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RESEARCH ARTICLE

Minimal invasive plating of distal radius fractures. A safe procedure?

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ABSTRACT

Background: Minimal invasive plate osteosynthesis (MIPO) with preservation of the pronator quadratus (PQ) muscle represents a new technique for stabilization of distal radius fractures. However, the complex anatomy of the distal radius metaphysis requires implants with features that address all morphologic specifics of this area to avoid complications, which are still reported with this technique. It was the aim of our anatomic investigation to evaluate the feasibility of plate insertion via a minimal transverse approach as well as the risk of soft- tissues compromise with the use of an implant, which is only partially adapted to the characteristics of distal radius metaphysis.
Methods: Twenty forearm specimens, conservated with Thiels method, have been used for this study. The majority (n = 19/20) of implants (2.4 mm small fragment juxta-articular locking compression/ LCP T-plate -5-hole; Depuy - Synthes®, Solothurn, Switzerland) could be inserted easily and all were seated proximal to the so called "watershed line" (n = 20/20).
Results: In a total of 8/20 specimens close contacts or potential compromise to neighboring soft- tissues was seen: perforation of the PQ muscle by the plate occurred in 2/20 specimens and was related to an extreme muscle morphology. In 7/20 specimens close contacts between the T-plate and other soft tissues were observed, which were exclusively located at the radial edge of the distal transverse bar. They affected the brachio-radialis tendon (elevation: 2/20, side-to-side contact: 3/20, overriding: 1/20) and the radial artery (elevation: 4/20, side-to-side contact: 2/20, overriding: 1/20). No significant differences of morphologic types of PQ muscle and the difficulty of plate insertion, adjustment on the bone, PQ muscle damage and contact to neighboring soft-tissues could be evaluated.
Conclusions: Insertion of volar radius plates through a MIPO approach can be easily accomplished without detachment and damage to the PQ muscle even with grossly adapted implants. However, perfectly pre-shaped plates which are adapted to all anatomic aspects of the distal radius metaphysis are required to achieve optimal contact with the metaphyseal bone and to avoid potential complications.

1. Introduction

Surgical stabilization of unstable radius fractures represents the current gold standard of treatment and is mainly achieved by plate osteosynthesis. The development of plates with angular stability enabled the use of a volar approach even for extension type fractures and became the standard technique for plating of distal radius fractures during the last decade (Orbay, 2005). Though it offers better soft-tissue coverage of the implant and less irritation of adjacent anatomical structures (Orbay, 2005), implant related complications have also been reported in up to 17.5% of the cases (Arora et al., 2007; Bentohami et al., 2014). The classic volar technique requires the pronator quadratus (PQ) muscle to be detached by default. On the other hand, the avoidance of implant related complications is dependent on the repair of the PQ muscle, as well as on the positioning of the implant on the distal metaphysis (Ahsan and Yao, 2012). However, the repair of PQ may be challenging in poor muscle mass or quality (Ahsan and Yao, 2012) and thus techniques have been developed to preserve the muscle tissues without detachment (Lo and Cheng, 2014). Additionally, various techniques of minimal invasive plate osteosynthesis (MIPO) have been generated for the

