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NEW GENERATION OF SUPERIOR SINGLE PLATING VS LOW-PROFILE DUAL MINI-FRAG-MENT PLATING IN DIAPHYSEAL CLAVICLE FRACTURES. A BIOMECHANICAL COMPAR-ATIVE STUDY

Running title: Dual versus single clavicle plating

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All procedures performed in this study were followed in accordance with relevant guidelines. The donor gave its informed consent inherent within the donation of the anatomical gift statement during his lifetime, as registered by Science Care.

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1 ABSTRACT

Background: Recently, a new generation of superior clavicle plates was developed featuring
the variable angle locking technology for enhanced screw positioning and a less prominent
and optimized plate-to-bone fit design. On the other hand, mini-fragment plates in dual
plating mode have demonstrated promising clinical results. The aim of the current study was
to compare the biomechanical competence of single superior plating using the new generation
plate versus dual plating using low-profile mini-fragment plates.

Methods: Sixteen paired human cadaveric clavicles were pairwise assigned to two groups for instrumentation with either a superior 2.7 mm Variable Angle Locking Compression Plate (Group 1), or with one 2.5 mm anterior combined with one 2.0 mm superior matrix mandible plate (Group 2). An unstable clavicle shaft fracture (AO/OTA 15.2C) was simulated by means of a 5mm osteotomy gap. Specimens were cyclically tested to failure under craniocaudal cantilever bending, superimposed with bidirectional torsion around the shaft axis and monitored via motion tracking.

Results: Initial construct stiffness was significantly higher in Group 2 (9.28 ± 4.40 N/mm)
compared to Group 1 (3.68 ± 1.08 N/mm), p=0.003. The amplitudes of interfragmentary
motions in terms of axial and shear displacement, fracture gap opening and torsion, over the
course of 12,500 cycles were significantly higher in Group 1 compared to Group 2, p≤0.038.
Cycles to 2mm shear displacement were significantly lower in Group 1 (22792 ± 4346)
compared to Group 2 (27437 ± 1877), p=0.047.

Conclusion: From a biomechanical perspective, low-profile 2.5/2.0 dual plates can be
considered as a useful alternative for diaphyseal clavicle fracture fixation especially in less
common unstable fracture configurations.

24 2.7 single superior variable angle locking plates and can therefore be considered as a useful

alternative for diaphyseal clavicle fracture fixation especially in less common unstable

26 fracture configurations.

27 Keywords: midshaft/diaphyseal clavicle fracture, dual plating, mini-fragment plates,

28 biomechanics, motion tracking, implant removal, symptomatic implants

29 Level of evidence: Basic Science Study; Biomechanics30

31

Fractures of the middle part of the clavicle account for 69% to 82% of all clavicular fractures 32 and for 2.6% to 5% of all human fractures ⁶. In patients with significantly displaced fractures, 33 primary operative fixation, as opposed to non-operative treatment of clavicle fractures, 34 promotes a quicker return to function and reduces early residual disability ¹⁰. Plating is a 35 common method for surgical treatment and the standard fixation technique for midshaft 36 fractures using a 3.5mm anatomic Locking Compression Plate (LCP) demonstrated good 37 clinical results and less non-unions on the long term follow-up⁸. However, high implant 38 removal rates due to disturbing hardware of 9 to 64% have been reported ²¹ and led to a search 39 for alternatives. One approach to reduce soft tissue irritation is using the recently introduced 40 41 2.7 variable angle locking compression plate (VA-LCP) for superior placement on the clavicle. 42 The main features consist of a low-profile design with a smoothened plate surface, tapered edges and variable angle locking holes. However, reports in the current literature related to 43 clinical outcomes are still scarce. Another strategy is the use of low-profile dual plates that have 44 already demonstrated good clinical outcomes² and theoretically lead to less soft tissue irritation 45 due to the low cross-sectional area of the two plates. The concept of dual plating is an additional 46 way to increase the multiplanar stability of the fracture fixation by using two smaller locking 47 plates instead of a single larger implant and offering a wider choice of screw anchoring sites to 48

enhance construct stability while reducing implant prominence. Therefore, it is especially
interesting in locations where prominent hardware disturbs patients after fracture fixation.
However, these new plate designs for diaphyseal clavicle fracture fixation have not been
subjected to a direct biomechanical evaluation so far. Therefore, the aim of the current study
was to investigate the biomechanical competence of the new generation single 2.7 mm VALCP superior clavicle plate versus superior-anterior dual plating using two low-profile minifragment plates in a human cadaveric bone model.

