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HANDSURGERY

Anatomical fit of seven different palmar distal radius plates

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Abstract
Introduction The purpose of this study was to compare the anatomical fit of different, precontoured palmar distal radius plates.
Methods The anatomical fit of seven different types of palmar distal radius plates [Königsee variable fixed-angle radius plate 7/3-hole, Königsee variable fixed-angle radius plate 5/3-hole (Allendorf, Germany), Medartis 2.5 Adaptive TriLock, Medartis 2.5 TriLock, Medartis 2.5 TriLock extraarticular, (Basel, Switzerland), Synthes VA-LCP distal two-column-radius, Synthes LCP extraarticular (Bettlach, Switzerland)] were investigated in 25 embalmed human cadaveric radii. An imprint of the space between the well-positioned plate and the distal radius was attained using a silicone mass and the maximum height of the silicone imprint was digitally measured. The mean maximum imprint height was compared between the seven plates using an analysis of variance with repeated measures and Bonferroni correction for multiple comparisons.
Results The mean maximum distance between the plates and the radial cortex was <2 mm for all plates. The greatest difference was found with the Medartis Adaptive (1.99 $\pm$ 0.45 mm) and the least difference with the Synthes two-column (1.56 $\pm$ 0.76 mm), this difference being statistically significant ($p = 0.005$).
Conclusion Although there was no complete congruency between the plates and the radial cortex, all distal palmar radius plates investigated in this study presented a reasonable anatomical shape. The Synthes VA-LCP distal two-column-radius plate palmar showed the best anatomical fit. A low profile and optimized anatomical precontouring minimizes irritation of the surrounding soft tissues and should be considered with plate design and implant choice.

Keywords Anatomical fit · Radius fracture · Palmar plate · Distal radius · Anatomical precontouring

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Introduction

Over the last decade, the incidence of distal radius fractures may have changed, but distal radius fractures are one of the most common types of fractures [1].

Unstable AO type A3, B, and C fractures often require open reduction and internal fixation (ORIF). Nowadays, limited contact internal locking plates are considered as gold standard in these types of fractures [2, 3]. If treated properly, the majority of cases heal completely, but if malunion occurred corrective osteotomies represented a useful treatment option, whether in failed conservative or operative (internal fixation) cases. According to Gradl et al., clinical and radiological outcomes after corrective osteotomy for malunions following failed internal fixation are comparable with those reported after initial non-operative treatment [4]. Numerous plates have been developed during the past decade, providing precontoured implants in various sizes and with various designs including shape and

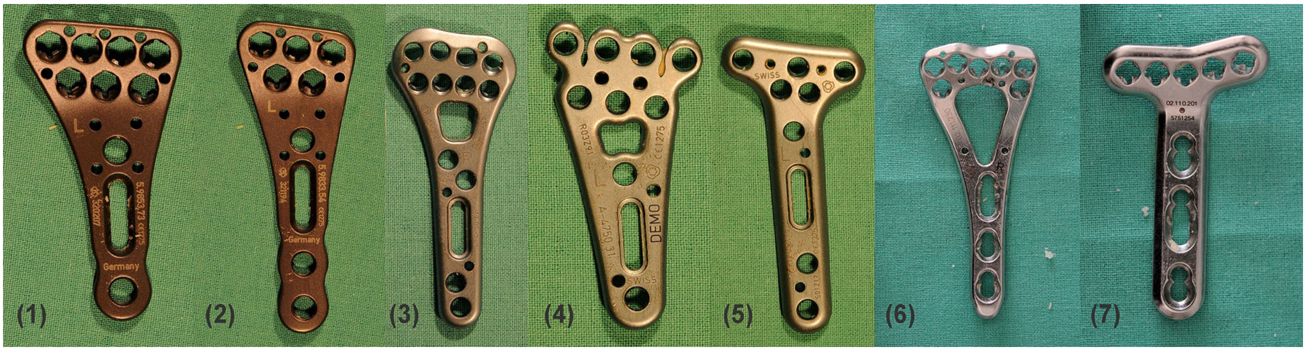

Fig. 1 The seven plates from left to right: (*1*) 51.0-mm Königsee variable radial plate 7/3 holes, (*2*) 51.0-mm Königsee radial plate 5/3 holes, (*3*) Medartis 2.5 Adaptive TriLock distal radius plate, (*4*) Medartis 2.5 TriLock distal radius plate, (*5*) Medartis 2.5 TriLock distal radius plate extraarticular, (*6*) Synthes VA-LCP distal two-column-radius plate, (*7*) Synthes LCP extraarticular distal radius plate

contour of the plates, plate material and the locking screw mechanism which are continuously improved. In a review regarding 21 different biomechanical studies of implant systems for distal radius fractures, Mehling et al. pointed out that all tested palmar angular stable plates showed sufficient biomechanical properties while being superior over non-angular stable plates in treatment of distal radius extension fractures [5].