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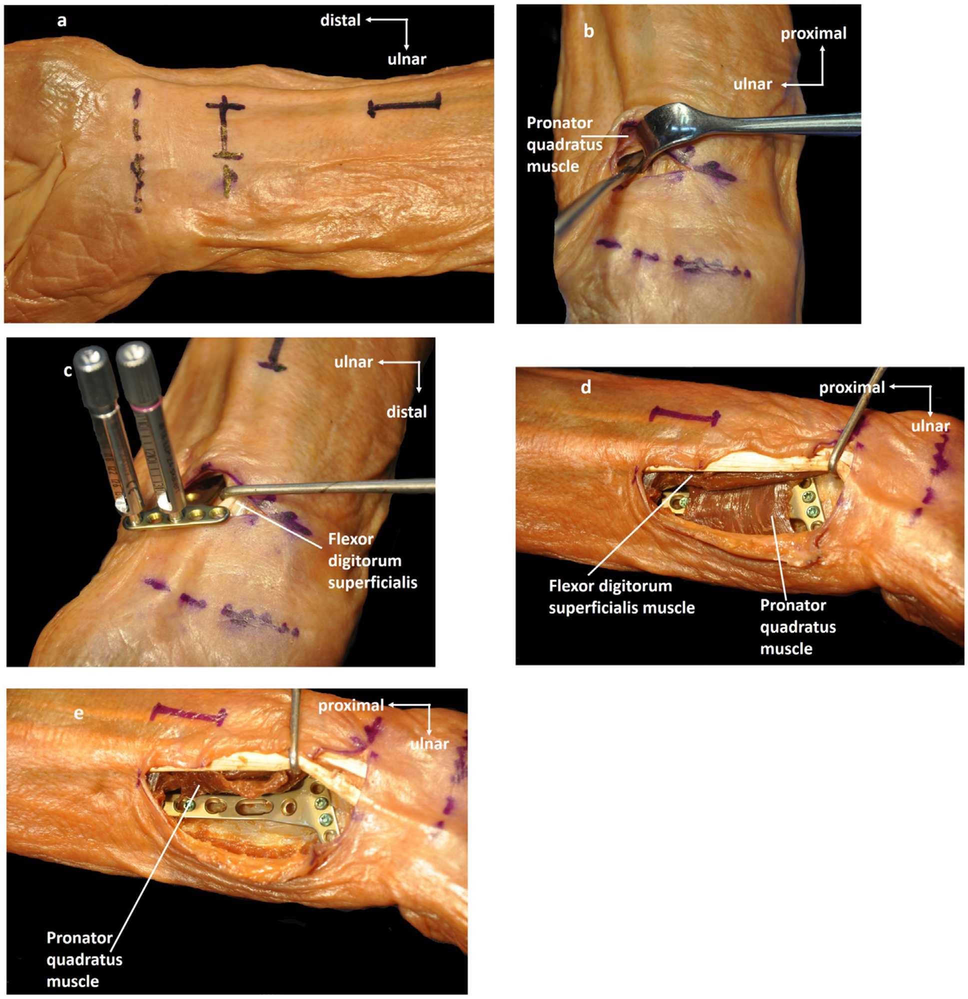

Fig. 1. Experimental set-up: (a) skin incisions (2 cm each) in a distance of 4 cm, the distal incision with transverse orientation; (b) after dissection of the submuscular space using an elevator (c) a 5-hole JA T-plate is inserted under the preserved PQ via the transverse incision; (d) situs of the PQ muscle with inserted T-plate; (e) after detachment of the muscle the alignment in relation to the bone is evaluated.

distal radius to preserve soft-tissues and vascularity as well as to obtain an improved cosmetic outcome (Imatani et al., 2005; Lebailly et al., 2014; Sen et al., 2008; Takada et al., 2012; Wei et al., 2014; Zenke et al., 2011). However, even preservation of the PQ muscle as well as MIPO techniques (Wei et al., 2014) cannot absolutely prevent complications in volar plating of distal radius fractures.

On the other hand, the surgical anatomy of the distal radius has been revised during the last decade and formed the basis of new requirements and plate designs for this area (Imatani and Akita, 2017; Orbay, 2005; Pichler et al., 2008).

Anatomic studies addressing MIPO techniques with preservation of the pronator muscle are infrequently found in literature (Takada and Otsuka, 2011; Zemirline et al., 2014) and mainly focus on PQ muscle damage. Therefore, it was the aim of our study to investigate volar MIPO techniques of the distal radius in respect of potential interference with neighboring soft – tissues and the impact of implant designs on potential soft tissue compromise.

