Surg Radiol Anat (2014) 36:705–711
DOI 10.1007/s00276-013-1240-z

ORIGINAL ARTICLE

# Arterial supply of the distal humerus

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Received: 18 April 2013 / Accepted: 18 November 2013 / Published online: 4 December 2013

**Abstract**
*Purpose* Distal humeral fractures are rare, but severe injuries, the treatment of which is often accompanied by serious complications and its outcome strongly depends on the quality of surgical therapy. Non-union is a common entity, compromising clinical results and requiring revision surgery. Osteonecrosis is an underestimated etiologic factor in the development of non-union. The present study aims to display the distribution patterns of the arterial vessels at the distal humerus, to correlate the displayed vessels with local nutrient foramina and to disclose an endangerment of these structures by common osteosynthetic implants.
*Methods* Eight plastinated fresh frozen upper extremities were digitally analyzed regarding the vascular density of the cancellous bone, by calculating the ratio of area comprised by arterial vessels and the area comprised by cancellous bone on sagittal cuts of the distal humerus. Possible differences in the vascular density of the medial epicondylar region, the lateral epicondylar region and a watershed area between the epicondyles and distal to the supracondylar region were investigated. On the basis of 200 macerated humeri, the distribution pattern of cortical nutrient foramina and their anatomic relation to properly applied common distal humerus plates were documented.
*Results* The data show a significantly higher density of vessels per cancellous bone in the epicondylar regions than in the watershed region ($p < 0.000$, median 0.148 vs. 0.103). The analysis of the nutrient foramina showed distinct distribution patterns with a single foramen over the medial epicondyle (55 specimens, 27.5 %) and an area of several foramina at the posterior part of the lateral epicondyle (200 of the specimens, 100 %). In almost every specimen, the application of the osteosynthetic implants led to an overlay over the investigated nutrient foramina.
*Discussion* Osteonecrosis and non-union are severe complications in the surgical treatment of distal humeral fractures. The biology of the bone, especially the blood supply, has to be respected as much as possible during open procedures, to optimize bony healing. This has to be considered when performing periosteal stripping or applying osteosynthetic plates over the postero-lateral and medial epicondyle. The watershed area of the distal humerus has to be considered as being prone to minor arterial blood supply and thereby non-union is possible, if the arterial vessels coming from the epicondyles are destroyed.

**Keywords** Distal humeral fracture · Blood supply · Nutrient foramina · Osteosynthetic implants · Osteonecrosis · Non-union · Watershed area

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Prof Koebke tragically deceased in February 2012.

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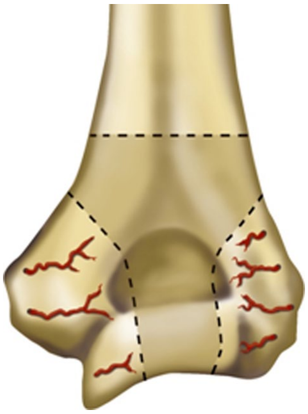

**Fig. 1** Watershed area (shown with *dotted outlines*) concerning the blood supply of the distal humerus

## Introduction

Double plating of the distal humerus for fracture treatment can be done in perpendicular (90° technique) or parallel fashion (180° technique) [14, 15]. Biomechanical studies showed advantages of the 180° technique regarding primary stability [1, 8, 19, 23]. Yet, the clinical outcomes of both fixation techniques are affected by severe complications, such as non-union and secondary dislocations [9, 10]. Moreover, the blood supply to the distal humerus is essential for fracture healing. It's impairment during trauma, surgical procedures, or by implant material has been considered causative for osteonecrosis [6].

Kimball et al. [6] summarized the Trochlea, Olecranon fossa and Coronoid fossa in an anatomic study concerning the blood supply of the distal humerus as a watershed area (Fig. 1), which might implicate consequences for fracture treatment.

The aim of the present study was to exhibit the arterial supply of the distal humerus in detail, and to point out differences between distinct anatomical areas. Furthermore, it was of interest, if a specific distribution pattern of nutrient foramina is present at the distal humerus, and if these foramina are overlaid by modern osteosynthetic plates for fracture treatment.

