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A retrospective multicenter study on the use of locking compression plates for scapulohumeral arthrodesis in small equids

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Abstract

Objective: To report on technical aspects and outcomes after scapulohumeral arthrodesis (SHA) with a locking compression plate (LCP) in small equids.

Study Design: Retrospective multicenter case series.

Animals: Client-owned Shetland Ponies, Miniature Shetlands, and American Miniature Horses ($n = 15$).

Methods: Inclusion criteria were completed SHA with an LCP to treat scapulohumeral osteoarthritis/subluxation and availability of postoperative radiographs. Contributing surgeons completed a questionnaire to collect data. All radiographs were reviewed for this study. Follow-up information was obtained via re-admission to the hospital or telephone interview of the referring veterinarian or owner. Outcome was subjectively scored as excellent, good, moderate, or poor based on lameness and function.

Results: Sixteen SHAs were performed in 15 equids (body weight 65–145 kg) by nine different surgeons. A narrow 4.5/5.0 mm LCP (7–16 holes) was used in 14 of the 16 SHAs. Follow-up was collected 2.5 years after surgery (median; range: 9 weeks to 10 years). Major complications related to the SHAs were noted in 4 of the 13 horses alive long term, consisting of implant failure

($n = 1$), surgical site infection ($n = 2$), and scapular fracture ($n = 1$). The outcome was graded as excellent in 4, good in 5, and moderate in 4 horses. Two ponies were euthanized because scapulohumeral osteoarthritis and subluxation developed in the contralateral limb.

Conclusion: Although major complications occurred in about one-third of ponies, SHA with LCP led to long-term survival with good function in most ponies.

Clinical Significance: SHA with an LCP offers a high chance for good long-term outcome in small equids although contralateral disease may affect outcome.

1 | INTRODUCTION

Osteoarthritis (OA) of the scapulohumeral joint is observed rarely in horses. However, this disease occurs more frequently in small equids such as Shetland ponies, Falabellas, and American Miniature Horses.[1] In these breeds, it can be associated with dysplasia and subluxation.[1] Lameness resulting from OA of the scapulohumeral joint can range from mild to severe. Although medical treatment including intra-articular injection of corticosteroids may result in transient alleviation of clinical symptoms, scapulohumeral arthrodesis (SHA) is the only therapeutic option that can provide permanent improved comfort. The technique of SHA in equids is well described.[2] However, the literature on complications and results achieved with SHA in equids is sparse.

Results achieved with SHA using a dynamic compression plate (DCP) are reported in three publications including a total of six equids.[3-5] Complications included implant infection, implant failure, and fracture of the scapula. The locking compression plate (LCP) is the implant of choice for surgical arthrodesis because of its superior biomechanical properties.[6-9] However, there is only one case report of a single Miniature Horse and a case series of four Shetland ponies that describe the use of an LCP for SHA.[10,11] In this limited number of ponies treated with an LCP, two cases of seroma (one of which became infected but responded to systemic antimicrobial treatment) were the only reported complications. Thus, using the LCP for SHA in small equids may offer a chance to improve outcome and reduce complication rates.

The aim of this study was to report on technical aspects and outcomes after SHA with an LCP in small equids. Our hypothesis was that SHA using an LCP would result in a favorable prognosis with regard to survival and animal's comfort.

2 | MATERIALS AND METHODS

For this retrospective case series, 24 ECVS-/ACVS-board certified surgeons from different academic and private equine hospitals in Europe, North America, and Australia were asked to contribute cases. To be included in the study, cases had to be ponies or Miniature horses of any size in which SHA was performed to treat scapulohumeral osteoarthritis and/or subluxation using an LCP and for which postoperative radiographs were available.

Data were collected on the basis of a questionnaire that was sent to the contributing surgeons. This questionnaire covered case data, history, preoperative clinical and radiologic findings, details of the surgical technique, implant specification, postoperative management, complications (subdivided into intraoperative, short-term, i.e., observed during hospitalization and long-term complications) and follow-up information (Supplemental Material: Questionnaire). Lameness was graded as mild, moderate, or severe at the walk and from 1 to 5 according to the modified American Association of Equine Practitioners (AAEP) scale at the trot.[12] The animal's comfort was assessed subjectively based on the ability to move willingly on pasture, to maintain social position in the herd's hierarchy, and the absence of signs of pain such as weight loss, abnormal behavior, pain face, or discharge positions. Preoperative and postoperative diagnostic imaging studies were reviewed by a board-certified radiologist (JSS), a board-certified equine surgeon (JMK), and the primary investigator (FS) for the purpose of this study. On preoperative radiographs, the focus was on the assessment of joint congruity (graded as present or absent), OA (graded as mild, moderate or severe), and on the presence of subluxation of the joint graded as present or absent. Postoperative radiographs obtained during hospitalization were evaluated for narrowing of the joint space, position of the implants, and complications. Furthermore, the angulation of the plate was measured on mediolateral projections. Radiographs obtained at the maximal follow-up interval of each case were assessed regarding degree of bony fusion (subjectively graded as absent, partial or complete) and complications associated with the surgical implants or bone/implant interface.

