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Comparison of Three Drilling Techniques for Carpometacarpal Joint Arthrodesis in Horses

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Objective: To evaluate 3 drilling techniques for arthrodesis of the equine carpometacarpal (CMC) joint.
Study Design: Experimental study.
Sample Population: Cadaveric equine forelimbs (n = 15).
Methods: Limbs were divided into 3 groups (5 limbs each) to evaluate 3 drilling techniques: (1) use of a 4.5 mm drill bit inserted into the joint through 4 entry points and moved in a fanning motion; (2) a 5.5 mm drill bit inserted through 2 entry points to create 3 nonfanned drill tracts (3 drill technique); and (3) a 4.5 mm drill bit used in a 3 drill technique. The CMC joint was disarticulated after drilling, and cartilage and subchondral bone damage evaluated visually and by gross and microradiographic examination using planimetry.
Results: Technique 1 produced significantly more damage of the proximal surface, but significantly less to the subchondral bone of the distal surface. Technique 1 produced the most damage to both the articular cartilage and subchondral bone of the total CMC joint than either of the 3 drill tract techniques; however, the difference between techniques 1 and 2 was not significant. Damage from technique 3 was significantly less than that with techniques 1 or 2.
Conclusions: Techniques 1 and 2 produced the most cartilage and subchondral bone damage with technique 2 changes more equally distributed between proximal and distal joint surfaces.
Clinical Relevance: Technique 1 (fanning) and 2 (5.5 mm 3 drill tracts) may be preferable to achieve arthrodesis of the CMC joint. Morbidity and efficacy of these arthrodesis techniques need to be evaluated in vivo.

INTRODUCTION

ARTHRODESIS HAS been successfully used to treat horses with osteoarthritis (OA) of the proximal interphalangeal joint[1] and distal tarsal joints.[2] Arthrodesis of low-motion joints should result in a return to normal activities in a pain-free manner without loss of function.[1,2] Like the distal tarsal joints, the carpometacarpal (CMC) joint has minimal movement[3] and arthrodesis techniques used for the distal tarsal joints might result in arthrodesis of the CMC joint. Arthrodesis by chemical destruction of articular cartilage as is used in the distal tarsal joints,[4,5] is not recommended because the CMC joint usually communicates[3,6] with the highly mobile middle carpal joint. For the distal tarsal joints, arthrodesis has been successfully achieved by use of a drill bit to damage articular cartilage and subchondral bone, and promote bone formation within the drill tracts.[2,7–12] The cartilage and subchondral bone damage necessary for arthrodesis has not been determined. Early reports suggest that >60% of the articular surface should be damaged,[11] and this can be achieved with a 4.7 mm drill bit

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using 5–6 drill passes.[11] Clinically, 3 tracts created with a 3.2 or 4.5 mm drill resulted in arthrodesis[2] and although it was estimated that <60% of the surface was damaged, the actual surface area affected was unknown.

CMC joint arthrodesis been achieved clinically, by fanning the drill bit during drilling from several insertion points around the joint circumference[13–15]; however, the joint surface area affected was not determined. Drill bit insertion at multiple sites is time consuming and the extent of fanning is subjective and may result in inconsistent results between surgeons. Development of a 3 drill tract technique (nonfanning) from 1 side of the carpal joint, similar to the technique used in the distal tarsal joints,[2] may be quicker, easier, and more repeatable. Thus, our purpose was to determine the distribution of articular cartilage and subchondral bone damage within the CMC joint using 3 different drilling techniques: a fanning technique[13–15] using a 4.5 mm drill bit inserted into the joint through 4 entry points (technique 1) and 2 nonfanning 3 drill tract techniques using either a 5.5 mm (technique 2) or a 4.5 mm (technique 3) bit using 2 drill entry points.

MATERIALS AND METHODS

Forelimb specimens (n = 15) from horses of various ages and breeds, euthanatized for reasons other than carpal disease, were collected by transection above the carpus and frozen. Before use, limbs were thawed, clipped, assigned numbers for identification and divided into 3 groups of 5 limbs by random selection of limb numbers from an envelope.

Surgery

For all techniques, limbs were positioned with the medial aspect facing up, as if the horse was in lateral recumbency. For technique 1, after drill insertion from the medial aspect, limbs were repositioned with the lateral aspect facing upward to complete drilling.