## Methods

### Analysis of the density of arterial vessels on the basis of plastinated specimens

Eight fresh frozen human cadaveric upper extremities without relevant pre-existing pathologies were collected from cadavers of 4 female and 2 male voluntary body donors (average age 80.5 years, 77–86). The blood vessels of these specimens were plastinated according to the sequential plastination technique [16]. The axillary artery was identified and to flush the specimens thoroughly with saline, a cannula was inserted. 2 % Formaldehyde was then instilled via gravity infusion. After such provisional fixation, the humeri were filled with epoxy resin (Acrifix190, viscosity 1,600–2,000 mPa.s at 20 °C) via the axillary artery by manual pressure at room temperature. The epoxy resin was mixed with red dye and lead oxide ($Pb_3O_4$) as a contrast agent. Due to a molecular-size of 60 $\mu$m, the fluid cannot leave the vessels and selectively fills the arteries. Following hardening of the epoxy resin, 7 specimens were cut with a diamond-wire saw (Well, Mannheim, Germany) in the sagittal plane, one in the transversal plane. In average, 14 cuts were made per humerus, giving a total of 98 (7 × 14) sagittal and 14 transversal plates of 3–4 mm thickness. These plates then were dehydrated and post-fixed at −25 °C in Acetone for a period of 2 months. Subsequently, degreasing was done at room temperature, in Acetone for 3 months as well. Finally, under vacuum-conditions impregnation with Biodur© was done for 10 h. Finally, the plates were polished to achieve optimal sight on the anatomic structures.

To display the density distribution of arterial vascular structures in the cancellous bone of the distal humerus, digital image analysis was used. The seven sagittally cut specimens were digitally photographed next to scale paper and the images were saved as.tif-images (1,600 × 900 res.). Image analysis software including measurement tools (Image-Pro Plus©; Version 6.0.0.260, MediaCybernetics Inc., MD, USA) was calibrated at hand of the scale paper on the photographs of the specimens. Using the measurements tool of the software a maximum of 4 cm of the distal humerus in proximo-distal direction was defined as region of interest for the analysis of the sagittally cut plates. The area comprised by cancellous bone in this region was digitally measured by manually defining the borders of the cancellous bone with the area measuring tool of the software, giving $A^{\mathrm{bone}}$. The software gives an area value, according to the calibration that has been done before. In Fig. 2b the distal 4 cm of the bony humerus has been digitally "cut out" of the image to show the measured area.

Then, the area comprised by the artificially stained arterial vessels running in that cancellous bone was measured, also by defining the outer borders of the stained vessels (Fig. 2c), giving $A^{\mathrm{vessel}}$. Vessels were measured down to a diameter of 0.1 mm per definition. Smaller vessels could not be included into the analysis due to insufficient accuracy when defining the borders. In Fig. 2b the vessels that were included into the measurements were also digitally cut out to display their individual area.