The contributing surgeons obtained follow-up information via re-admission to the hospital or telephone interview of the referring veterinarian or the owner. In some cases, the owners sent videos of the ponies at different gaits to evaluate residual lameness. The contributing surgeon graded the outcome based on the following scheme:

Excellent: Pony is free of lameness at walk and trot (or only mildly lame at trot) and can serve its intended function.

Good: Lameness reduced significantly compared to preoperatively; pony is sound or mildly lame at the walk, mildly lame at the trot, and comfortable on pasture.

Moderate: Lameness reduced significantly compared to preoperatively; pony is moderately lame at walk, moderately lame at trot, and comfortable on pasture.

Poor: No significant improvement in lameness or pony markedly lame at the walk and uncomfortable on pasture.

Four equids included in this study were published in a recent case series at the same time.[11]

3 | RESULTS

3.1 | Case data

This study included 15 equids from nine surgeons working in eight institutions (Table 1). Four equids were operated at the Department of Surgery and Anaesthesiology at the Domestic Animals Faculty of Veterinary Medicine Ghent University, three equids were treated at The Equine Specialist Hospital at the University of Queensland, and two ponies were contributed by the Equine Department Vetsuisse Faculty of the University of Zurich. Liphook Equine Hospital, the Department of Equine Surgery of the University of Bern, Donnington Grove Veterinary Surgery, the Equine Clinic Faculty of Veterinary Medicine Free University of Berlin, and the Department of Clinical Studies at the New Bolton Center University of Pennsylvania each contributed one case, respectively.

3.2 | Case history

The duration of lameness at the time of operation was 3 weeks to 6.5 years (median 3.5 months).

Eight ponies had been treated previously with systemic nonsteroidal anti-inflammatory drugs (NSAIDs) and in three ponies intra-articular corticosteroid injection had been performed at least once. In the other equids, there had been either no prior treatment or there was no information available concerning previous therapy.

3.3 | Clinical findings

Information on preoperative clinical findings was available in 13 equids. The majority of equids (8/13) showed severe lameness at the walk. Median lameness at the trot was 4/5 (range 3–5/5) according to the modified AAEP scale.[12] In two ponies, instability of the shoulder joint

TABLE 1 Case data

Case no.	Age at surgery (years)	Breed	Sex	Body weight (kg)	Use
1	19	Miniature shetland	Gelding	110	Pasture pet, carriage pony
2	7	Miniature shetland	Stallion	82	Pasture pet
3	10	Shetland pony	Gelding	145	Pasture pet
4	2	Miniature shetland	Mare	65	Pasture pet
5	5	Miniature shetland	Gelding	88	Pasture pet
6	3	Miniature shetland	Gelding	81	Pasture pet
7	3	Shetland pony	Stallion	105	Pasture pet
8	2	Shetland pony	Mare	65	Pasture pet
9	2	Miniature shetland	Stallion	83	n/a
10	4	Miniature shetland	Gelding	140	Pasture pet
11	11	Miniature horse	Gelding	102	Pasture pet
12	8	Miniature horse	Gelding	90	Pasture pet
13	3	Miniature horse	Mare	138	Breeding animal
14	4	Miniature shetland	Gelding	70	Pasture pet
15a, b	n/a	Shetland pony	Mare	n/a	n/a

Abbreviation: n/a: data not available.

was palpable, and in seven ponies, local swelling of the shoulder region was noted. In nearly all equids (12/13), local muscle atrophy was present. Five ponies resented manipulation of the limb or reacted painful to flexion. In two ponies, intrasynovial anesthesia of the scapulohumeral joint was performed and resulted in marked improvement of lameness.