Technique 1. A 4.5 mm drill bit inserted in 4 sites (Fig 1): medially at the 2nd carpal bone (C2)/2nd metacarpal bone (MC2) articulation; dorsomedially and dorsolaterally (just medial and lateral to the extensor carpi radialis tendon) at the 3rd carpal bone (C3)/3rd metacarpal bone (MC3) articulation; and laterally at the 4th carpal bone (C4)/4th metacarpal bone (MC4) articulation. A 20 G needle was independently inserted at each site and its position and angle verified with a fluoroscope. A stab incision (#10 scalpel blade) was made with a through the skin adjacent each needle and into the joint. Using a drill guide, a 4.5 mm drill bit was inserted, and after its position was verified fluoroscopically, advanced ~3 cm with a continuous fanning motion (arc ~2–3 cm) primarily in a transverse plane but also somewhat in a sagittal plane (arc ~1 cm) of the limb (Figs 1 and 2). The fanning motion was performed in the same manner reported in clinical cases and by the same surgeon (S.M.B.).[13–15]

Technique 2. Using a 3 drill tract technique, a 5.5 mm drill bit was inserted at 2 sites: medially (1 drill tract) and dorsomedially (2 drill tracts; Fig 1). A 20 G needle was inserted into the C2/MC2 articulation (medial site), its position confirmed fluoroscopically, and a stab incision into the joint (#10 scalpel blade) made adjacent the needle. A 3.2 mm drill bit was inserted into the edge of the joint to allow the surgeon to feel the joint space and correctly position the 5.5 mm drill guide over it. Then, with the drill guide in position, the 3.2 mm drill bit was replaced with a 5.5 mm drill bit, which was drilled ~1–1.5 cm into the joint space and its correct positioning

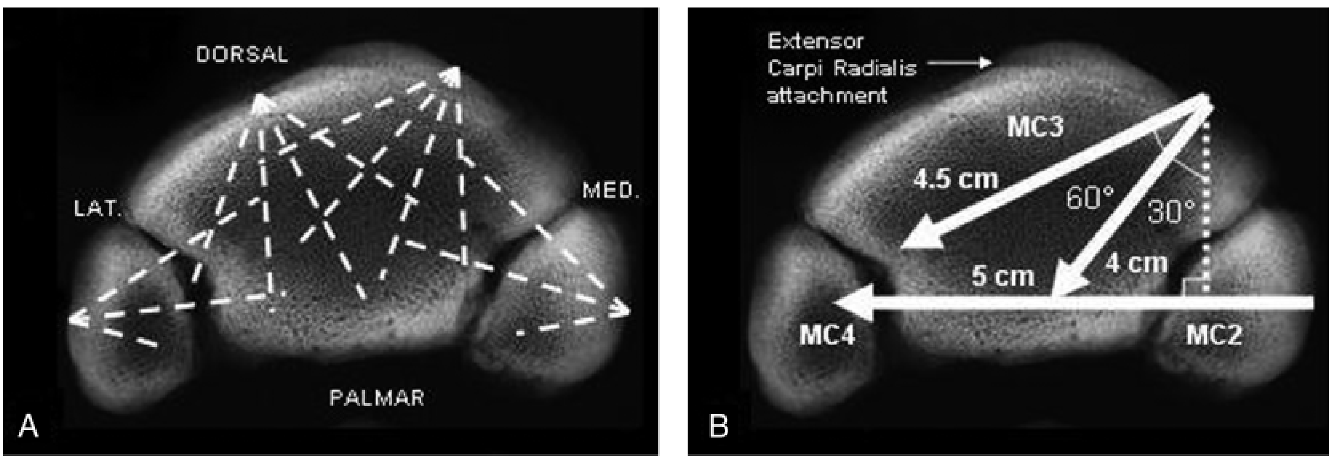

Fig 1. Schematic representation of the 3 drilling techniques shown on a transverse section. (A) Technique 1: fanning with a 4.5 mm drill bit inserted through 4 entry points. Dashed lines represent fanned drill tracts. (B) Technique 2 and 3: three drill tract technique with a 5.5 or 4.5 mm drill bit inserted through 2 medial entry points. Arrows represent 3 drill tracts. MC2, 2nd metacarpal bone; MC3, 3rd metacarpal bone; MC4, 4th metacarpal bone.

within the CMC joint confirmed fluoroscopically. Drilling was continued in a straight path for 5 cm.