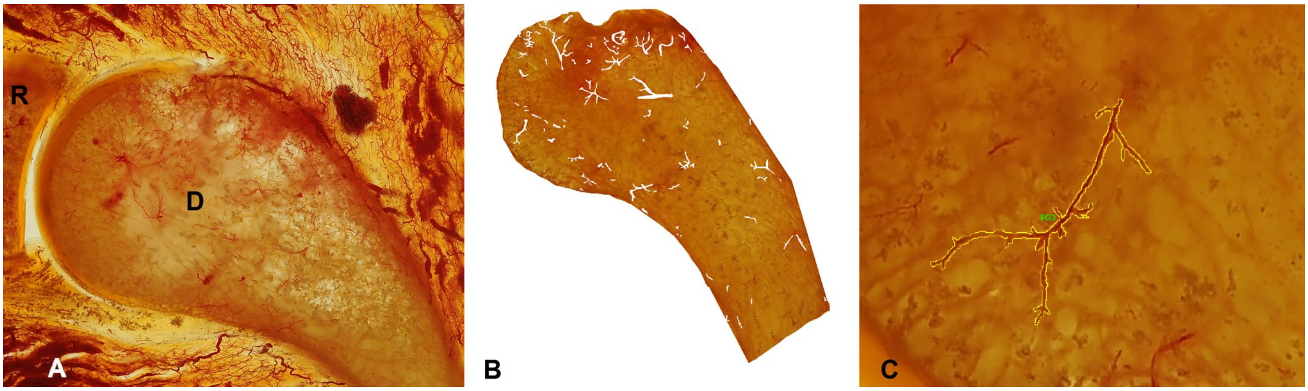

**Fig. 2** Digital image of a plastinated specimen of the distal humerus, at the level of the capitulum, e.g. the radial head. **a** Overview of distal humerus (*D*) and the radial head (*R*). **b** The region of interest has been digitally cut out of the original image. Also, and the arteries have been cut out. The computer software gives the cut area, so that the relation can be calculated. **c** Example for an arterial vessel with designated boundaries for area calculation

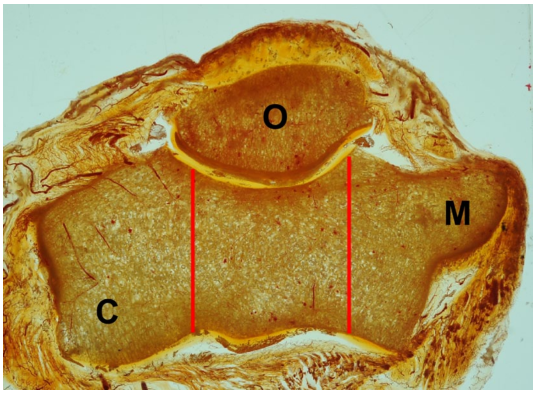

**Fig. 3** Presentation of the regional segmentation of the distal humerus in the medial, central and lateral area by splitting the maximum medio-lateral distance in thirds

With the two parameters the ratio of vessel-area per bone-area was calculated ($A^{\mathrm{vessel}}/A^{\mathrm{bone}}$) per each sagittal cut. The distal humerus was separated into three equal sized parts (each 33 % of the maximum medio-lateral diameter of the distal humerus, Fig. 3) to allow standardized analysis of the specimens. By distinguishing between medial, lateral and central sagittal cuts according to the anatomic regions of the specimens the ratio was determined for the medial and lateral column of the distal humerus, as well as for the aforementioned watershed area. Thereby, a potential difference in the density of arterial vessels per bone of the lateral and medial epicondyle and the watershed area should be pointed out. The watershed area according to Kimball et al. [6] is found at the distal humerus, as a t-shaped area starting at the central part of trochlea and capitulum, reaching proximally in the midline of the shaft and between the medial and lateral epicondylar region (Fig. 1).

### Analysis of the nutrient foramina of the distal humerus and correlation with the intraosseous run of the arterial vessels

On the basis of 200 macerated humeri, the nutrient foramina at the middle and distal humerus were analyzed. Constant distribution patterns of nutrient foramina at the distal humerus were in the center of interest. Therefore, foramina in the cortex were localized, counted and classified according to their size and in relation to the most lateral tip of the lateral epicondyle. Three categories of nutrient foramina were established according to their size, by the use of three puncture needles of different diameters. Large foramina took needles of at least 1.2 mm diameter. Medium ones took needles of at least 0.9 mm and small ones took needles of at least 0.4 mm. The distribution of the foramina was correlated with the intraosseous run of arterial vessels of the cancellous bone, meaning arterial vascular structures running within the cortical boundaries of the distal humerus. The potential interference of common osteosynthetic implants with the displayed foramina was demonstrated, by properly applying Medartis distal humerus osteosynthesis-plates (Medartis Aptus Distal Humeral Plates, Medartis AG, Basel, Switzerland) to the medial and postero-lateral epicondyle (Fig. 3).