56

57 2. MATERIALS AND METHODS

58 2.1 Specimens and study groups

Sixteen paired fresh frozen human cadaveric clavicles from 4 female and 4 male donors aged 59 60 72.5 years on average (range 48–96 years) were used in this study. The specimens were thawed at room temperature, freed from all soft tissues and subjected to computed tomography (CT) 61 scanning at a slice thickness of 0.63mm (Revolution EVO, GE Medical Systems AG, 62 Switzerland) to calculate volumetric bone mineral density (BMD) within the clavicle bone 63 using a phantom (European Forearm Phantom QRM-BDC/6; QRM GmbH, Möhrendorf, 64 65 Germany). Subsequently, the specimens were pairwise assigned to two groups for single superior plating in Group 1, or superior-anterior dual plating using two low-profile mini-66 fragment plates in Group 2, with equal distribution of left and right clavicles in each group. 67

68 2.2 Surgical technique

For instrumentation in Group 1, a 2.7 mm VA-LCP Clavicle Shaft Plate (size CS1; length 98
mm; DePuy Synthes, Zuchwil, Switzerland) was used. Each plate was positioned such that the
fracture gap was located centrally between the two innermost plate holes 6 and 7, counting from

medial. Contouring of the plates to fit the anatomy was not necessary as they fitted well to the anatomy of the 8 donors. Pilot holes of 2.0 mm were predrilled using the VA-LCP Drill Sleeve in bicortical fashion through plate holes 1, 3, 4, 5, 8, 9, 10, and 12, counting from medial after plate fixation to the bone with two repositioning forceps. Final plate securing was achieved via locking screw fixation through these pilot holes using a total of four bicortical 2.7mm variable angle locking screws in each fragment starting with plate holes 1 and 12. Finally, a 1.2 Nm torque limiter was used for screw locking.

For instrumentation in Group 2, one 2.5 mm 9-hole 68 mm long Matrix mandible plate and one 79 80 2.0 mm 5-hole 36 mm long Matrix mandible plate (2.5 Matrix mandible 20-hole plate and 2.0 Matrix mandible 20-hole plate; DePuy Synthes, Zuchwil, Switzerland) were considered. Both 81 were cut from 20-hole plates as they are not available in the according length. Whereas the 2.5 82 mm plate was contoured to fit the anatomy of the anterior aspect of the clavicle, the 2.0 mm 83 plate was pre-shaped to cling to the superior aspect of the clavicle. Both plates were positioned 84 and secured with repositioning forceps such that the middle hole – number 5 of the 2.5 mm 85 anterior plates and number 3 of the 2.0 mm superior plates, counted from medially – was located 86 centrally over the osteotomy gap. Pilot holes of 1.8 mm were predrilled using a Drill Sleeve in 87 bicortical fashion through plate holes 1, 2, 4 and 5 of the superior plate and through plate holes 88 1, 4, 6 and 9 of the anterior plate. Final plate securing was achieved via locking screw fixation 89 through these pilot holes using a total of two bicortical 2.4mm locking screws in each fragment 90 91 and plate, starting with plate holes 1 and 5 of the superior plate and plate holes 1 and 9 of the anterior plate. No torque limiter was used, and all screws were tightened according to best 92 knowledge of the surgeon. All instrumentations were performed by one experienced surgeon 93 following the technical prescriptions of the individual implants (Figure 1). All implants were 94 made of commercially pure titanium (cpTi)/titanium alloy (TAV/TAN), and were provided by 95 the same manufacturer (DePuy Synthes, Zuchwil, Switzerland). 96

97 A 5 mm wide osteotomy gap was created in the mid-shaft region of each specimen using an oscillating saw and a cutting jig to simulate a displaced unstable diaphyseal AO/OTA 15.2C 98 fracture (type 2B according to Robinson's classification). The lateral and medial ends of the 99 clavicles were embedded in collinear cylindric forms using polymethylmethacrylate (PMMA, 100 SCS-Beracryl D28; Suter Kunststoffe AG, Fraubrunnen, Switzerland) with the innermost sites 101 of the cylinders measuring 120 mm in distance between each other. This distance resembled 102 the lowest common denominator allowing secure fixation in each specimen, given the variable 103 clavicle sizes with the shortest one measuring 140 mm. Furthermore, this uniform length 104 allowed consistent loading of each specimen. Finally, two optical marker sets were mounted to 105 the clavicle on both sides of the osteotomy gap for motion tracking. 106