Several studies have reported excellent postsurgical results and minimal complication rates using precontoured palmar distal radius locking plates [6, 7]. However, a recent retrospective study by Tarallo et al. reported a complication rate of 5.9 % in 303 patients, including synovitis of the flexor tendons and tendon ruptures [8]. Specific risks concerning palmar locking plate (PLP) fixation such as intra-articular screw placement, prominent hardware and possible extensor and flexor tendon injuries are reported [9].

It was suggested that plate prominence at the palmar distal radius may have accounted for these complications [10, 11]; however, no current study investigated the gap between distal radius palmar plates and radius cortex quantitatively. The purpose of our study, therefore, was to compare the anatomical fit of seven different, precontoured palmar distal radius plates.

Materials and methods

Twenty-five human radius specimens were used in this study. The latter were obtained from body donors of the Centre of Anatomy with a mean age of 84.6 years, who consented in writing during their lifetime to the use of their body for research and education. The study was approved by the Ethics Committee of the Medical Faculty.

Seven different models of precontoured palmar distal radius locking plates were investigated (Fig. 1): (1) 51.0-mm Königsee variable radial plate 7/3 holes (Allendorf, Germany) (2) 51.0-mm Königsee radial plate 5/3 holes (Allendorf, Germany), (3) Medartis 2.5 Adaptive TriLock distal radius plate (Basel, Switzerland), (4) Medartis 2.5 TriLock distal radius plate (Basel, Switzerland), (5) Medartis 2.5 TriLock distal radius plate extraarticular (Basel, Switzerland), (6) Synthes VA-LCP distal two-column-radius plate (Bettlach, Switzerland), (7) Synthes LCP extraarticular distal radius plate (Bettlach, Switzerland).

Fig. 2 Palmar view of a left dorsal radius with a fixed Königsee plate 5/3 holes with two K-wires (*asterisk*)

The plates were individually positioned proximally to the watershed line at the location of their best anatomical fit. Therefore, the plates were positioned on the palmar radius and moved distally on the cortex until the watershed line was reached by the distal plate edge. Implant positioning was performed in mutual agreement by two experienced trauma surgeons for each plate and bone combination. Fixing the plate as distally as possible without plate prominence above the watershed line was defined as the place of “best anatomical fit”. The plates were first placed, hold in position with a Weller forceps, and then fixed with two Kirschner wires (Fig. 2). Under guidance of those wires the plates were lifted and a viscous C-silicone mass [Optosil Comfort Putty by Heraeus Kulzer, Inc. (Hanau, Germany)] which hardens within 4 min after application, was placed on the palmar distal radius cortex.

The plates were then repositioned and final fixation was achieved by inserting a lag screw through the centre hole of the plate with a defined torque of 1.2 Nm, following the operation manuals (Fig. 3). Of each plate model the same plate was used for all 25 radii investigated.

The imprint which embodies between plate and bone, was removed after hardening of the silicon and then embedded in axial position with a second, more fluid silicone mass in contrasting color (Honigum Mono, Heraeus), which allowed standardized transverse sectioning of the imprints.

Afterwards, the blocks resulting from secondary embedding were cut in the median line using a band-saw. All slices were scanned and the maximum height of the silicone imprint was digitally measured (Fig. 4).