### Statistical analysis of the data

The distribution of normality concerning the vascular density of the cancellous bone of the distal humerus was tested with the Kolmogorov–Smirnov-test and the Shapiro–Wilk-test. A statistical difference within the data between the epicondylar regions and the central, so-called watershed zone was displayed by using the Wilcoxon test. *p* values of <0.05 were set to be significant.

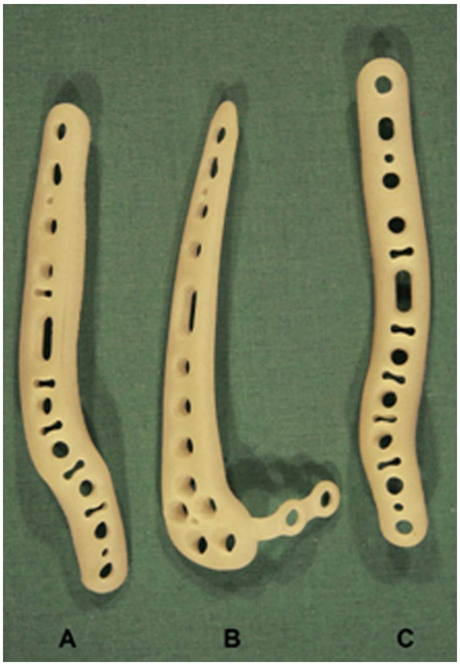

**Fig. 4** Illustration of the medartis lateral (**a**), postero-lateral (**b**) and medial (**c**) plates that were used to display a possible anatomic relation to the nutrient foramina at the distal humerus

## Results

### Analysis of the density of arterial vessels on the basis of plastinated specimens

The digital computing of the arterial vessel density in the cancellous bone showed a significantly higher density of arterial vessels in the cancellous bone in the medial and lateral epicondylar regions than in the so-called watershed area ($p < 0.000$, Fig. 4). No statistical significance was found between the medial and lateral epicondyle. The analysis of the intraosseous run showed arterial vessels entering the lateral epicondyles from posterior and then spreading out through the cancellous bone (Fig. 5). The vessels enter the lateral epicondyle from the posterior stem mostly of the recurrent interosseous artery arising distally, which itself stems from the ulnar artery via the common interosseous artery and the posterior interosseous artery. Few contributions represent branches of the posterior branch of the profound brachial artery, coming from proximal. No relevant contributions to the lateral epicondyle from anterior were found. The medial epicondyle showed vessels entering from anterior and posterior.

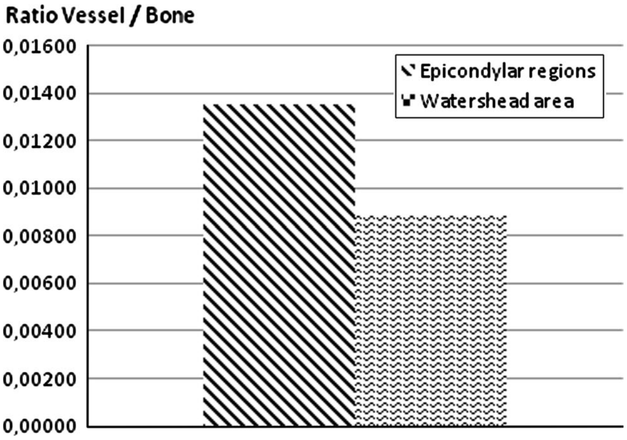

**Fig. 5** Density of arterial vessels at the distal humerus. Lowest density of vessels per bone was found in the watershed area

### Analysis of the nutrient foramina of the distal humerus and correlation with the intraosseous run of the arterial vessels

The analysis of the nutrient foramina at the distal humerus showed two areas with relatively constant areas featuring nutrient foramina. Such, in every one of the 200 analyzed macerated humeri, at the postero-lateral epicondyle an area with several nutrient foramina was found, which correlated with the findings in the sagittally cut plastinated specimens (Fig. 5). In average, 5.97 foramina per specimen were found at the posterior aspect of the lateral epicondyle. 11.9 % of these foramina were accounted for large, 45.9 % for medium and 42.3 for small diameter. Figure 6 illustrates the distribution pattern of the foramina at the posterior aspect of the lateral epicondyle. Moreover, in 27.5 % of the 200 specimens a nutrient foramen was found on the crest of the medial epicondyle, with a size of at least 0.4 mm in diameter. The average distance of the foramen of the lower edge of the medial epicondyle was 4.3 cm. No other constant distribution patterns of nutrient foramina were found.