107 2.3 Biomechanical Testing

Biomechanical testing was performed on an electrodynamic material testing machine (MTS 108 Acumen; MTS Systems Corp., Eden Prairie, MN, USA) equipped with a 3kN load cell and a 109 test setup adopted from previous work ^{13,24}. Whereas the PMMA embedding at the sternal side 110 was connected to the machine base via an XY table, the embedding at the acromial clavicle end 111 was fixed to the machine actuator via a cardan joint (Figure 2). A pin placed beneath the 112 specimens medial to the osteotomy gap was used to support the sternal clavicle end and ensure 113 cantilever bending of the plated specimen. The cardan joint was angled at 20 degrees 114 corresponding to 25 mm posterior offset of the machine actuator axis with respect to the axis 115 of the acromial clavicular embedding. This configuration allowed complex loading comprising 116 cantilever bending superimposed with shear and torsional loading, initiated by the actuator 13,24 , 117 118 with the aim to simulate clavicle torsion due to arm swinging during walking, as well as bending and shear loading during breathing induced by the sternocleidomastoid, delta, subclavius, 119 120 pectoralis major, and trapezius muscles.

121 The loading protocol commenced with of an initial non-destructive quasi-static compression ramp from 0 N to 30 N at a rate of 5 N/s, followed by cyclic sinusoidal loading pattern with a 122 constant amplitude between 50 N compression and 20 N tension at 2 Hz test frequency over 123 20000 cycles and was adapted from previous work ^{5,13,24}. Subsequently, compression and 124 tension were increased at a rate of 0.01 N/cycle until catastrophic failure of the bone-implant 125 construct. The application of progressively increasing cyclic loading has been demonstrated as 126 useful in previous studies ^{3,15–17} and allows construct failure of specimens with different bone 127 quality to occur within a predefined number of cycles. Peak torque values induced from the 128 posterior offset of the applied load under 20 N tension and 50 N compression, were 0.5 Nm and 129 1.25 Nm, respectively. According to previously published work 13,24 , the test was stopped after 130 catastrophic failure, which was characterized as a 45 mm axial displacement of the machine 131 132 actuator.

133 2.5 Data Acquisition and Analysis

134 Machine data in terms of axial load and axial displacement were acquired at a rate of 32 Hz. Initial construct stiffness was calculated from the ascending load-displacement curve of the 135 quasistatic ramp in the range between 10 N and 25 N compression. Further, the coordinates of 136 the optical markers attached to the tested constructs were continuously acquired throughout the 137 tests at 20 Hz by means of stereographic optical measurements using contactless full-field 138 deformation technology (Aramis SRX; GOM GmbH, Braunschweig, Germany) to assess 139 interfragmentary movements in all six degrees of freedom. Based on the motion tracking data, 140 the following parameters were evaluated: (1) shear displacement, defined as the relative 141 142 displacement within the osteotomy plane between the two fragments measured at the most inferior aspect lying in the fracture gap; (2) axial displacement, defined as the relative 143 displacement perpendicular to the osteotomy plane between the two fragments measured at the 144 145 most inferior aspect lying in the fracture gap; (3) torsional displacement, defined as the relative

angular displacement between the two fragments within the osteotomy plane; (4) gap angle 146 displacement, defined as the magnitude of fracture gap opening between the two fragments. 147 The outcome values of these parameters were analyzed after 2500, 5000, 7500, 10,000 and 148 12,500 test cycles under peak and valley loading conditions to assess the evolution of the 149 amplitude over the course of cyclic testing. Furthermore, a margin of 2 mm of shear 150 displacement was defined as clinically relevant criterion for construct failure and the numbers 151 of cycles until fulfilment of this criterion under peak loading condition were calculated. Finally, 152 catastrophic failure modes were evaluated by X-ray imaging and visual inspection of the 153 implant at the end of each test. 154

Statistical evaluation was performed with SPSS software package (IBM SPSS Statistics, version 27; IBM, Armonk, NY, USA). Shapiro-Wilk test was used to screen and prove normality of the data distribution. Differences in fracture gap movements and their change over time were analyzed with General Linear Model Repeated Measures test. Significant differences between the study groups were identified using Paired-Samples T-tests. Level of significance was set to 0.05 for all statistical tests.