2. Material and methods

2.1. Specimens

Twenty Thiel-embalmed specimens of the upper extremity were used for dissection and came from bodies donated to science to the Department of Anatomy of the Medical University Graz under the approval of the Anatomical Donation Program of the University of Graz (Thiel, 2002). This unique embalming procedure preserves tissue color and consistency (Benkhadra et al., 2009). The limbs represented 12 right side versus eight left side specimens and the donators comprised had an age of 77.3 years on average (63–91 years). Prior injuries to the forearm bones or hand skeleton, as well as entities affecting bones and soft tissues were excluded by medical history and image investigation of the specimens with a C-arm intensifier before dissection.

2.2. Surgical technique

Two incisions – 2 cm each – were created in a distance of 4 cm to each other. The distal one was situated 2 cm proximal to the proximal wrist crease in a transverse direction, while the proximal incision was performed longitudinally in line of the flexor carpi radialis tendon (FCR) (s. Fig.1a). After dissection of the soft tissues first the distal fascia attachment of the pronator quadratus (PQ) was incised and an elevator introduced beneath the muscle belly without detachment of the PQ (s. Fig.1b). Then a 2.4 mm small fragment juxta-articular locking compression (LCP) T-plate -5-hole (Depuy - Synthes®, Solothurn, Switzerland) was inserted through the distal incision and sled in proximally underneath the PQ muscle belly (s. Fig.1c); up to two placement attempts were considered as an “easy insertion”. The selected implant represents a T-plate which is spe-

