ultrasound and morphometry

All examinations were performed by the same consultant orthopedic and trauma surgeon with DEGUM (German society for ultrasound in medicine) level II qualification (CF). All examinations were performed under identical conditions on both shoulders, starting with the operated shoulder.

During the examination all participants of the study were sitting with their palms on their thighs and ultrasound of the deltoid muscle was performed at the transition between the posterior and lateral part of the muscle in the coronal plane with a linear probe (9L4 probe, 4–9 MHz, ACUSON S3000, Siemens Healthcare, Erlangen, Germany). As a standardized reference, the teres minor muscle and the surgical neck of the humerus were always visualized. We set the depth of field at 4 cm and performed three caliber measurements of the deltoid muscle in a perpendicular angle to its external fascia: at the proximal end, the middle and at the distal end of the cross-section to the teres minor muscle. The mean of these three measurements was calculated (mean deltoid muscle diameter). The teres minor diameter was measured in two perpendicular planes and the elliptic cross-sectional area was calculated.

CEUS examination

In cadence contrast specific mode, the mechanical index was individually adapted to optimize image quality (MI, 0.07–0.11) and the focus was placed below the deltoid muscle. The side-by-side dual view of cadence with B-mode was applied and the patients performed a specific exercise to activate the deltoid muscle by repeatedly abducting the arm up to 90° for two minutes with a 1 kg dumbbell. Immediately after exercise, a bolus of 2.4 ml SonoVue® (sulfur hexafluoride microbubbles with a phospholipid shell) (Bracco Imaging, Milan, Italy) was injected intravenously (right cubital vein, 20 gauge cannula) and flushed with 10 ml 0.9% saline solution (NaCl). A video clip of 90 s with a frame rate of 5 Hz was digitally recorded, starting with the injection of the contrast agent. The described settings comply with the most recent recommendations of the EFSUMB [33].