161 **3. RESULTS**

162 3.1 Volumetric bone mineral density

163 Cortical and trabecular volumetric BMD were respectively $383.9 \pm 18.9 \text{ mgHA/cm}^3$ and $349.5 \pm 4.7 \text{ mgHA/cm}^3$ in Group 1, as well as $383.4 \pm 12.9 \text{ mgHA/cm}^3$ and $349.9 \pm 6.7 \text{ mgHA/cm}^3$ in 165 Group 2, with no significant differences between the groups (p ≥ 0.815).

166

167 3.2 Initial construct stiffness

168 Initial construct stiffness was significantly higher in Group 2 (9.28 ± 4.40 N/mm) compared to 169 group 1 (3.68 ± 1.08 N/mm), p=0.003.

170

171 3.3 Fracture gap movements

The amplitude at the five intermittent time points over the course of 12,500 cycles for the four investigated parameters shear displacement, axial displacement, gap angle, and torsion are displayed in (*Figure 3*). For each of these parameters, the amplitude was significantly higher in Group 1 versus Group 2, $p \le 0.038$. Furthermore, whereas the amplitude for shear displacement, axial displacement, and gap angle remained without significant changes over the cycles in each group ($p \ge 0.232$), it significantly increased for torsion in both groups ($p \le 0.031$).

178 3.4 Cycles to clinically relevant failure

179 Cycles to 2 mm shear displacement were significantly lower in Group 1 (22792 \pm 4346) 180 compared to Group 2 (27437 \pm 1877), p = 0.047 (*Figure 4*).

181 3.5 Failure modes

In Group 1, plate plastic deformation in all specimens was followed by screw breakage of up to all 4 screws at the medial side in five specimens. Whereas in two specimens screw breakage occurred at the lateral side, in one specimen all screws remained intact. Main failure mode in Group 2 was breakage of one or two screws of the anterior plate at the medial side in six specimens. In two specimens screw breakage occurred at the lateral side. Plate breakage was not observed in any specimen of both groups (*Figure 5*).

188 **4. DISCUSSION**

The current study compared the biomechanical competence of the recently introduced 2.7 mm VA-LCP superior clavicle plate with low-profile dual plate constructs (2.5/2.0) used for the fixation of unstable mid-shaft clavicle fractures. The main findings were a significantly higher initial stiffness and a significantly higher resistance failure of the low-profile dual plate constructs compared to the new 2.7 mm VA-LCP superior clavicle plate. Moreover, the lowprofile dual plates were associated with significantly less fracture gap movements in terms of

shear and rotational displacement over the first 12,500 cycles. In a clinical setting with a gap 195 fracture as simulated in the current study, less adverse interfragmentary shear movements in 196 dual plate constructs might be beneficial for bone healing, whereas the longer endurance 197 theoretically allows more time for bone healing. In contrast, single plates were associated with 198 more favorable axial movements which theoretically is beneficial for bone healing in bridge 199 plate constructs. However, the single plates demonstrated less resistance to failure. The current 200 study used a worst-case scenario with a gap fracture of 5 mm to maximally stress the plates. 201 Thus, less interfragmentary movements of the single plates should occur in more stable fracture 202 configurations. However, the current study is not able to categorize the amount of 203 204 interfragmentary movements as beneficial or harmful.

Although the current study cannot compare the biomechanical competence of the new 2.7 mm 205 VA-LCP against the thicker 3.5 mm clavicle plates, it is hypothesized that the reduced thickness 206 207 to minimize soft tissue irritation comes at costs of biomechanical stability. Since the new plate design has only recently been introduced, it is obvious that reports are scarce in the current 208 literature. However, first clinical reports on the new 2.7 VA-LCP are promising with excellent 209 clinical results although the study included shaft fractures with lateral extension ¹. One 210 advantage of the single plate is the possible use in minimally invasive plate osteosynthesis 211 (MIPO) technique as described by Michelitsch et al in comminuted midshaft fractures ¹². 212

There are several other biomechanical studies available in the current literature comparing the biomechanical competence of dual plate constructs to single plates in midshaft clavicle fractures. In the beginning, thicker dual plate constructs with 3.5 mm reconstruction plates were compared to single 3.5 mm reconstruction plates which led to expectable increased construct stiffness and higher resistance to failure ²⁴. In a further consequence, dual plate constructs with thinner plates were evaluated biomechanically. Ziegler et al reported similar superior results with 2.7 mm and 3.5 mm dual plate constructs when compared to single 3.5mm plates ²⁶.