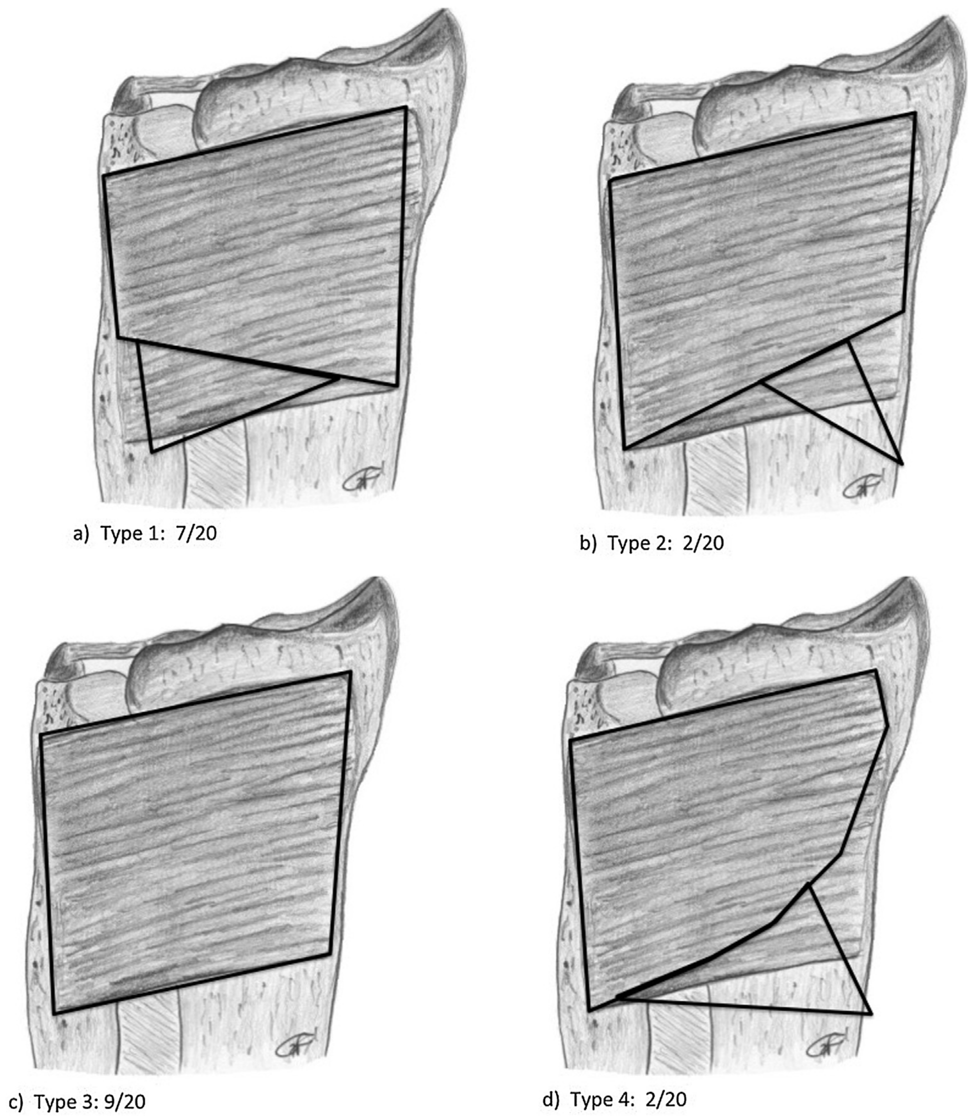

Fig. 2. Stuart classification of PQ muscle types and their distribution (bracketts) in the evaluated specimens (n = 20).

cially designed to address small articular fragments and provide the option to place the implant quite distally (Lee et al., 2018). Due to primary exclusion of any deformed fore-arm bones all specimens revealed a perfect volar surface of the distal radius metaphysis resembling a perfect temporary reduction achieved by K-wires, for instance. Thus, difficulties during implant insertion could be solely attributed to soft tissues conditions or a poor surgical technique. After insertion the plate was adjusted through the proximal incision under image intensifier control and fixed with locking head screws in the distal metaphysis and the radius shaft following the recommendations of Soong et al. (2011).

2.3. Measurements

When fixation of the plate had been accomplished, both minimal skin incisions were connected to create a wide approach for careful assessment (s. Fig.1d). The PQ belly was exposed and the morphologic parameters were evaluated according to the *Stuart* classification (Stuart, 1996) (s. Fig. 2). Any eventual local damage to the adjacent soft tissues by the plate was checked and recorded. The overall length of the PQ was measured on the radial and ulnar side of the muscle as well as the width on the distal and proximal edge with the use of a vernier calliper. The distance of the distal PQ margin to the most distal edge of the radius was measured in line of the scaphoid and the lunate fossa, respectively (s. Fig.3). Thereafter, the muscle belly was detached from the metaphyeal bone for work-up of the plate and the adjustment in relation to the radius shaft axis and the watershed line (s. Fig. 1e).

2.4. Statistical methods

Data were screened for consistency. Pearson's Chi-Square, Jonckheere Tepstra, linear by linear and Barnard's test for superiority were used to analyze cross-tabulation tables based on Monte Carlo methods. Two-sided, independent t-tests were used to compare means in several groups. Data were analyzed for normality and were tested for variance homogeneity by using the F-test. 95% confidence intervals were used to estimate differences of means. Data were analyzed by using STATISTICA 12 (Hill, T. & Lewicki, P. Statistics: Methods and Applications. StatSoft, Tulsa, OK) and StatXact 10 (Cytel Software 2013, Cambridge MA, USA) and were done by one of the authors (WH).

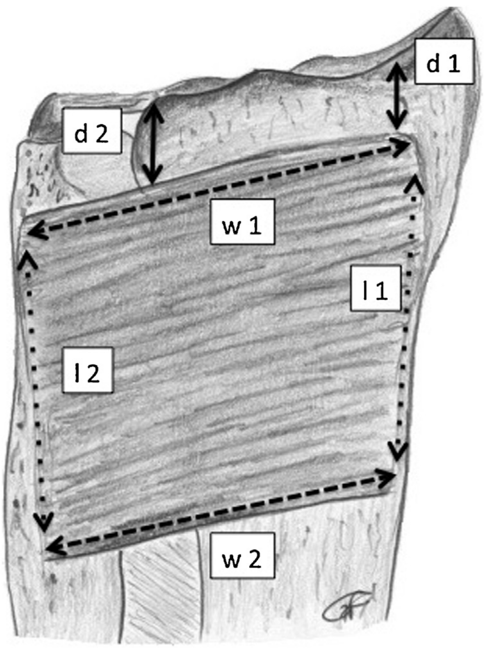

Fig. 3. Measurements performed on PQ muscle; d1: distance distal PQ edge to scaphoid fossa, d2: distance distal PQ edge to lunate fossa; w1: width distal PQ edge, w2: width proximal PQ edge; l1: radial PQ length, l2: ulnar PQ length.