Using the same technique, a drill bit was introduced into the C3/MC3 articulation just medial to the extensor carpi radialis tendon (dorsomedial entry point). Through this single entry point into the CMC joint, 2 drill tracts were made across the joint surface. The 1st tract was made at $\sim 30^\circ$ to the sagittal plane and extended for 4 cm. The 2nd tract was created by redirecting the drill through the original opening so that the tract was made $\sim 60^\circ$ from the sagittal plane and extended for 4.5 cm. Fluoroscopy was used to assure correct placement and advancement of the drill bit. All drilling was performed by 1 surgeon (L.P.) to standardize the procedure; however, without an alignment jig to ensure the orientation described above, drill bit placement was somewhat subjective and variable because it was on the surgeon's visual assessment.

Technique 3. Mirroring technique 2, a 4.5 mm bit was used instead of a 5.5 mm drill bit (Fig 1).

Joint Surface Evaluations

Gross observations and planimetry were each performed by 1examiner (A.A. and H.M.L., respectively) unaware of limb treatment group.

Gross Examination

Each limb was carefully disarticulated at the middle carpal and CMC joints using a scalpel blade. The proximal and distal articulating surfaces of the CMC joint were examined visually to subjectively evaluate the effects of each drilling technique. More specifically: whether the drill bit was advanced successfully within the joint space creating equal damage to the proximal and distal articulating surfaces, whether all articulations were equally affected, and how deep the drill tracts extended into the cartilage and entered the subchondral bone.

Planimetry of Articular Surfaces

Digital photographs were taken of the articulating surfaces of the CMC joint. To accomplish this C2, C3, and C4 were removed from the carpus as an intact row, and the MC2, MC3, and MC4 bones were cut as a unit with a band saw parallel to their proximal articular surface, at a thickness equal to that of the carpal bones. The 2 sections of bones were positioned with their palmar surfaces facing each other and their articulating surfaces facing up. Photographs were taken from directly above the specimens with a ruler positioned level with the articular surface.

Digital photographs were individually downloaded into a computer program (Northern Eclipse 6.0, Empix Imaging Inc., Mississauga, ON, Canada) and measurement calculations standardized using the ruler located in the photograph. Using a tracing tool the articulating surface of each bone was followed along its perimeter 3 times; the results were averaged to calculate the total articular area of each bone. The total area of the proximal and distal articular surfaces of the CMC joint and the total CMC joint surface were determined by the sum of the involved articular surfaces. The area of the visible drill tracts for each bone was measured in this manner to