Fig. 3 Palmar view of the left dorsal radius as in Fig. 2 with K-wire (*asterisk*)-fixed Königsee plate 5/3 holes impressed into Optosil Comfort Putty (*hash*)

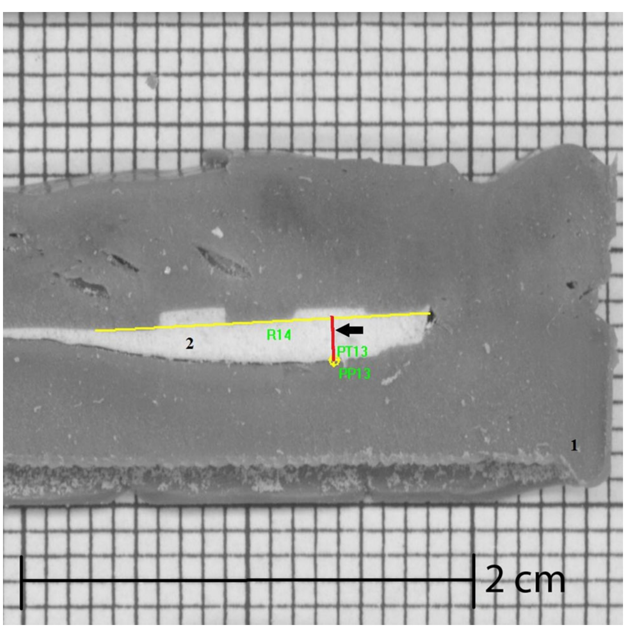

Fig. 4 Median transverse section of the embedded impression of a right radius. The *red line* corresponds to the measurement, the maximum distance between implant and cortex of the radius. The *yellow line* delineates the plate contact surface to bone. *1* is the Hongium Mono Block for embedding the Optosil impression (*2*)

The mean maximum imprint height was compared between the seven types of plates using an analysis of variance with repeated measures and Bonferroni correction for multiple comparisons. Significance was set at $p < 0.05$.

Results

The maximum height of the imprints ranged from 0.8 mm (Synthes 2-column) to 4.8 mm (Synthes 2.4) (Table 1). The least mean imprint height was 1.56 ± 0.76 mm for the Synthes two-column implant, while the greatest mean imprint height was 1.99 ± 0.45 mm for the Medartis Adaptive plate.

Significant differences were found between the Medartis Adaptive implant and the Medartis 2.5 TriLock ($p = 0.001$), the Medartis 2.5 TriLock extraarticular ($p = 0.003$), and the Synthes VA-LCP two-column ($p = 0.005$). The greatest difference in imprint height was found between the Medartis Adaptive and the Synthes VA-LCP two-column plate (0.43 mm) (Table 2).

Discussion

In this study, we investigated the anatomical fit of seven different, precontoured palmar distal radius locking plates. The study results showed that there was no complete congruency between the plates and the radial cortex and that all distal palmar radius plates investigated in this study presented a reasonable anatomical shape. The Synthes VA-LCP distal two-column radius plate showed the best anatomical fit, the Medartis Adaptive TriLock distal radius plate showed the least anatomical fit.

The goal of surgical treatment is to achieve the best anatomical restoration and functional recovery. To achieve this, there are various treatment options. Since the introduction of palmar plating systems the technique of internal fixation of distal radius fractures has been applied increasingly [12].

The well-recognized complication of tendon rupture and tenosynovitis after dorsal plate fixation with early generation plates focused the interest to palmar plate osteosynthesis by following the ORIF concept which is most widely used today [13, 14]. Nevertheless, it should be recognized that for certain fracture patterns, the dorsal plate fixation is the preferred surgical technique and new studies cannot show superiority of palmar plating over latest generation dorsal plates [15]. Leaving the discussion about palmar versus dorsal locking plates aside, column-specific fixation of the distal radius as described by Rikli and Regazzoni seems more important and modern angle stable implants consider this concept [16].