Table 1
Measurements of the PQ muscle (lengths, widths, distances).

	Average (mm)	Min. (mm)	Max. (mm)	Stdev. (mm)
PQ width distal (w 1)	36.8	28	44	4.25
PQ width proximal (w 2)	35.3	24	45	6.00
PQ length radial (l 1)	36.2	24	52	6.74
PQ length ulnar (l 2)	38.8	31	60	6.47
Distance scaphoid fossa (d1)	11.2	7	17	2.69
Distance fossa lunata (d2)	9.8	5	14	2.57

3. Results

Morphology of the PQ muscle according to the classification system of *Stuart* represented most often type III (n = 9/20), followed by type I (n = 7/20) and type II or IV, respectively (n = 2/20) (s. Fig. 2). The main source for blood supply for the muscle was most often (n = 19/20) provided by the anterior interosseous artery and in only 1/20 specimen by the radial artery. Radial length of the PQ muscle (l 1) was 36.2 mm (range: 24 mm–52 mm) on average and ulnar length (l 2) was 38.8 mm (range: 31 mm–60 mm) on average. The distal width of PQ (w 1) was 36.8 mm (range: 28 mm–44 mm) and the proximal PQ width (w 2) was 35.3 mm (range: 24 mm–45 mm) on average. The distance between the distal edge of the PQ muscle and the joint in line of the scaphoid fossa (d 1) was 11.2 mm (range: 7 mm–17 mm) on average and 9.8 mm (range: 5 mm–14 mm) in line of the lunate fossa (s. Table 1).

Plate insertion via the distal incision was considered difficult in 1/20 specimen (3 insertion attempts) with an extremely thick PQ muscle belly, which also contributed to PQ tissue damage. Another damage to PQ occurred in an extremely thin muscle substance favouring perforation near the proximal edge; in this specimen the insertion was not considered to be difficult. All implants (20/20) were placed proximally to the volar distal ridge of the radius, the so called "watershed line" and revealed close-fitting contact to the underlying bone, except one implant with poor alignment to the shaft axis due to poor technique.

Table 2
Contacts/lesions between implants and neighboring soft tissues observed in 8/20 specimens with MIPO plating of the distal radius (multiple nominations possible).

	RA	BR - T	PQ –M
Elevation	4	2	
Side-to-side contact	2	3	
Overriding/compression	1	1	
Perforation			2
	7	**6**	**2**

PQ-M: pronator quadratus muscle, RA: radial artery, BR: brachioradialis muscle.

Overall, potential conflict between the implant and surrounding soft tissues was seen in 8/20 specimens, including 2/20 perforations of the PQ muscle belly itself (s. Table 2). Except for PQ muscle compromise contacts between the implant and soft tissues were observed in 7/20 specimens. In relation to the T-plate they were exclusively seen at the radial edge of the transverse bar and affected the radial artery and /or the brachioradial tendon (BR) which were most often elevated (s. Fig. 4).

No significant differences for *Stuart* PQ muscle types and difficulty of plate insertion, plate adjustment onto the bone, damage to the muscle belly, contacts /lesions to the local tendons and radial vascular bundle could be evaluated. Also all other morphologic characteristics of the PQ muscle (width, length, distance to scaphoid or lunate fossa) revealed no significant differences for the above mentioned parameters.