3.4 | Preoperative radiography

Marked signs of OA were present in the affected scapulohumeral joint in all equids (Figure 1). In nine equids, the radiographs indicated subluxation of the joint. The proximal humeral physis was closed or narrowed radiographically compared to the contralateral limb in three 2-year-old ponies (Figure 2) indicating premature physeal closure (Figure 2). Eight of 14 contralateral shoulders that were examined radiographically were found incongruent, flattened, or shallow with osteoarthritic changes present additionally in five of these.

3.5 | Preoperative computed tomography

Computed tomography (CT) was performed in two ponies. In one of these, CT confirmed severe OA, medial subluxation of the humeral head, and an intra-articular fragment resulting from a fractured osteophyte. In the other pony, CT also confirmed severe OA, caudal subluxation of the humeral head, and premature closure of the physis of the humeral head (Figure 2). The contralateral shoulder was without relevant findings on CT in both ponies.

3.6 | Surgical technique

SHA was performed unilaterally in 14 equids and bilaterally in one pony using the technique described previously.[2] Osteotomy of the intermediate tubercle was performed in all SHAs except 1 (No. 13). Similarly, a complete biceps tenotomy was performed in all surgeries except 1 (No. 13) that only had partial transection of about half the width of the tendon. One surgeon, who contributed four cases (Cases No. 5–8), removed part of the supraglenoid tubercle to achieve better contouring of the plate and performed temporary osteotomy of the greater tubercle with final reattachment using either a 4.5 mm or a 5.5 mm cortex screw inserted in lag fashion.

To protect the suprascapular nerve from iatrogenic damage,[13] a Penrose drain was used for isolation and manipulation of the nerve. Subsequently, the plate was either placed over the nerve or underneath the nerve, or a groove

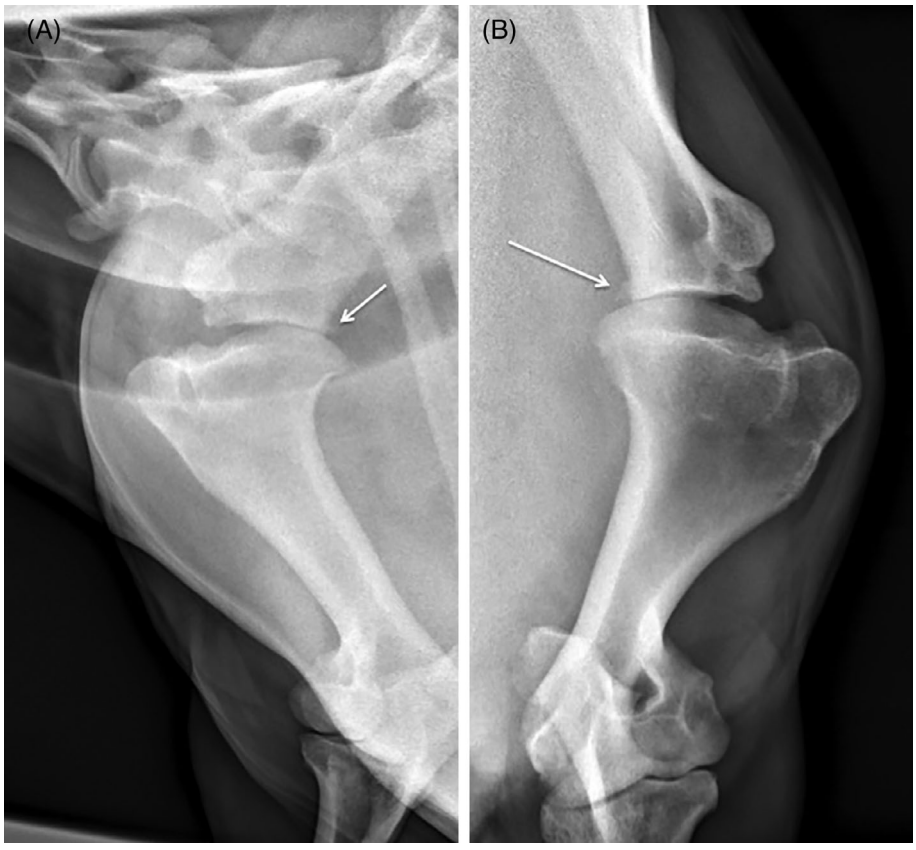

FIGURE 1 (A) Preoperative mediolateral radiographic projection of Case No. 13. Marked flattening of the glenoid cavity and incongruity with the humerus are evident. The width of the joint space is reduced caudally. The subchondral bone of the scapula is mildly sclerotic. The osteophyte at the caudal aspect of the glenoid cavity (white arrow) is not easy to see. (B) Preoperative craniomedial-caudolateral radiographic projection of Case No. 13. The osteophyte at the articular margin of the scapula is obvious (white arrow). Both projections together reveal caudomedial subluxation of the humeral head