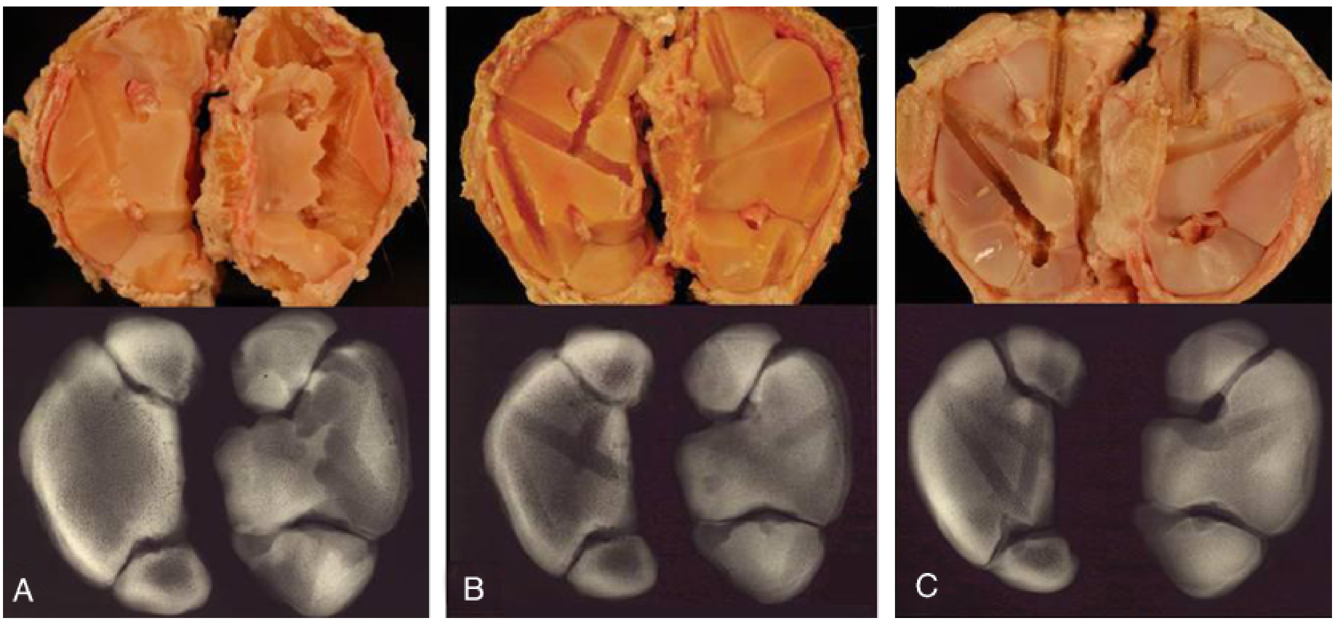

Fig 2. Photographs (top) and radiographs (bottom) of the articulating surfaces of the CMC joint showing the distal carpal (right) and proximal metacarpal bones (left). In each individual image the medial aspect is orientated to the top and the palmar surfaces face each other in the center. (A) Technique 1: note the limited damage to the subchondral bone of the MC surfaces (left) but the extensive damage to the surface of the carpal bones (right); (B) technique 2 (5.5 mm); and (C) technique 3 (4.5 mm). Note the more consistent biarticular pattern of damage to the articular surfaces and subchondral bone with techniques 2 and 3.

obtain the mean defaced area of each surface. Using these means, the percentage of defaced articular surface area was calculated for each bone, for the entire proximal articular (distal surfaces of C2, C3, and C4) and distal articular surfaces (proximal surfaces of MC2, MC3, and MC4) of the CMC joint independently, and for the cumulative articular surfaces of the CMC joint.

Planimetry of Microradiographs

The 2 sections of joined metacarpal and carpal bones used for photography were placed on radiographic cassettes in the same manner as for the photographs and radiographs taken with a Cabinet X-ray System (Faxitron Series, Hewlett–Packard, McMinnville, OR) at a setting that produced an image of sufficient quality so that drilling damage to the subchondral bone could be identified. An object of known length was included in each radiograph to allow for accurate area calculations.

Digital photographs of the radiographs were entered into the same computer program used for the photographs of the articular surfaces. Drill tracts that had reached subchondral bone were represented by areas of decreased bone density. The tracing tool was used to measure the area of the subchondral bone for each articular surface that was damaged by the drilling techniques and determine an average value for each bone. From these values, the percentage of articular area with damaged subchondral bone was calculated for each bone, for the entire proximal articular (distal surfaces of C2, C3, and C4) and distal articular surfaces (proximal surfaces of MC2, MC3, and MC4) of the CMC joint independently, and for the cumulative articular surfaces of the CMC joint.

Statistical Analysis

Data was checked for normality (GraphPad Prism Version 3.00, GraphPad Software Inc., San Diego, CA) then analyzed using ANOVA with post-hoc comparison using a Tukey's Multiple Comparison Test to examine the effect of technique on percentage of articular surface damage. $P<.05$ was considered significant.

RESULTS

Gross Examination

Drill tracts created using technique 1 (fanning) were angled proximally and produced widespread defacement of cartilage and bone of the proximal articulating surface of the CMC joint. In several places, the drill bit appeared to have reached the subchondral bone or had penetrated into cancellous bone; however, the distal articulating surface was less damaged and in many places the tracts appeared to be superficial to the bone (Fig 2).

With techniques 2 and 3, the drill tracts were generally maintained along the plane of the joint surface and produced approximately equal destruction of both opposing surfaces. The drill pattern was basically as expected, with some variation in orientation of the drill tracts to the carpus and between each other. In contrast, the surfaces of the C4/MC4 articulation seemed relatively untouched, especially with technique 3 (4.5 mm) compared with the major changes produced by technique 1 (Fig 2).

Planimetry of Articular Surfaces

Technique 1 resulted in more damage to the cartilage of all carpal bones and of the total proximal surface of the CMC joint than technique 3. Significant differences between technique 1 and 2 were only observed for the C4 articulation and the total combined proximal joint surface (42.1% versus 22.3%; Table 1, Fig 3).