4. Discussion

The pronator quadratus (PQ) muscle is located on the volar surface of the distal forearm and consists of a superficial and a deep muscle head in various configurations (Stuart, 1996). It represents the most important pronator of the forearm and the deep head is an important stabilizer of the distal radio-ulnar joint (DRUJ). Moreover, this muscle provides good coverage for a volar locking plate which is the current standard fixation method in unstable distal radius fractures (Orbay and Touhami, 2006). It offers adequate stability, coverage by adjacent soft tissues and no compromise of the blood supply of dorsal comminution zones in extension type fractures (Orbay, 2005).

In the classic technique the distal radius can be addressed volarily either by a Henry approach through the sheath of the FCR (flexor carpi radialis) tendon or by an extended variant including a release of brachioradialis'(BR) distal insertion (Orbay and Touhami, 2006). Both options require detachment of the PQ muscle from the metaphyseal bone by default to address the fracture and the plate site. Refixation of the detached muscle after accomplished osteosynthesis can be difficult. Though refixation of the released PQ muscle is discussed controversely by some authors (Hershman et al., 2013) it plays for us an important role in the avoidance of complications independently on the quality of repair (Ahsan and Yao, 2012), as complications reported with volar locking plates are most often related to soft-tissue compromise or fracture redislocation (Arora et al., 2007; Bentohami et al., 2014; Rampoldi and Marsico, 2007). Thus, surgical techniques with preservation of the PQ muscle were developed in minimal invasive plate osteosynthesis (MIPO) (Orbay et al., 2005; Sen et al., 2008) as well as in open procedures (Lo and Cheng, 2014; Zenke et al., 2011) and achieved good results. In MIPO techniques additional reduction of soft tissue trauma and improved cosmetic results were expected independently on the use of one or two short skin incisions of different lengths and directions (Imatani et al., 2005; Lebailly et al., 2014; Sen et al., 2008; Takada et al., 2012; Zenke et al., 2011). Most actually a transverse distal incision has been discussed (Wei et al., 2014; Zenke et al., 2011) and was used in our study set-up without drawing any conclusions about the cosmetic advantages.

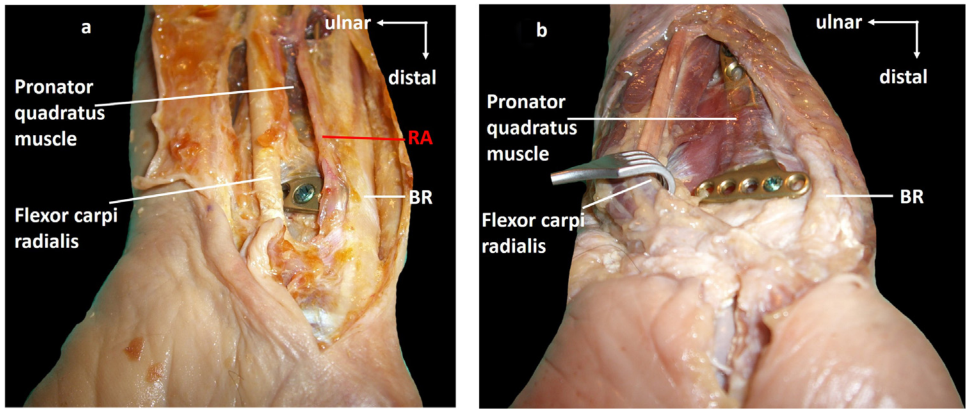

Fig. 4. (a) radial artery (RA) elevated by the transverse bar of the implant causing kinking of the vessel; (b) brachioradialis tendon (BR) in close contact with the radial edge of the transverse bar of the JA T-plate causing deviation.