FIGURE 2 Preoperative mediolateral radiograph and sagittal computed tomography (CT)-reconstruction of the left (A) and right (B) shoulder of Case No. 4. Apart from osteoarthritic changes, the left radiograph reveals caudal subluxation of the humeral head. The radiographic and CT image of the left shoulder indicate premature closure of the proximal humeral physis. In contrast, the proximal humeral physis on the right is open physiologically and can be clearly identified (white arrows)

was created in the scapula to accommodate the nerve. If the plate was placed over the nerve, the plate was contoured in a manner that left a gap between the plate and the nerve. Arthroscopy was performed in one pony (Case No. 13) and revealed full thickness cartilage erosion. Cartilage removal was performed in all surgeries except 1 (No. 3). A curette was always used for this purpose, supplemented by an oscillating saw in three ponies and a motorized burr in one pony. Based on surgeon's assessment, cartilage removal was considered complete in eight but only partial in six equids (including Case No. 15 that was operated bilaterally). Osteostixis was performed in nine joints using a 3.2 mm or a 2.5 mm drill bit.

Six ponies had antibiotic-impregnated material applied alongside the implants (gentamicin-impregnated collagen sponges or amikacin-impregnated plaster of Paris beads) at the end of the surgical procedure.

3.7 | Implant specification

In two SHAs, a 3.5 mm LCP was used, while in all other surgeries, a 4.5/5.0 mm LCP was applied (Figure 3, Table 2). In the two surgical procedures using a 3.5 mm LCP, plate screws were 3.5 mm LS or 3.5 mm CS. If a 4.5/5.0 mm LCP was used, plate screws were 4.5 mm CS or 5.0 mm LS, except in two ponies that had 4.0 mm LS implanted. One of the 3.5 mm plates was a broad LCP, but all other plates were narrow. Median length of the plate was 11 holes (range 7–16). Transarticular plate screws were placed in all SHAs and additional lag screws were placed across the joint in five SHA procedures. One or two plate screws were inserted in load position to achieve compression across the joint eight in SHAs. Four equids (with five operated joints) had an additional implant, that is, a 1.5 mm stainless steel wire used as a caudal tension band. The wire was inserted through holes drilled from craniproximal to caudodistal in the scapula and craniodistal to caudoproximal in the humerus, wrapped around the plate, and tightened on both ends.

The median plate angle was 113° (range 95°–130°) (Table 2).

3.8 | Postoperative management

Recovery from general anesthesia was hand-assisted in all cases. Postoperatively, all equids were treated with antibiotics and NSAIDs. Median duration of antimicrobial therapy was 10 days (range 5–48 days). NSAIDs were administered a median of 16 days (range 6–30 days). In 12 equids, additional analgesics (lidocaine CRI, methadone CRI, ketamine CRI, morphine IM, gabapentin PO or fentanyl patches) were administered in the first days after surgery. Two ponies were cross-tied for 10 days or 2.5 weeks, respectively. Box rest was prescribed for