For the bones of the distal joint surface, technique 1 resulted in significantly more damage to the surface of MC4 than the other techniques. Technique 2 produced significantly more damage than technique 3 for MC3. Techniques 1 and 2 produced the greatest amount of damage to the combined total distal joint surface (24.6% and 27.2%, respectively; Table 1; Fig 3).

When evaluating the effectiveness of the techniques for producing defacement of the bone for the entire CMC joint surface, techniques 1 and 2 were both significantly better (33.3% and 24.8%, respectively) than technique 3 (16.1%), but not different from each other (Table 1, Fig 4).

Planimetry of Microradiographs

The subchondral bone changes were very similar but not identical to those observed for planimetry of the articular surfaces. Technique 1 produced significantly more subchondral bone damage in every bone of the proximal articular surface, and therefore of the entire proximal joint surface (41.6%). Technique 2 only produced greater damage than technique 3 for C4 (Table 1, Fig 3).

For all of the distal articular surfaces of the CMC joint there was no difference between techniques 2 and 3. For the surface of MC2, technique 3 produced greater damage then technique 1, whereas techniques 2 and 3 were significantly different from technique 1 for MC3 and total distal articular surface (Table 1, Fig 3).

Techniques 1 and 2 were not significantly different from each other and both produced more damage (23.2% and 21.4%, respectively) to the total combined CMC joint surface then did technique 3 (14.6%; Table 1, Fig 4).

DISCUSSION

We evaluated the potential value of 3 drilling techniques to facilitate arthrodesis of the CMC joint based

Table 1. Mean Percentage (Range) Damage to the Articular Surface and Subchondral Bone Produced by 3 Drilling Techniques

% Damage	Technique 1 Fanning Technique (4.5 mm Drill Bit)	Technique 2 3 Drill Tract (5.5 mm Drill Bit)	Technique 3 3 Drill Tract (4.5 mm Drill Bit)
Articular surface			
C2	49.95 (18.22–70.28)	26.96 (4.66–35.83)	24.06 (12.97–31.77)
C3	36.76 (18.30–53.08)	25.34 (15.48–35.69)	16.36 (9.99–24.29)
C4	49.41 (34.11–69.00)	11.25 (0.00–18.83)	1.806 (0.00–9.03)
Total proximal CMC joint (carpal bones)	42.10 (34.04–52.87)	22.32 (10.51–29.84)	13.97 (10.38–19.81)
MC2	13.77 (0.00–28.31)	23.41 (11.15–32.97)	20.72 (8.98–27.46)
MC3	24.55 (15.16–31.68)	30.25 (20.31–38.31)	19.55 (12.32–24.61)
MC4	40.19 (19.68–77.52)	5.32 (0.00–24.67)	2.798 (0.00–7.80)
Total distal carpometacarpal joint (metacarpal bones)	24.57 (18.86–30.27)	27.17 (18.35–33.91)	18.17 (10.43–22.91)
Total carpometacarpal joint	33.31 (26.52–39.17)	24.78 (14.39–30.52)	16.09 (10.41–21.39)
Subchondral bone			
C2	39.46 (14.90–51.38)	19.45 (8.63–26.31)	17.08 (5.20–24.50)
C3	40.37 (32.99–46.94)	18.79 (8.52–29.90)	11.31 (6.97–17.44)
C4	46.67 (39.27–54.38)	12.92 (0.00–19.65)	1.38 (0.00–6.92)
Total proximal cmc joint (carpal bones)	41.60 (38.15–45.67)	17.58 (6.61–26.36)	9.96 (5.97–13.89)
MC2	1.65 (0.00–4.82)	16.91 (0.00–27.58)	18.41 (3.85–28.09)
MC3	4.47 (0.00–16.34)	31.24 (23.45–38.04)	23.55 (18.16–28.99)
MC4	2.93 (0.00–9.32)	2.268 (0.00–11.34)	0.780 (0.00–2.89)
Total distal carpometacarpal joint (metacarpal bones)	3.82 (0.00–12.81)	25.51 (16.96–32.76)	19.77 (13.64–24.75)
Total carpometacarpal joint	23.19 (20.10–26.78)	21.36 (16.61–24.15)	14.62 (10.73–19.01)

C2, 2nd carpal bone; C3, 3rd carpal bone; C4, 4th carpal bone; MC2, 2nd metacarpal bone; MC3, 3rd metacarpal bone; MC4, 4th metacarpal bone.

primarily on the total amount of articular cartilage and subchondral bone damage to all articular surfaces and its uniform distribution between the proximal and distal surfaces. Techniques 1 and 2 produced the most damage which was more evenly distributed with technique 2. Whereas the speed and ease of the techniques are important considerations they were not evaluated.