Our investigation grossly supports clinical experience that the insertion of volar plates under a mobilized PQ muscle is easily accomplished through a minimal incision and only muscles of exceptional size are prone to potential damage. Heidari et al. (2012) reported that the PQ can be mobilized without detachment by 13.1 mm on average which reveals enough volar exposure for plate osteosynthesis. However, complications are also reported with preservation of PQ muscle and in minimal invasive procedures (Chiu et al., 2013; Lebailly et al., 2014; Wei et al., 2014). Thus, it seems reasonable that only optimal congruence of the volar radius metaphysis with a pre-shaped implant can avoid irridations. Buzzell et al. (2008) compared seven widely used types of volar locking plates and found small point contacts with the bone surface in all implant types (between 3% and 6%). He attributed this mainly to the difficulties to reproduce the complex anatomy of the volar side of the distal radius. Knowledge on this topic improved dramatically during the last decade and revealed relevant data for surgical practice (Imatani and Akita, 2017; McCann et al., 2012; Obert et al., 2012; Windisch et al., 2007). The volar metaphysis of the distal radius is not a flat area, but consists of various tubercles and ridges (Orbay and Touhami, 2006; Windisch et al., 2007) as well as multidirectional curvatures (Oura et al., 2015; Pichler et al., 2008). To avoid irridation of soft tissues, especially the flexor tendons, anatomically pre-shaped plates must fit closely to the complex distal radius anatomy and must not protrude over the so called *"watershed"* line (McCann et al., 2012). Orbay and Touhami (2006) reported in 2005 for the first time this important structure which represents a transverse ridge limiting the volar plane of the radius metaphysis distally. Morphologically it is not only a simple line but consists – at least in the ulnar half – of two lines, which merge into a single one radially (s. Fig. 5) (Imatani and Akita, 2017). Within the ulnar half of the watershed line the distal PQ muscle edge lies proximal to it while the radial half of the line is overlapped by the muscle (Orbay, 2005) (Imatani and Akita, 2017). The watershed line also contains two prominences first reported by Imatani and Akita (2017) in an investigation of 20 specimens — a smaller radial one and a larger ulnar one. Moreover, the volar surface of the distal radius metaphysis reveals not only a single curvature in the sagittal plane, but also another one in the axial plane. Oura et al. (2015) proved this "transverse concavity" in a clinical study based on 3D-CT scan cross sections of the distal radius in 70 normal patients. Pichler et al. (2008) verified that the circular curvature of the radial volar groove is assymetrical and flattens in 37% towards the ulnar side and in 63% towards the radial side. The authors conclude that a discrepancy between volar plates and bony surface may contribute to malrotation of distal fracture fragments or may lead to flexor tendon irridations by the implant (Pichler et al., 2008). Thus, authors emphasize that the great variability of the distal radius requires perfectly pre-shaped anatomical plates, which respect all aspects of the complex morphology to provide adequate stability to avoid complications (Oura et al., 2015; Windisch et al., 2007).

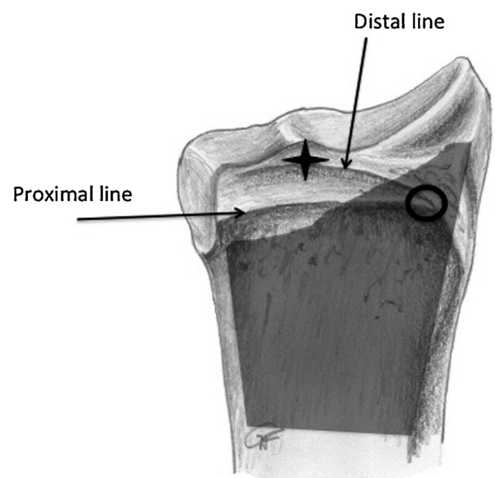

Fig. 5. New concept of the so called "watershed –line", which is formed of a distal and proximal rim according to (Imatani and Akita, 2017); note an ulnar (asterix) and radial (circle) protuberance as well as the area covered by the PQ muscle (shadow).