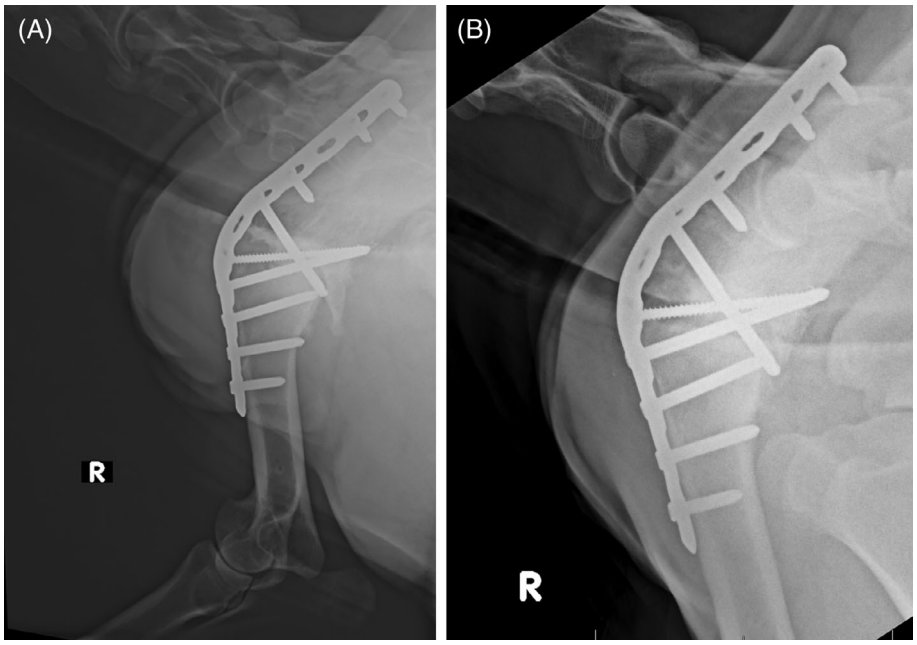

FIGURE 3 (A) Postoperative mediolateral radiographic projection of Case No. 1. A narrow 11-hole 4.5/5.0 mm locking compression plate (LCP) was implanted. The third hole from proximally was left unfilled because the suprascapular nerve was located underneath. Three plate screws, a 4.5 mm cortex screw and 2 5.0 mm locking head screws, were placed transarticularly. (B) Follow-up mediolateral radiographic projection obtained 14 months postoperatively

TABLE 2 Implant specification

Case no.	Length of LCP	Broad/ narrow	Size of LCP	Angulation applied to the plate	Number of plate screws in load position	Number of trans-articular plate screws	Additional implants
1	11-hole	Narrow	4.5/5.0 mm	123°	n/a	3	None
2	16-hole	Broad	3.5 mm	118°	n/a	1	None
3	16-hole	Narrow	4.5/5.0 mm	120°	0	1	None
4	9-hole	Narrow	4.5/5.0 mm	110°	0	2	None
5	11-hole	Narrow	4.5/5.0 mm	103°	2	2	5.5 CS to fix the transected greater tubercle of the humerus
6	11-hole	Narrow	4.5/5.0 mm	108°	2	3	4.5 CS to fix the transected greater tubercle of the humerus
7	12-hole	Narrow	4.5/5.0 mm	98°	2	2	4.5 CS (and washer) to fix the transected greater tubercle of the humerus
8	11-hole	Narrow	4.5/5.0 mm	117°	2	2	4.5 CS (and washer) to fix the transected greater tubercle of the humerus
9	12-hole	Narrow	4.5/5.0 mm	95°	1	2	None
10	10-hole	Narrow	4.5/5.0 mm	110°	1	2	1.5 mm stainless steel wire around caudal aspect of the shoulder joint. One 5.5 mm nonplate trans-articular CS (and washer) in lag fashion

TABLE 2 (Continued)

Case no.	Length of LCP	Broad/ narrow	Size of LCP	Angulation applied to the plate	Number of plate screws in load position	Number of trans-articular plate screws	Additional implants
11	8-hole	Narrow	4.5/5.0 mm	120°	1	1	1.5 mm stainless steel wire around caudal aspect of the shoulder joint. Two 5.5 mm nonplate trans-articular CS in lag fashion
12	9-hole	Narrow	4.5/5.0 mm	115°	1	4	1.5 mm stainless steel wire around caudal aspect of the shoulder joint. One 5.5 mm nonplate trans-articular CS (and washer) in lag fashion
13	12-hole	Narrow	4.5/5.0 mm	105°	0	2	None
14	10-hole	Narrow	4.5/5.0 mm	115°	0	2	None
15a	7-hole	Narrow	4.5/5.0 mm	112°	n/a	1	1.5 mm stainless steel wire around caudal aspect of the shoulder joint. One 4.5 mm nonplate trans-articular CS in lag fashion
15b	8-hole	Narrow	3.5 mm	130°	n/a	1	1.5 mm stainless steel wire around caudal aspect of the shoulder joint. One 4.5 mm nonplate trans-articular CS (and washer) in lag fashion

Abbreviations: CS: Cortex screw; LCP: locking compression plate; n/a: information not available.

2 months in median, ranging from 6 weeks to 6 months. Light hand grazing and light walking exercise were started between 2 weeks and 2 months postoperatively. Pasture turnout was allowed at a median of 3 months after surgery (range 2–8 months).

3.9 | Intraoperative complications

The only intra-operative complication was one broken tap or two broken drill bits, respectively, that remained in the scapula without any further consequences.