Technique 1 has been used successfully for CMC joint arthrodesis in horses with CMC-OA.[13–15] In our study, technique 1 produced damage to $\sim 33\%$ of the articular surface and although this was the most damage of the 3 techniques, it was not significantly more than that produced by technique 2 (24.8%). This suggests that technique 2 might be equally as effective for arthrodesis of the CMC joint.

Initial reports recommended damaging $\geq 60\%$ of the joint surface for arthrodesis of the distal tarsal joints.[11,16,17] Removal of $\sim 90\%$ of the articular cartilage has been associated with numerous complications and morbidity, and is not recommended.[18] Using a 4.7 mm drill bit, 5–6 tracts were required to damage 60% of the tarsal joint surface.[11] Either a 3.2 or 4.5 mm drill bit in a 3 drill tract technique, produced damage to $<60\%$ of the tarsal joint surface, and resulted in successful arthrodesis.[2] In reality, the amount of articular cartilage and subchondral bone that must be damaged to promote arthrodesis is unknown and may vary between joints; however, it appears from our study and the successful use of technique 1 clinically for CMC OA that $\sim 33\%$ is adequate for success arthrodesis of the CMC joint.[13–15] Whereas a large amount of damage (90%) has resulted in complications,[18] it seems logical that insufficient damage might not result in arthrodesis. Bone formation is not necessary throughout the entire joint surface as long as there are areas where bone formation unites the 2 articular surfaces.[4,5]

The CMC joint is formed by several bones and articulations that occupy more than a single plane. Technique 1 was originally developed to treat CMC-OA in hopes that insertion of the drill at multiple locations around the circumference of the joint, and moving the drill bit in a fanning manner, would produce sufficient cartilage and subchondral bone damage at the multiple articulations to promote CMC joint arthrodesis.[13–15] Whereas this technique was successful in producing arthodesis,[13–15] the amount of drilling is subjective and may result in longer anesthetic and surgery times than either techniques 1 or 2 because of the need for repositioning of the horse for insertion of the drill bit at 2 additional sites around the circumference of the carpus.

For arthrodesis to occur, the defect must penetrate the full thickness of the cartilage and extend into subchondral bone to allow bone formation between the subchondral surfaces.[19,20] Technique 1 produced excessive damage to both the articular surface and subchondral bone of the proximal surfaces of the CMC joint, but very limited damage to the subchondral bone of MC2 and MC3, which may affect the ability to consistently pro-