Our data demonstrate that MIPO provides good alignment of the implant along the radius shaft and along the sagittal curvature of the distal radius. However, a potential conflict with surrounding soft tissues is inherent when implants are used with a flat cross section which respect only the sagittal curvature. Thus, all of our inserted plates fit well proximal to the watershed line but more than one third of these implants, revealed a close contact between the radial edge of the transverse bar and the BR tendon and /or the radial artery (RA). Neuro-vascular copromise occurs infrequently in volar plating of the radius, but has been reported in the literature (Rampoldi and Marsico, 2007). Based on the investigation of McCann et al. (2012), who demonstrated in a cadaver study of Henry approach the small distance between the FCR tendon and the RA yields only 8.9 mm and between the FCR and BR 13.3 mm on an average, potential soft-tissue compromise cannot be ignored. To us, the miss-match between the flat cross section of the implant and the axial curvature of the radius metaphysis (Obert et al., 2015; Pichler et al., 2008) promotes an overriding of the implant at the distal radial edge causing elevation or impingement of neighboring soft tissues. This should be avoided at all costs to prevent wrist pain, flexor tendon irridation and, as far as the RA is affected, arterial kinking or stenosis. Probably, the special design of the used plate for quite a distal placement intensifies the potential conflict with neighboring soft tissues. None of the soft tissue contacts in our investigation were detected during implant insertion (Zenke et al., 2011) which could be attributed to the restricted view of a minimal invasive approach.

Damage to the PQ muscle in our study was rare and related to extreme muscle morphology. We consider PQ damage closely related to the applied surgical technique. Zemirline et al. (2014) evaluated MIPO of the distal radius in a cadaveric study using a single mini-incision of 15 mm and an anatomically pre-shaped plate which perfectly respects the anatomy of the distal radius in all planes. He saw no compromise of adjacent soft tissues but on the other hand he reported compromise to the PQ muscle in more than half of his specimens as he used the plate itself as a reduction tool. In this technique the pre-shaped plate is primarily fixed to the distal fragment and then the radius shaft is adjusted to the anatomically pre-shaped implant with insertion of a cortical shaft-screw. However, with this technique the initial distance between the proximal implant edge and bone exceeds a distance (>12.2 mm) at which damage to the undetached PQ tissue occurs (Takada and Otsuka, 2011). In contrast we saw PQ damage in our series only in specimens with extreme muscle morphology. This would favor primary reduction and temporary K-wire fixation of the distal radius in MIPO procedures instead of using the implant as a reduction tool (Takada et al., 2012). Similarly, Lebailly et al. (2014) reported in the largest investigated MIPO collective plate specific complications in 9%, but no PQ muscle damage with primary reduction and K-wire fixation followed by plate insertion. To us temporary K-wire fixation provides a reliable intra-operative stability for an easy application of palmar plates (Huang et al., 2017). The achieved stability in certain fracture forms is even comparable to volar locking plates in respect to radiographic anatomy and functional outcome (Chaudhry et al., 2015; Costa et al., 2014; Geller et al., 2009).

5. Conclusions

Our study offers some limitations as it was performed on cadavers and not in living patients and the surface of the distal radius in our specimens was intact as no metaphyseal fracture was created in the study set-up. However, we believe that our set-up resembles well the situs of a sound-reduced distal radius fracture after temporary K-wire fixation.

Our data indicate that in the majority of cases anatomically pre-shaped plates can be easily inserted and aligned along the distal radius shaft with the use of a MIPO insertion technique and without detachment of the PQ muscle. However, care should be taken in implants which do not address all aspects of the complex anatomy of the distal radius metaphysis, especially the axial curvature. This can lead to potential soft-tissue compromise, which was seen in our study in one third of T-plates and exclusively on the radial edge of the transverse bar. On the other hand, damage to the PQ muscle seems to be related to extreme morphology and the applied surgical technique.

Ethical statement

The study was approved by the local Ethic Committee.

CRediT authorship contribution statement

T. Neubauer: Conceptualization, Writing - original draft. **M. Plecko:** Conceptualization, Investigation. **S. Grechenig:** Project administration. **A. Hartmann:** Investigation. **R. Ortmaier:** Conceptualization, Investigation. **W. Hitzl:** Formal analysis. **G. Feigl:** Writing - review & editing.

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