Prasarn et al used 2.7 mm plates superiorly and 2.4 mm plates anteriorly and compared them to 3.5 mm reconstruction plates in an artificial bone model and also reported superior biomechanical behavior for the dual plate constructs when compared to 3.5 mm single plates¹⁸. Kitzen et al also evaluated 2.7 mm plates superiorly and 2.4 mm plates anteriorly and compared them to 3.5 mm single reconstruction plates in a human cadaveric bone model. Again, the authors reported similar biomechanical properties as found in 3.5 mm single plate constructs ⁷.

The plates used in the aforementioned studies were relatively thick and it is questionable if 226 227 hardware removal rates can be significantly lowered with their use in clinical practice. Therefore, even thinner plates were recently investigated and compared 2.5/2.0 mm dual plate 228 constructs as well as 2.0/2.0 mm dual plate constructs with conventional 3.5 mm anterosuperior 229 plates in an artificial bone model ¹³. The used low-profile plates were initially designed for 230 mandible fractures and although the 2.5/2.0 mm dual plate constructs demonstrated higher 231 232 initial stiffness and comparable resistance to failure as a 3.5mm single plate, the 2.0/2.0 mm constructs demonstrated comparable initial stiffness. However, during cyclic testing the 2.0/2.0 233 mm constructs showed significantly lower resistance to failure and might not be considered as 234 235 valid alternative to 3.5 mm single plating. On the other side, a worst-case scenario with a 5 mm gap fracture was used. The 2.0/2.0 dual plate construct might be sufficient to achieve fracture 236 healing in a near to anatomically reduced fractures. 237

In the current study main failure mode of the dual plate constructs was screw breakage in the anterior stronger plate at the medial or lateral side of the fracture gap. In a clinical application the additional insertion of screws in this area (screw hole 2 and 8) might even further increase the resistance to clinical failure. Despite the superior biomechanical characteristics of the dual plate constructs, there are several concerns regarding their routinely use in patients. The additional soft tissue dissection around the clavicle due to orthogonal dual plating might be a drawback since it could impair bone healing, however, a recently published meta-analysis

compared low profile dual plating with single plating in midshaft clavicle fractures and the 245 authors conclude that dual plating is a safe procedure attaining the same union rates as seen in 246 single plating ¹⁹. Moreover, the dual plate constructs used in the current study were shorter than 247 the 2.7 mm single plates. Therefore, less soft tissue dissection is required on either the superior 248 or anterior side. Furthermore, the amount of surgical exposure required for anatomic reduction 249 rather than the number of utilized plates determines intraoperative exposure in multi-250 fragmentary displaced diaphyseal clavicle fractures ¹¹. Another concern of implants with a high 251 initial stiffness are higher non-union rates due to decreased fracture gap movements especially 252 in gap fractures where the bridge plating concept is applied. In contrast, modern low-contact 253 254 angular stable plate designs to minimize the negative impact on the blood supply have been 255 developed and clinical studies using low-profile dual plate constructs have shown no nonunions so far ^{2,18}. Furthermore, a systematic review and meta-analysis described high union 256 rates for dual plating (99.5%), and an implant removal rate of only 4.2% investigating 7 clinical 257 studies regarding low-profile dual plating ²⁵. Another meta-analysis concluded that dual plating 258 seems to have a lower overall complication and re-intervention rate, mostly driven by the lower 259 incidence of implant related complaints ¹⁹. However, when interpreting implant removal rates, 260 one has to keep in mind that they are dependent on several factors like length of follow-up, 261 262 activity level of the patients (e.g. backpack), individual costs of implant removal in different health care systems and cultural differences. Furthermore, disturbing hardware might also be a 263 subjective feeling in some patients who are disturbed just by the fact of foreign material in their 264 body. 265

The results of the current study revealed that dual plate constructs offer more initial stiffness, higher resistance to failure and less fracture gap formation and therefore may have a role clinically. However, further clinical trials would be necessary to determine whether low profile dual plate fixation with 2.5/2.0 plate configurations offers improved healing compared to single plate fixation.