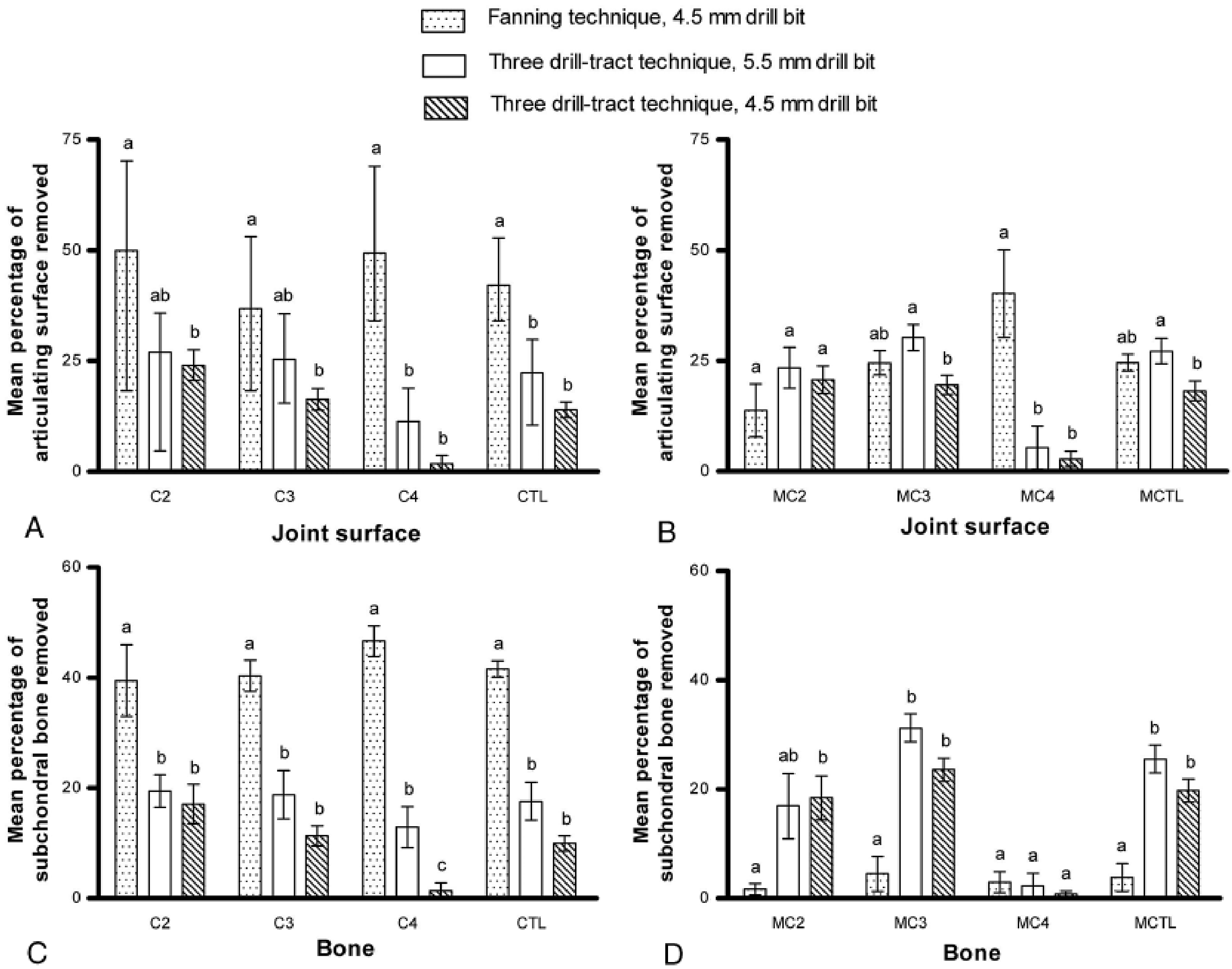

Fig 3. Mean percentage of articular surface (A and B) and subchondral bone (C and D) damage to the CMC joint surfaces, produced by the 3 techniques determined by planimetry of photographs and radiographs respectively. Techniques represented by different lower-case letters are significantly different ($P < .05$), whereas those represented by the same or including the same lower case letter are not significantly different. C2, 2nd carpal bone; C3, 3rd carpal bone; C4, 4th carpal bone; CTL, total proximal CMC joint (carpal bones); MC2, 2nd metacarpal bone; MC3, 3rd metacarpal bone; MC4, 4th metacarpal bone; MCTL, total distal CMC joint (MC bones). Error bars represent minimum and maximum values.

duce bony fusion. This difference in distribution of damage may be because of a tendency of the surgeon to rotate the handle of the pistol grip drill distally relative to the limb while drilling or because of the individual psychomotor pattern of the surgeon.

In contrast to technique 1, both techniques 2 and 3 produced articular and subchondral bone damage that was more equally distributed between the proximal and distal articular surfaces of CMC joint. These results are likely because of the less subjective nature of techniques 2 and 3, where the drill bit is passed in a single plane, and the repeated use of fluoroscopic guidance to determine the correct entry site and bit angulation during advancement. Use of intraoperative radiography or fluoroscopy is important for accuracy in any drilling technique and likely is very important for achieving successful arthrodesis and minimizing morbidity.