In 100 % of the tested specimens, the distal part of the postero-lateral plate comes to rest over the aforementioned area with several nutrient foramina at the postero-lateral epicondyle (Fig. 7). The screw-holes lead the screws directly onto the nutrient foramina. Similar, the foramen over the medial epicondyle was in almost every specimen (76 %) found to be superimposed by the medial plate.

## Discussion

The arterial blood supply to the distal humerus is essential for fracture healing and by that for fracture treatment, also. In 1956, Laing et al. [11] showed that the arterial supply of the distal humerus relies on the central nutrient artery of the humeral shaft reaching down to the supracondylar region and on several nutrient arteries entering the epicondylar regions. They infused mercury in cadaveric human upper extremities

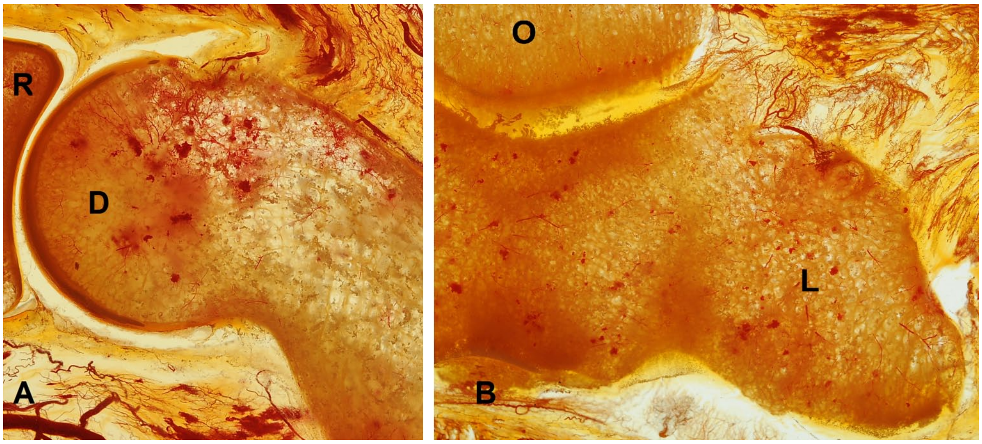

**Fig. 6** Arterial vessels entering the distal humerus at the postero-lateral epicondyle. **a** Sagittal cut, **b** transversal cut. (*R* radial head, *D* distal humerus, *O* olecranon, *L* lateral epicondyle)

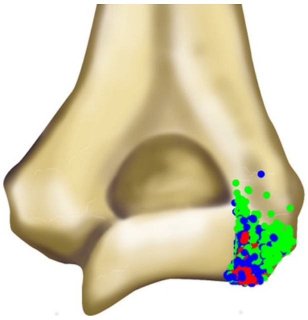

**Fig. 7** Graphical illustration of the distribution pattern of the nutrient foramina at the posterior aspect of the lateral epicondyle in 200 macerated humeral bones. *Green*: small foramina, *blue*: medium foramina, *red*: large foramina (color figure online)

to make the intra-osseous vascular anatomy visible on roentgenograms. They did not find a considerable amount of vascular supply to the epicondyles from anterior, especially not to the lateral epicondyle. Yet the authors found vascular contributions the posterior aspect of the epicondyles. Also in the 1950s, profound investigation of the vascular anatomy of the distal humerus has been done by Harraldson et al. [4]. The author too found distinct distribution patterns at the lateral epicondyle and the capitulum. Similarly, Kimball et al. [6] reported in 2007 that vascular contribution to the epicondyles is following a constant pattern. They exhibited with the aid of a modified Spalteholz technique the intraosseous vascular anatomy in 9 fresh frozen distal humeri, which were previously injected with India ink and Ward's blue latex solution. The authors displayed in particular the vascular supply of the epicondyles. It was found, that the medial epicondyle is supplied by vessels, which mainly enter from anterior and posterior. The lateral epicondyle instead was only found to be supplied by vessels entering from posterior.