Table 1 Measurement of the maximal distance between plate and bone

Radius nr.	Königssee 7/3 holes	Königssee 5/3 holes	Medartis adaptive	Medartis 2.5 TriLock	Medartis 2.5 TriLock extraart.	Synthes two-column	Synthes LCP extraart.
1	1.73	1.73	2.29	1.73	1.52	1.54	1.56
2	1.90	2.11	2.11	1.90	1.83	1.73	1.39
3	3.95	3.45	3.16	2.53	4.05	3.71	4.84
4	1.73	1.60	1.90	1.81	1.94	1.48	1.77
5	3.16	2.66	2.82	3.16	2.07	3.83	3.90
6	1.90	1.85	2.32	2.23	1.56	1.60	1.31
7	1.77	1.77	2.11	1.81	1.56	1.82	2.40
8	1.44	1.77	1.56	1.28	1.47	1.39	2.02
9	1.98	1.77	2.28	1.69	1.73	1.31	2.19
10	0.93	1.05	1.85	1.10	1.14	1.39	1.01
11	1.73	2.63	2.11	1.39	1.09	1.05	1.85
12	1.48	1.26	1.43	1.14	1.14	0.82	1.02
13	1.60	1.52	1.43	1.14	1.14	0.93	1.31
14	1.40	1.98	2.28	1.64	1.64	1.23	1.26
15	1.73	1.61	0.97	1.43	1.05	1.02	0.98
16	1.18	1.31	1.60	1.43	1.18	0.93	1.01
17	1.68	1.35	2.24	1.52	2.02	2.23	1.68
18	1.99	1.98	1.98	1.77	2.07	1.77	1.81
19	2.11	2.02	2.15	1.68	1.56	1.10	1.01
20	1.73	2.11	1.77	1.35	1.35	1.27	1.90
21	1.81	1.43	1.90	1.48	1.69	1.06	1.31
22	2.00	1.85	2.02	1.94	1.65	1.90	1.94
23	2.19	2.15	2.23	2.19	1.68	1.91	0.89
24	1.47	1.77	1.73	1.43	1.22	0.98	2.15
25	1.35	1.43	1.60	1.31	1.47	1.02	1.43
Mean	1.84	1.84	1.99	1.68	1.63	1.56	1.75
SD	0.60	0.51	0.45	0.47	0.59	0.76	0.91

Treating unstable distal radius fractures by palmar plate fixation with fixed-angle locking screws bears acceptable functional and radiographic outcomes. In a prospective study, Fowler et al. concluded that palmar plate fixation of distal radius fractures results in excellent clinical outcome and restoration at a 1-year follow-up [17]. Besides sole palmar plating, Kainz et al. showed an improvement of biomechanical properties by treating AO 23-A3 fractures with palmar locking plates and additional injection of calcium phosphate cement into the dorsal communication zone [18].

Due to the fact, that osteoporotic bone is a major risk factor regarding distal radius fractures, cement augmentation of the metaphyseal screw holes can decrease the subsidence of distal fragments and increase the construct stiffness in contrast to non-augmentation [19]. The advantage of palmar locking plates can be found in the topographical anatomy of the distal radius. While on the extensor side tendons running in direct contact to bone, muscle tissue protects tendons on the palmar side of the radius. In the transverse plane, the cortex of the palmar radius features a flat contour which embodies a perfect surface for implant placement. In the sagittal plane, the cortex of the palmar radius displays a concavity enveloping the pronator quadratus muscle. This anatomical particularity holds the advantage of providing more space for implants on the palmar radial side [20]. During surgery, the pronator quadratus muscle is detached and can be refixed at least across the plate to protect the flexor tendons against tearing. Concerning the latter study, results are not ambiguous. Hershman et al. showed in contrast to the recommendation of Brown and Lifchez that there is no advantage in repairing the pronator quadratus during palmar plating of distal radius fractures [21, 22]. No difference could be recognized concerning range of motion, grip strength or DASH and VAS score 1 year postoperatively if the pronator quadratus was refixed or not after palmar plating of the distal radius [23].

In this context, optimized congruency between the palmar cortex and the plate seems to be important to achieve

Table 2 Measurement of the different plates, the overall mean difference (mm), the standard deviation (mm) and the significance ($p < 0.05$) in comparison amongst itself is shown in a cross table