Technique 2 (5.5 mm) produced significantly more damage to both the articular surface and subchondral bone of the entire CMC joint than technique 3 (4.5 mm). Although the percent of articular surface damage needed to facilitate successful arthrodesis is unknown, it seems reasonable that the greater surface area of damage from technique 2 would likely result in arthrodesis in a more timely manner than technique 3. However techniques 1 and 2 may be equally successful in causing arthrodesis as

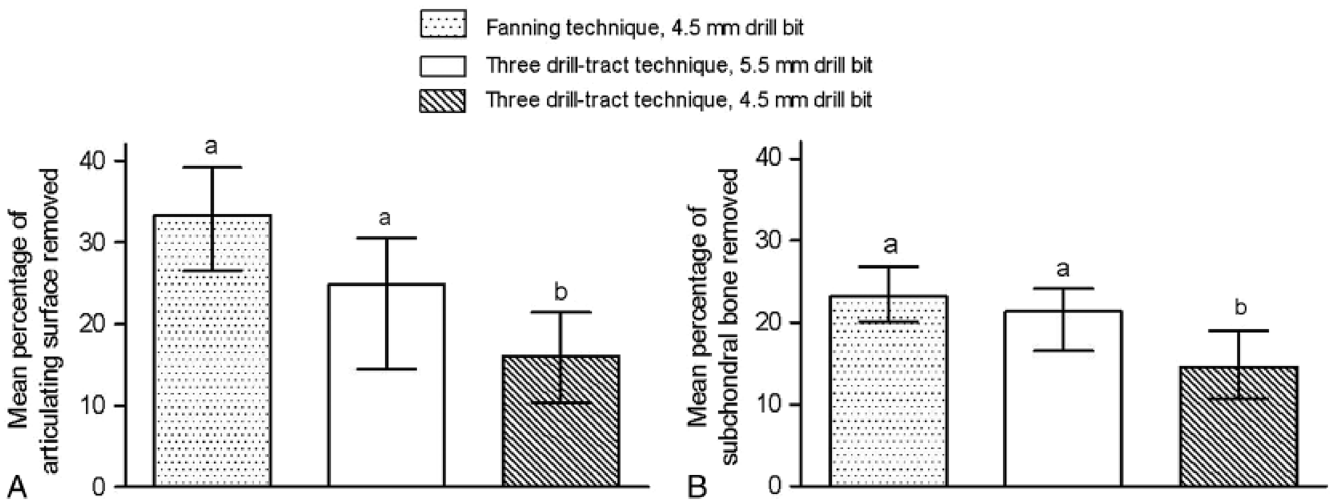

Fig 4. Total mean percentage of articular surface (A) and subchondral bone (B) damage to the entire CMC joint produced by the 3 techniques determined by planimetry of the photographs and radiographs, respectively. Techniques represented by different lower-case letters are significantly different ($P < .05$) whereas those represented by the same lower-case letter are not significantly different. Error bars represent minimum and maximum values.

the total amount of damage to the CMC joint produced by technique 2 was not significantly different from technique 1, which has been successful clinically.[13–15]

Technique 1 created more damage at the C4/MC4 articulation, both to the articular surface of both C4 and MC4, and to the subchondral bone of C4. This is because in technique 1, the drill bit was inserted directly into the C4/MC4 articulation. The importance of arthrodesis of the C4/MC4 articulation is unknown.

Technique 1 has been successfully used in CMC-OA to return horses to a lameness free condition without radiographic evidence of arthrodesis of the C4/MC4 articulation.[13–15] The likelihood of producing considerable damage to this portion of the articulation using either techniques 2 or 3 is low given that this articulation is located at a considerable distance from the 2 drill entry sites and is at a lower level than the rest of the CMC joint surface.

Based on our results, we recommend technique 2 (5.5 mm) for arthrodesis of the CMC joint because it resulted in comparable articular damage to technique 1 (fanning), which has been successful clinically. Further, technique 2 had more even distribution of damage to the proximal and distal surfaces, is less subjective and less invasive with 2 less entry points, and likely can be performed easier and quicker. Nevertheless, technique 1 (fanning) has been successfully used with minimal associated morbidity and no observed adverse effects on the communicating middle carpal joint.[13–15] Technique 3 (4.5 mm) has many of the advantages of technique 2 (5.5 mm), but we are uncertain if the lower proportion of articular surface destruction is sufficient to cause arthrodesis. Each of the 3 techniques tested might be successful at producing CMC joint arthrodesis. Further in-vivo research and histologic examination is warranted to compare the efficacy of both techniques 2 and 3 to produce arthrodesis and to assess associated morbidities.

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