Thus, summarizing the existing literature, the distal humerus is supplied with arterial blood mainly through a central nutrient artery stemming from the profound brachial artery, entering the humeral diaphysis through a characteristic nutrient foramen at the mid-shaft-level and then traveling towards the distal section of the humerus to reach the supracondylar region [2, 7]. The epicondyles on their part are fed by segmental arteries, stemming mainly from the posterior ulnar recurrent artery, the recurrent interosseous artery and the recurrent radial artery (Fig. 8). This distinct configuration of the intra- and extra-osseous vascular anatomy of the distal humerus leads to a watershed area at the Trochlea, Olecranon fossa and Coronoid fossa and the supracondylar region. Yamaguchi as well as Kimball et al. used that term in their anatomic studies [6, 22].

On the basis of the findings of the present study, we confirm that the arterial blood supply of the distal humerus is subjected to a distinct distribution pattern. The study shows that the epicondylar regions are endued by a significantly higher density of arterial vessels per cancellous bone, compared to the so-called watershed area. Also a constant pattern of nutrient foramina at the distal humerus was displayed, with a constant area of few to several foramina at the postero-lateral epicondyle and a relatively constant single foramen over the medial epicondyle. By means of their anatomic location, it is possible to correlate the foramina with arterial vessels, that are visualized on the sagittally and transversally cut plastinated specimens. It has been stated by several authors, that the nutrient foramina in human long bones follow constant distribution patterns and that they are crucial for the blood supply in fracture healing [2, 3, 7, 11, 13, 20]. Just one brand of osteosynthetic plates has been used to display the interference with the nutrient foramina and different designs of plates might show more or less interference. Still, the used plates feature slim

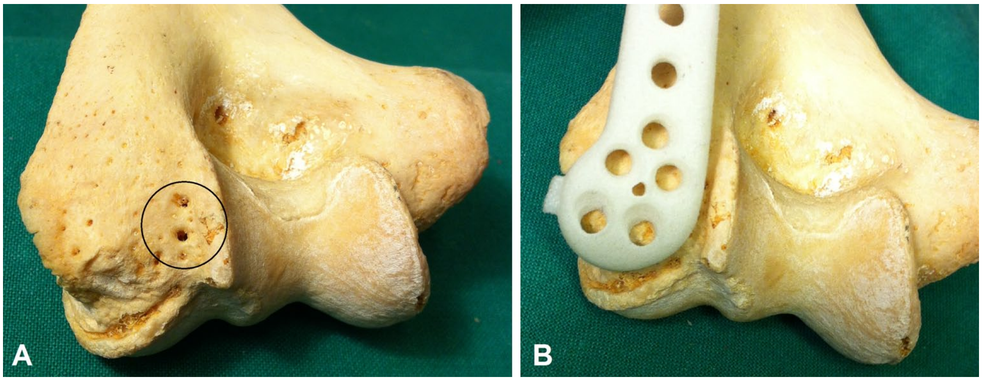

**Fig. 8** **a** The nutrient foramina at the postero-lateral aspect of the distal humerus are shown. **b** Demonstration of the superimposed area, after application of a postero-lateral plate

designs and thereby do not over represent possible overlap with the foramina and do not exaggerate a possible compromising effect.