	Medartis adaptive	Medartis Art 71/72	Medartis 31/32	Königsee Art. 53	Königsee Art. 73	Synthes two-column	Synthes 2.4
Medartis Adaptive		0.361 (SD 0.079) ($p = 0.03$)	0.306 (SD 0.059) ($p = 0.01$)	0.149 (SD 0.075) ($p > 0.05$)	0.154 (SD 0.082) ($p > 0.05$)	0.430 (SD 0.099) ($p = 0.005$)	0.241 (SD 0.137) ($p > 0.05$)
Medartis Art 71/72	0.361 (SD 0.079) ($p = 0.03$)		0.055 (SD 0.091) ($p > 0.05$)	0.211 (SD 0.092) ($p > 0.05$)	0.207 (SD 0.068) ($p > 0.05$)	0.096 (SD 0.093) ($p > 0.05$)	0.120 (SD 0.118) ($p > 0.05$)
Medartis 31/32	0.306 (SD 0.059) ($p = 0.01$)	0.055 (SD 0.091) ($p > 0.05$)		0.157 (SD 0.073) ($p > 0.05$)	0.152 (SD 0.70) ($p > 0.05$)	0.124 (SD 0.88) ($p > 0.05$)	0.065 (SD 0.134) ($p > 0.05$)
Königsee Art. 53	0.149 (SD 0.075) ($p > 0.05$)	0.211 (SD 0.092) ($p > 0.05$)	0.157 (SD 0.073) ($p > 0.05$)		0.005 (SD 0.062) ($p > 0.05$)	0.281 (SD 0.112) ($p > 0.05$)	0.091 (SD 0.127) ($p > 0.05$)
Königsee Art. 73	0.154 (SD 0.082) ($p > 0.05$)	0.207 (SD 0.068) ($p > 0.05$)	0.152 (SD 0.70) ($p > 0.05$)	0.005 (SD 0.062) ($p > 0.05$)		0.276 (SD 0.083) ($p > 0.05$)	0.087 (SD 0.104) ($p > 0.05$)
Synthes two-column	0.430 (SD 0.099) ($p = 0.005$)	0.096 (SD 0.093) ($p > 0.05$)	0.124 (SD 0.88) ($p > 0.05$)	0.281 (SD 0.112) ($p > 0.05$)	0.276 (SD 0.083) ($p > 0.05$)		0.189 (SD 0.098) ($p > 0.05$)
Synthes 2.4	0.241 (SD 0.137) ($p > 0.05$)	0.120 (SD 0.118) ($p > 0.05$)	0.065 (SD 0.134) ($p > 0.05$)	0.091 (SD 0.127) ($p > 0.05$)	0.087 (SD 0.104) ($p > 0.05$)	0.189 (SD 0.098) ($p > 0.05$)	

Table 3 Palmar cortical angle of the different plates (manufacturer's data)

Manufacturer	Plate	Angle (°)
Königsee	Variabel fixed-angle radius plate 5/3 holes	20
Königsee	Variabel fixed-angle radius plate 7/3 holes	20
Medartis	Medartis 2.5 TriLock	19
Medartis	Medartis 2.5 TriLock extraarticular	19
Medartis	Medartis 2.5 Adaptive TriLock	19
Synthes	Synthes LCP volar extraarticular	25
Synthes	Synthes VA-LCP distal two-column radius	25

proper plate positioning. Buzzel et al. concluded that there is a considerable variation in the ideal plate positioning. While the Synthes JA plate achieved optimal position 1.7 mm distal to the watershed line, the Acumed plate should ideally be placed directly on the watershed line and all other plates investigated proximal to the watershed line [24]. If the plate juts out beyond the watershed line, it can lead to flexor tendon lesions or peg penetrations into the radio-carpal joint. It is worth mentioning that the watershed line does not have to be a distinct line. In an anatomical study Iminati et al. identified two bony lines: the proximal line of the distal pronator fossa and a second, more distal line featuring a medial prominence. This prominence was recommended as a good landmark of the distal limit for safe plate positioning [25]. Due to flexor pollicis longus (FPL) and flexor digitorum profundus tendons particular anatomical course palmar locking plates placed distally to the watershed line may be associated with flexor tendon irritations up to ruptures. Limthongthang et al. found that the FPL was located at an average of 19 mm lateral to the palmar-ulnar corner of the radius at the watershed line. Significant differences in plate prominence were noted for various plate designs [26].