3.10 | Short-term complications

Four equids developed short-term complications related directly to surgery: two surgical site infections, one seroma, and one fracture of the scapula. Surgical site infection resolved with medical therapy in one of these equids, but the other equid finally required implant removal to resolve infection. The sagittal fracture of the distal part of the scapula with a dislocated lateral fragment occurred when the pony was walking from the recovery box back to its barn. On radiographs, it seemed that the fracture occurred at the level of the second most proximal plate screw and the proximal hole for the caudal tension band wire. The construct remained fairly stable, the pony remained comfortable in the box and at the walk, and no further measures were taken.

There were some other short-term complications that occurred during hospitalization but which were not specifically related to surgery. All these non-specific complications responded to medical therapy (Table 3).

TABLE 3 Complications and outcome

Case no.	Complications	Treatment of complications	Implant removal	Outcome[a]
1	None	None	No	Good
2	Intraoperative breakage of one tap	None	No	Excellent
3	Intraoperative breakage of two drill bits Breakage of all screws in the scapula and of one transarticular screw	Intra-articular ethanol injection 12 and 14 months postoperatively	No	Good
4	Loosening of two screws in the scapula	None	No	Moderate
5	Postoperative seroma	Prolonged postoperative systemic antibiosis (26 days)	No	Good
6	None		No	Moderate
7	Surgical site infection with streptococci and staphylococci spp.	Prolonged postoperative systemic antibiosis (16 days) resulted in resolution of infection	No	Moderate
8	None	None	No	Good
9	None	None	No	Excellent
10	Postoperative pneumonia	Systemic antibiosis (7 days)	No	Excellent
11	Corneal abrasion. Colitis. Contralateral scapulohumeral OA and subluxation 4 months postoperatively	Antibiotic eye ointment Medical colitis therapy	No	Euthanasia 4 months postoperatively
12	Corneal abrasion Postoperative pneumonia. Implant infection with fistulous tract 9 months postoperatively. Contralateral laminitis Contralateral scapulohumeral OA and subluxation	Antibiotic eye ointment. Systemic antibiosis (7 days)	No	Euthanasia 9 months postoperatively
13	Implant infection	Prolonged postoperative systemic antibiosis (48 days) and implant removal	Yes, 12 months postoperatively	Moderate
14	Colitis and hyperlipemia	Medical management	No	Good
15a	Scapular fracture	None	No	Excellent
15b	Breakage of one plate screw in the scapula	None	No	Excellent

[a]Outcome as judged by the contributing surgeon. *Excellent*: Pony is free of lameness at walk and trot (or only mildly lame at trot) and can serve its intended function. *Good*: Lameness reduced significantly compared to preoperatively; pony is sound or mildly lame at the walk, mildly lame at the trot, and comfortable on pasture. *Moderate*: Lameness reduced significantly compared to preoperatively; pony is moderately lame at walk, moderately lame at trot, and comfortable on pasture. *Poor*: No significant improvement in lameness or pony markedly lame at the walk and uncomfortable on pasture.

3.11 | Long-term complications

Five horses developed long-term complications: three implant failures, one contralateral shoulder subluxation, and one implant infection plus contralateral shoulder subluxation plus contralateral laminitis. Two cases of implant failure were minor and did neither seem to impair the stability of the construct nor result in clinical problems. Major implant failure was detected 7 weeks postoperatively in another pony and was managed successfully by intra-articular ethanol injection performed 12 and 14 months after the arthrodesis. Radiographs obtained another year later showed progressive ankylosis. In one pony, subluxation of the contralateral shoulder was diagnosed 4 months postoperatively. The owner was pleased with the outcome of the operated limb but did not consent to contralateral SHA and the pony was euthanized. The other pony had implant infection

FIGURE 4 Follow-up mediolateral radiographic projection of Case No. 13 obtained 3 years after the arthrodesis procedure shows complete ankylosis. This pony had implant removal performed 1 year postoperatively to resolve infection. The shaft of a 4.5-mm cortex screw broke and was left in the bone

recognized 9 months postoperatively because a fistulous tract developed at that time. This pony also showed instability and subluxation of the contralateral shoulder as well as contralateral laminitis and was euthanized (Table 3).

3.12 | Implant removal

As mentioned above, implants were removed in one pony 12 months after arthrodesis surgery to resolve infection. During the procedure, one screw in the scapula broke and could not be removed (Figure 3). No other equids had implant removal (Table 3).

3.13 | Follow-up

Median follow-up time was 2.5 years postoperatively (range 9 weeks to 10 years). Information was obtained by re-admission to the hospital in nine cases, telephone interview of the referring veterinarian in one case, and by telephone interview of the owner in five cases.