As there is only little blood supply to watershed areas, this is prone to failure during bone healing. According to Laing et al., the vessels entering the epicondyles medially and laterally must be accounted as contributing factors to the overall blood supply of the distal humerus [11]. Carrol et al., as well as Joshi et al., conducted studies on the nutrient foramina of the humeral shaft [2, 5]. The authors stated that respecting the foramina during surgical interventions protects the arterial blood supply of the fracture fragments. It is reasonable to accept that fact for the nutrient foramina at the superior part of the medial epicondyle and at the posterior aspect of the lateral epicondyle in the same way. They serve as entrance points for arterial vessels, as it was seen on the plastinated specimens. In the situation of bicolumnar distal humeral fractures, however, the displayed tenuous system is endangered, as the central nutrient artery might get disrupted in the moment of trauma.Also, in fracture treatment periosteal stripping is necessary. Thereby breaching the epicondylar vessels and potentially impeding the epicondylar blood supply is necessary too. But not only periosteal stripping compromises the epicondylar vessels. According to the present study, the relevant paths of the blood supply can get hard-pressed by osteosynthetic implants. In the surgical treatment of distal humeral fractures, there are different ways to apply the osteosynthetic implants, as we mentioned at the start of the report. A superior method of treatment has not been depicted by clinical studies, yet. The studies performed so far, indicate a superiority of the parallel plating concerning primary stability, due to improved biomechanics [14, 19, 23]. In the course of perpendicular plating, the postero-lateral plate is placed onto the part of the distal humerus that, based on our findings, plays a role for the blood supply. It is not known, whether the application of osteosynthetic plates impedes vascular supply, nor it has been investigated by the present study. Still, it is reasonable to expect deterioration of the blood supply by plates compressing the tissue overlaying the epicondyle, or screws breaching through and into the bone, to fix the plates.

Wiggers et al. [21] stated in their report of 4 cases of osteonecrosis after surgical treatment of bicolumnar distal humeral fractures, that surgical dissection or even the application of osteosynthetic implants might be causative. They suppose limited awareness of osteonecrosis as a complication that leads to non-union. Non-union is a well-known complication in the treatment of complex fractures of the distal humerus and often leads to the need for reoperation. Its frequency is named with 5.4–32 % [12, 17, 18]. As discussed by Kimball et al. [6] in their study on the intraosseous vascular anatomy of the distal humerus, vascular insufficiency could represent an important contributing factor in the development of non-union.

In summary, the epicondylar vessels have to be respected during the surgical treatment of distal humeral fractures as much as possible. Summarizing the present data, only subtle stripping of the periosteum at the posterior aspect of the lateral epicondyle should be performed and if double plate osteosynthesis is performed with respect to the blood supply, preferably parallel plating should be done to spare the nutrient foramina of the entering vessels at the postero-lateral epicondyle. Still, it has not been investigated whether the rate of osteonecrosis differs between parallel and perpendicular plating. As the present study and the findings of similar works have shown, only few to none epicondylar vessels enter the lateral epicondyle from lateral. During dissection less endangerment of arterial vessels has to be expected at the lateral aspect of the lateral epicondyle than at the posterior aspect of the lateral epicondyle. Osteosynthetic implants should be designed not only according to physical constraints such as stability [8], but also the local anatomical and physiological context of the distal humerus such as the blood supply. This would probably request a redesign of the currently available materials, but it could on the other hand probably decrease the post-surgery complications such as osteonecrosis.

**Conflict of interest** The biomechanical laboratory of the Department of Trauma Surgery is supported by a yearly grant by the "Medartis" Company, but not specifically for this study. K.J.B. and L.P.M. did not and will not receive any financial benefit in any form. No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