Several limitations that inherent to all biomechanical studies done on human cadaveric bones 271 have to be considered when interpreting the findings of the current study. First, using a 272 cadaveric bone model, it was not possible to fully replicate the in vivo conditions following a 273 fracture in a real human with soft tissue swelling and biological reaction. Second, only a limited 274 number of human clavicles were tested, restricting the generalization of the study findings. 275 However, the results deem sufficient, demonstrating significant differences between the groups. 276 Third, the dual plates used in the current study had to be slightly prebent to perfectly fit to the 277 clavicle, which might have influenced their material properties, which was not necessary in the 278 single plate group. However, in an anatomical investigation on more than 100 clavicles 279 280 Vancleef et al concluded that it is improbable that a clavicle plating system can match the entire population ²⁰. In consequence, minor adjustments to the implants are virtually always necessary 281 for surgeons to match the patient's anatomy perfectly ²⁰. New techniques like the application of 282 three-dimensional patient specific surgical guides might further improve fracture reduction and 283 optimal plate positioning ¹⁴. Fourth, the chosen 2mm of shear displacement is an arbitrarily 284 defined criterion for construct failure as this contrasts with Perren's strain theory. However, the 285 displacement curve demonstrated a sudden drop in stability near this chosen criterion, which 286 was found to be suitable. Lastly, the donors for the specimens of the current study were 287 288 relatively old and are therefore not the primary target group for surgical treatment of clavicle shaft fractures. However, main failure mode was screw breakage rather than screw pullout. It 289 is therefore expected that the results of the current study can be transferred to younger patients. 290

The strengths of the current study lie especially in the use of a precise motion tracking system. Furthermore, the failure modes correspond to clinical failures observed during clinical practice, rendering the used test setup and loading protocol clinically relevant. Furthermore, the use of paired cadaveric specimens allowed for a reliable assignment into the two study groups. This biomechanical investigation adds valuable knowledge to the existing literature regarding the

296 groundwork of the relatively new technique of clavicle low-profile dual plating which might297 reduce the high implant removal rates after midshaft clavicle fractures.

Future research should focus on the optimal implant length of the low-profile dual plates and 298 their clinical evaluation ⁹. It is expected that the dual plates can be further shortened to achieve 299 a similar stiffness and resistance to clinical failure as the 2.7 single plates especially in more 300 stable fracture patterns. Furthermore, implant removal rates and patient satisfaction of the two 301 investigated plate designs should be evaluated. Moreover, the major issue with biomechanical 302 303 studies on the upper extremity is that it remains unclear which construct stiffness and loading thresholds fixation constructs have to withstand in vivo⁴. Up to now there is no data in the 304 literature on how many cycles the constructs must withstand to achieve bone healing. New 305 technologies like continuous implant load monitoring to assess the bone healing status might 306 bring new insights to this problem ^{22,23}. 307

308 5. CONCLUSION

From a biomechanical perspective, low-profile 2.5/2.0 dual plates can be considered as a
useful alternative for diaphyseal clavicle fracture fixation especially in less common unstable
fracture configurations.

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409 FIGURE LEGENDS

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- 411 Figure 1: Exemplified photographs of two left clavicles instrumented with a 2.7 mm VA-
- LCP clavicle shaft plate in superior position (A, B), and with a 2.5/2.0 mm low-profile dual
- 413 plate construct (C, D), shown from superior (A, C) and from anterior (B, D).
- 414 Figure 2: Test setup with a left specimen mounted for biomechanical testing. F indicates
- 415 loading direction; T indicates passively induced torque via posterior offset of F with respect to416 the clavicle axis.
- Figure 3: Fracture gap movement amplitudes over the course of 12.500 test cycles, shown foreach group separately in terms of mean and SD.
- Figure 4: Cycles to clinically relevant failure shown in terms of mean and SD. Star indicates
 significant difference.
- 421 Figure 5: Main failure modes of the investigated specimens. Orange arrows indicate plate
- 422 deformation. Blue arrows indicate screw breakage or loosening. A: X-ray of a clinical failure
- 423 of a low-profile dual plate construct. View from 40° caudo-cranial to a right clavicle. **B**: View
- 424 from superior to a right clavicle. The dual plate construct failed via screw breakage of the two
- 425 medial screws in the anterior 2.5 low profile plate. **C:** View from anterior to a right clavicle.
- 426 The single plate failed via plate deformation and screw breakage of all 4 medial screws.

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