Thirteen out of 15 (87%) equids survived long term. Outcome was graded as excellent in 4, as good in 5, and as moderate in 4 equids. As mentioned above, two equids were euthanized. Follow-up radiographs were available in nine equids with a median interval between surgery and radiographic re-examination of 14 months (range 2 months to 8 years). Complete bony fusion was observed in five equids (Figure 4), and partial bony fusion in the other four equids. One of these ponies was followed out to 4 years and only had radiographic signs of incomplete ankylosis.

4 | DISCUSSION

This study shows that ponies suffering from OA with or without subluxation of the scapulohumeral joint and not responding to conservative therapy have a good prognosis when treated by SHA using an LCP. Overall, the LCP construct provided sufficient stability in 15 of the 16 SHAs.

All equids included in the study were miniature breeds suffering from scapulohumeral OA/subluxation. Lameness was usually chronic corresponding to the degenerative nature of the condition, although the onset of lameness can be acute. It is assumed that scapulohumeral OA in miniature breeds can result from underlying dysplasia and instability of the joint.[1] The dysplasia is characterized by a flat and shallow glenoid cavity.[14] This goes in line with the results of our study in which joint incongruity with a shallow glenoid cavity and subluxation was present in the majority of equids. Radiographic imaging is the method of choice to diagnose scapulohumeral OA with a mediolateral projection as the standard technique. A craniomedial-caudolateral oblique view can be more sensitive to detect early abnormalities.[1,15] However, this projection was only available in three equids in our study (Figure 1). An interesting—and previously unreported—finding was premature physeal closure of the humeral head on the affected side in three ponies. Interestingly, premature closure of the proximal humeral physis can lead to deformity of the humeral head and joint instability in dogs.[16] Radiographic examination should be performed bilaterally. This recommendation is based on the following findings of our study: contralateral shoulder joint dysplasia was detected in 8 of 14 equids (57%) that had contralateral radiographs taken preoperatively, osteoarthritic changes were present in 5 of these 8 joints (62%), and there is a potential impact of contralateral disease on long-term outcome. CT imaging represents an excellent modality to

reveal the three-dimensional nature of the bony changes associated with OA and eventually dysplasia or subluxation of the scapulohumeral joint. CT was performed in two ponies in this study and confirmed the radiographic findings but did not reveal additional pathologies. For this reason, CT seems not mandatory in the diagnostic work-up before SHA.

Concerning surgical technique for arthrodesis, the standard approach[2] was used including osteotomy of the intermediate tubercle and transection of the biceps tendon, and found to be adequate by the surgeons. The only major modification was temporary osteotomy of the greater tubercle that was performed by one surgeon in 4 out of the 16 SHA procedures. Outcome in those four equids was good and no complications arose from this modification.

The sparse information on SHA in the equine literature limits comparative assessment of the results achieved in our study. Comparing our results with those achieved in the six procedures reported with SHA using a DCP[3-5], infection rate (3/16 procedures in our study vs. 2/6 in the literature), implant failure rate (3/16 in our study vs. 3/6 in the literature), and scapular fracture rate (1/16 in our study vs. 1/6 in the literature) are lower in our study while final outcome seems similar but numbers are too low to draw firm conclusions.

A complication that is directly related to biomechanics is implant failure. The implant failure rate of 19% in our study is lower than in previous studies[3-5] but still deserves some attention. Breakage of a 3.5 mm screw in one pony can be related to the smaller radius and therefore exponentially lower area moment of inertia and bending stiffness compared to larger diameter screws.[17] This single screw breakage as well as loosening of two LS in another pony did not seem to have a significant effect on stability of the construct and final outcome. The most significant case of implant failure occurred in the heaviest equid in this study with a body weight of 145 kg. In this pony, a very long, that is, a 16-hole, 4.5/5.0 mm LCP was used. However, some technical aspects of the repair might have rendered it prone to implant failure: only one transarticular screw had been placed in lag fashion, no plate screw was placed in load position and it was the only pony in which cartilage removal had not been performed. Thus, adequate reduction and compression of the joint were not achieved resulting in increased stress for the implants. This phenomenon has been observed previously in other anatomical locations such as the cervical spine.[18] Body weight alone cannot be the reason as successful arthrodesis was reported in a 250 kg Arabian filly in the literature.[4]

It is likely that biomechanical advantages of the LCP contribute to the relatively low implant failure rate in this study. The locking system allows creation of an angle-stable construct that proved biomechanically superior in an experimental study.[19] The large core diameter of locking head screws further contributes to bending stiffness and constructs stability.[17] The LCP allows stable constructs even if not all holes of the plate are filled with a screw.[20] Furthermore, there is no need of perfect contouring of the LCP, as stability does not rely on the friction between the plate and the bone. Imperfect contouring should be taken into account when the angulation of the plate and the joint are considered during arthrodesis. In general, a scapulohumeral joint angle of approximately 120° is recommended.[2] However, imperfect contouring of the plate means that the angle applied to the plate does not directly reflect the angle of the joint. This explains the median angulation of the plate of 113° in this study.