## References

1. Arnander MW, Reeves A, MacLeod IA, Pinto TM, Khaleel A (2008) A biomechanical comparison of plate configuration in distal humerus fractures. J Orthop Trauma 22(5):332–336
2. Carroll SE (1963) A study of the nutrient foramina of the humeral diaphysis. J Bone Joint Surg Br 45:176–181
3. Crock HV (ed) (1996) An atlas of vascular anatomy of the skeleton and spinal cord. Taylor and Francis Ltd, London
4. Haraldsson S (1957) The intra-osseous vasculature of the distal end of the humerus with special reference to capitulum; preliminary communication. Acta Orthop Scand 27(2):81–93
5. Joshi H, Doshi B, Malukar O (2011) A study of the nutrient foramina of the humeral diaphysis. Nat J Integrat Res Med 2(2):14–17
6. Kimball JP, Glowczewskie F, Wright TW (2007) Intraosseous blood supply to the distal humerus. J Hand Surg Am 32(5):642–646
7. Kizilkanat E, Boyan N, Ozsahin ET, Soames R, Oguz O (2007) Location, number and clinical significance of nutrient foramina in human long bones. Ann Anat 189(1):87–95
8. Korner J, Diederichs G, Arzdorf M, Lill H, Josten C, Schneider E et al (2004) A biomechanical evaluation of methods of distal humerus fracture fixation using locking compression plates versus conventional reconstruction plates. J Orthop Trauma 18(5):286–293
9. Korner J, Lill H, Muller LP, Hessmann M, Kopf K, Goldhahn J et al (2005) Distal humerus fractures in elderly patients: results after open reduction and internal fixation. Osteoporos Int 16(Suppl 2):S73–S79
10. Kundel K, Braun W, Wieberneit J, Ruter A (1996) Intraarticular distal humerus fractures. Factors affecting functional outcome. Clin Orthop Relat Res 332:200–208
11. Laing PG (1956) The arterial supply of the adult humerus. J Bone Joint Surg Am 38(5):1105–1116
12. Lob G, Burri C, Feil J (1984) Operative treatment of distal intra-articular humerus fractures; results of 412 follow-up cases (AO-collected statistics). Langenbecks Arch Chir 364:359–361
13. Murlimanju BV, Prashanth KU, Prabhu LV, Saralaya VV, Pai MM, Rai R (2011) Morphological and topographical anatomy of nutrient foramina in human upper limb long bones and their surgical importance. Rom J Morphol Embryol 52(3):859–862
14. O'Driscoll SW (2005) Optimizing stability in distal humeral fracture fixation. J Shoulder Elbow Surg 14((1 Suppl S)):S186–S194
15. O'Driscoll SW (2009) Parallel plate fixation of bicolumn distal humeral fractures. Instr Course Lect 58:521–528
16. Rath B, Notermans HP, Franzen J, Knifka J, Walpert J, Frank D et al (2009) The microvascular anatomy of the metatarsal bones: a plastination study. Surg Radiol Anat 31(4):271–277
17. Rubberdt A, Surke C, Fuchs T, Frerichmann U, Matuszewski L, Vieth V et al (2008) Preformed plate-fixation system for type AO 13C3 distal humerus fractures: clinical experiences and treatment results taking access into account. Unfallchirurg 111(5):308–322
18. Sodergard J, Sandelin J, Bostman O (1992) Mechanical failures of internal fixation in T and Y fractures of the distal humerus. J Trauma 33(5):687–690
19. Stoffel K, Cunneen S, Morgan R, Nicholls R, Stachowiak G (2008) Comparative stability of perpendicular versus parallel double-locking plating systems in osteoporotic comminuted distal humerus fractures. J Orthop Res 26(6):778–784
20. Tien YC, Chen JC, Fu YC, Chih TT, Huang PJ, Wang GJ (2006) Supracondylar dome osteotomy for cubitus valgus deformity associated with a lateral condylar nonunion in children. Surgical technique. J Bone Joint Surg Am 88(Suppl 1 Pt 2):191–201
21. Wiggers JK, Ring D (2011) Osteonecrosis after open reduction and internal fixation of a bicolumnar fracture of the distal humerus: a report of four cases. J Hand Surg Am 36(1):89–93
22. Yamaguchi K, Sweet FA, Bindra R, Morrey BF, Gelberman RH (1997) The extraosseous and intraosseous arterial anatomy of the adult elbow. J Bone Joint Surg Am 79(11):1653–1662
23. Zalavras CG, Vercillo MT, Jun BJ, Otarodifard K, Itamura JM, Lee TQ (2011) Biomechanical evaluation of parallel versus orthogonal plate fixation of intra-articular distal humerus fractures. J Shoulder Elbow Surg 20(1):12–20