With increasing numbers of palmar systems used in the past years, more flexor tendon complications have been reported [22, 27–29]. As fixed-angle plate systems do not necessarily need direct bone contact due to their fixation principle, the plates do not have to be customized to the bone. However, achieving optimum anatomical fit seems to be desirable to avoid soft tissue irritation. Buzzel et al. were able to verify a plate-bone contact ranging from 3 to 6 % of the plate surface [24]. Several groups showed that fixed-angle plate osteosynthesis at the distal radius has a low rate of complications and allows exact anatomical reposition of the fracture. Esenwein et al. examined the complications following palmar plate fixation in 665 cases. They found 75 complications in 65 patients. The most common causes for revision surgery were postoperative median nerve compression, secondary dislocation, a complex regional pain syndrome and an ulnar impingement [30]. Specific attention should be paid to the palmar lunate facet in distal radius fractures. It is widely known that an inadequate fixation may result in displacement, malunion, and wrist dysfunction. In a prospective observational study, Beck et al. examined 51 patients with AO B3 distal radius fractures treated with internal fixation. Loss of reduction was totally seen in seven patients. All of them had an AO B3.3 and were treated with new-generation plates with a palmar lunate extension. The authors stated that B3.3 fractures with 15 mm bone available for fixation and initial lunate subsidence of >5 mm are "risk for failure fractures". An adequately fixation may not be possible through palmar plate fixation alone, even with an optimal plate position. In these cases the authors suggested that the plate can be positioned distally to the watershed line and should be early removed [31].

In our study, the Medartis Adaptive implant displayed the least fit with an average maximum distance of 1.99 mm, while the Synthes 2-column implant yielded the best fitting result. The difference was significant; however, the Medartis Adaptive plate also showed a significant difference to all the other Medartis plates tested. All other comparisons showed no significant differences between various manufacturers.

The palmar cortical angle was described in a radiographic study by Bassi et al. The mean values for the palmar cortical angle in 50 radiographs of healthy wrists were measured at 37° (range 26°−50°) [32]. The different default angles of precontoured plates may not address the palmar cortical angle sufficiently.

The plates used in our study were precontoured in a palmar cortical angle ranged from 19 to 25° (Table 3). The plate with the least difference (Medartis Adaptive) was precontoured in the palmar cortical angle of 19°, whereas the plate with the best fit (Synthes two-column) showed a molding of 25° for the palmar cortical angle.

No plate tested in this study respected the fact that the distal radius cortex tilts in various angles from the distal radius, as shown by Gasse et al. These authors examined 74 radii with computer tomography and measured the angle of the lateral and medial column according to the three-column-concept of Rikli and Rigazzoni [16]. The mean angle of the lateral column was 24.7 and 35.1° that of the medial column [33]. These findings were confirmed by Evans et al. [34].

To achieve an anatomically correct fit, it may become necessary to design new plates with a medial column angle approximately 10° greater than in those plates available to date. An advantage of anatomical fitting could be seen during the reduction process of the distal fragment. Following manufacturers technique guide for using palmar locking plates, one opportunity is to start by placing the lag screw in the radius shaft and to reduce the bone by aligning the distal fragments on the plate's surface. In this context, the plate functions as a template and inadequate anatomic plate design could result in imprecise fracture reduction. According to the product information, fine contouring with a bending forceps is possible for Synthes and Medartis plates, so that they can be adapted to the actual anatomical condition. It remains an open question, however, to which extend these plates can be bent without compromising the locking screw mechanism or altering the position of the pins. It is a declared aim of surgical treatment of distal radius fractures to reconstruct the anatomical and biomechanical conditions of the radius [35]. A radius plate preshaped correctly according to anatomical structures would promote these objectives unequivocally. In this context, palmar fixed-angle radius plates, which were also used in our study, show good to very good outcomes [36–39]. Current generation of palmar plates commonly offer multiple screw rows for fixation of the metaphyseal fragment. A current study by Drobert et al. showed that multi-row design does not inevitably lead to superior construct stability and loss of reduction in comparison to older designs with single screw rows [40].

Limitations of this paper are the use of embalmed cadavers; the limited number of 25 radii and only seven different plate designs whereas many others are available. Another potential limitation of our study is that we tested the best anatomical fit on a bone without a fracture situation. At last, we tested under optimal conditions after removing any soft tissue from the bone, which can possibly not be done to that extent in vivo.

In conclusion, this study proved that although there was no complete congruency between the plates and the radial cortex, all distal palmar radius plates investigated in this study presented a reasonable anatomical shape but exhibited significant differences in accuracy of anatomical fit. The Synthes VA-LCP distal two-column-radius plate palmar showed the best anatomical fit.

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Conflict of interest There is no conflict of interest of all authors.

Ethical standard The study was approved by the Ethics Committee of the Medical Faculty of the University of Cologne (Reference Number 13-190).

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