As in a previous case series,[5] a scapular fracture occurred as a postoperative complication in our study. This occurred in a pony that had an additional wire implanted with the idea of creating a caudal tension band. It is unclear whether the additional holes for the wire, stress concentration along the screws arranged longitudinally in the narrow plate, or other factors contributed to this fracture. Despite the fracture, overall construct stability was sufficient to allow progressive ankylosis and a good clinical outcome.

A minor complication in our study was transient seroma formation. While implantation of a closed active suction drain system during surgery could avoid seroma formation, there is some risk of retrograde infection.[21] For this reason, none of the equids in this study had a drain system installed at surgery.

Despite some major short- and long-term complications, the overall clinical outcome regarding the operated limb was good in all equids of our study. Two equids (Cases No. 11 and 12) were euthanized, not as a result of lack of success of surgery on the primarily affected limb, but because of OA and subluxation of the contralateral shoulder several months postoperatively. In both cases, radiographs of the contralateral shoulder had been obtained preoperatively but had not revealed relevant findings apart from mild dysplasia in Case No. 12.

All other ponies could return to their intended, non-athletic use and became at least comfortable on pasture. Furthermore, it is interesting to note that the mechanical gait anomaly in ponies with an excellent or good outcome is only minor. This is important to know when SHA is discussed as a possible treatment option with owners or referring veterinarians. One pony of the study was a brood mare. However, owners should not be encouraged to breed with affected equids, as it is plausible to assume that dysplasia of the scapulohumeral joint

is, among other causes, genetically determined although specific studies on the heritability are lacking in the equine species.[14]

Since this is a retrospective multicenter study, conditions were not standardized. Surgical technique, case management, quality, and duration of follow-up, as well as interpretation of outcome may differ among the contributing surgeons. To minimize this bias, all radiographs that were available were re-assessed by the same board-certified radiologist and board-certified surgeon for the purpose of this study.

In conclusion, SHA using an LCP can be recommended as a good therapeutic option for small equids with OA that can be associated with dysplasia and subluxation. Even if short- or long-term complications develop, a good outcome can be achieved. Affected ponies or miniature horses can return to pasture soundness and become comfortable at all gaits with often only a slight mechanical gait anomaly remaining. Concerning surgical technique, use of a narrow 4.5/5.0 mm LCP and effective compression of the joint achieved by cartilage removal and transarticular screws is recommended. Radiographs of the contralateral shoulder should be obtained prior to surgery as bilateral shoulder joint pathology is quite common. Even if there are no significant radiographic findings in the contralateral shoulder at this time point, the owner should be made aware that the animal may still develop OA of the contralateral shoulder joint which can have a strong impact on the overall outcome and require a second arthrodesis procedure.

CONFLICT OF INTEREST

The authors declare no conflict of interest related to this study.

AUTHOR CONTRIBUTION

Fabienne Somm: Study organization, data collection, drafting of the manuscript, approved the final version of the manuscript. José Suárez Sánchez-Andrade: Data collection, data analysis, manuscript revision, approved the final version of the manuscript. Ann Martens: Data collection, manuscript revision, approved the final version of the manuscript. Steven T. Zedler: Data collection, manuscript revision, approved the final version of the manuscript. Micael D. Klopfenstein: Data collection, manuscript revision, approved the final version of the manuscript. Jane C. Boswell: Data collection, manuscript revision, approved the final version of the manuscript. Bruce M. Bladon: Data collection, manuscript revision, approved the final version of the manuscript. Christoph J. Lischer: Data collection, manuscript revision, approved the final version of the manuscript. Dean W. Richardson: Data collection, manuscript revision, approved the final version of the manuscript. Jörg A. Auer: Data collection, manuscript revision, approved the final version of the manuscript. Anton E. Fürst: Study design, data collection, manuscript revision, approved the final version of the manuscript. Jan M. Kümmerle: Study initiation, study design, data analysis, drafting of the manuscript, approved the final version of the manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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