DR. PAOLO RAVANETTI (Orcid ID : 0000-0001-6558-3989)

Article type : General Article

Reference number: EVJ-GA-20-344.R1

A composite absorbable implant used to treat subchondral bone cysts in 38 horses

Paolo Ravanetti[1], Antoine Lechartier[2], Muriel Hamon[2] and Enrica Zucca[3]

[1]Equitecnica Equine Hospital, Parma, Italy;

[2]Clinique Veterinaire Equine Méheudin, Ecouché, France and

[3]Università degli Studi di Milano, Department of Veterinary Medicine, Milan, Italy.

*Corresponding author email: ravauno@gmail.com

Keywords: horse; different anatomical locations; subchondral bone cyst; absorbable; implant

Running title: Absorbable implant to treat equine bone cyst

Summary

Background: In the last 30 years, several treatments have been proposed to treat subchondral cystic lesions (SCLs) but there have been no randomised studies to compare different methods and there is no consensus as to the optimal treatment.

Objectives: To evaluate a biocompatible absorbable implant for the treatment of SCLs in young horses in different anatomical locations.

Study design: Retrospective case series.

Methods: Horses with SCLs were treated with debridement through a trans-cortical extra-articular approach and an absorbable implant was inserted in the cavity. Clinical and radiographic follow-up was recorded and follow up ranged from 28 to 46 months (mean 37 months). Racing records

were reviewed.
Results: Thirty-eight horses between 10 and 24 months of age were included in the study. In 36 out 38 horses treated, lameness resolved, and 77% average filling of the cyst was measured 120 days after surgery on radiographs. In two cases, surgical complications were recorded.
Main limitations: Information about the resorption of the implant is not available. Radiographs were performed in various hospitals or at farms or training stables, therefore, possible minor variations in technique and positioning occurred.
Conclusions: The extra-articular approach to the SCLs followed by the insertion of the absorbable implant led to clinical and radiographic improvement of the SCLs at 120 days after surgery. This technique, feasible in different anatomical locations, may offer an alternative to treat SCLs in young horses.

Introduction

Subchondral cystic lesions (SCLs) can involve most bone segments but are located frequently in the medial femoral condyle (MFC) and less frequently in the phalanges, metacarpus/metatarsus, radius, scapula, tibia, and carpal bones [1]. Recently, a study demonstrated the presence of SCLs in cervical vertebrae [2]. SCLs located close to or in communication with a joint, especially in weight-bearing locations, are likely to cause lameness [1,3,4]. The pathogenesis is controversial; several theories have been hypothesised and include the hydraulic theory, where synovial fluid is pulled through the subchondral bone into the cancellous bone via a slit-like lesion in the cartilage [5]; and the inflammatory theory, in which SCLs become lined with fibrous tissue that secretes inflammatory mediators including PGE2 and IL-6 [6]. SCLs can also develop following primary damage of the subchondral bone with collapse of the articular surface [5,7]. Finally, osteochondrosis or a combination of the aforementioned processes are proposed causes of SCLs development [1,5–7]. In humans, venous obstruction to the bone blood supply has been suggested as being the most probable cause of bone cysts [8].

The scientific literature cites medical and surgical options for SCLs, based upon patient age, skeletal maturity, lesion location and size. Several medical treatments like rest, joint or SCL injection with steroids, plasma derived products, and stem cells have been reported [1,9]. Surgical treatments as bone filling with bone morphogenetic protein-2, stainless steel transcondylar screws, simple debridement, osteochondral grafts, bone substitutes, allogenic cartilage and mosaic arthroplasty have also been described [1,9–13]. To date, there have been no randomised studies to compare different methods and there is no consensus as to the optimal treatment.

In equine orthopaedic surgery, absorbable implants made of synthetic polymers, such as polyglycolide, poly L-lactic acid (PLLA) or poly-dioxanone, have been described for fracture fixation, angular limb deformities correction and bone grafting [14–16]. A number of ceramic analogues of bone (e.g. hydroxyapatite, tricalcium phosphate) have shown promise because they have good tissue compatibility and bond directly to native bone without an intermediary layer of connective tissue [17]. These materials and related composites (e.g. hydroxyapatite/polymer) are essentially osteoconductive matrices, acting as substrates that provide a favourable scaffolding for vascular ingress, cellular infiltration and attachment cartilage formation [8,17]. The aim of this study was to evaluate the use of a composite absorbable implant for the treatment of SCLs in different anatomical locations in young horses. The selected implant, that reproduces the biological bone, was composed of nano-hydroxyapatite (μ-HA) and calcium phosphate, mixed with PLLA that is reported to be bioabsorbable, biocompatible, osteoinductive and osteoconductive [8]. We hypothesised that extra-articular decompression of the SCL by drilling [9,18], followed by curettage and placement of an absorbable implant would improve radiographic appearance, enhance healing of the subchondral lesion, and resolve lameness.

Materials and Methods

Materials: The implant (Osteotrans-OT[1]) is made as a forged composite of unsintered nano-hydroxyapatite (μ-HA) and poly L-lactic acid (PLLA). The composite implant is described as containing 30 weight fractions of raw uncalcined, unsintered HA particles with a particle size, 0.2–20 μm (average, 3–5 μm); Ca/P = 1.69 (mol, ratio); and $CO3^{2}$= 3.8 (mol%) mixed with PLLA. The μ-HA and carbonate ion act as a filler while the polymeric substance (PLLA) serves as a matrix. A pin of 4.6 mm diameter was used for lesions with a diameter less than 9 mm, while a 9 mm interference screw was selected for larger lesions (Figure 1C).

Subjects: Medical records of horses presenting to eight different Equine Hospitals (Data S1), for evaluation of lameness between January 2017-June 2018 were reviewed. Inclusion criteria included a diagnosis of SCL as the cause of lameness, the presence of lesions equal to or larger than 8 mm and < 10 mm from the articular surface, surrounded by a variably sclerotic edge. Cases were excluded if there was any history of previous treatment (surgical or medical) or if the horses were not lame. The authors and the referring veterinarians evaluated lameness using the AAEP scale [19] and digital standard radiographic projections were carried out. Examinations were performed at walk and trot. When possible, intra-articular diagnostic anaesthesia was performed to confirm SCL as the cause of lameness. Preoperative records included demographic data, results of orthopaedic examination, degree of lameness, results of diagnostic analgesia, and radiographic findings. Treatment options, including placement of a bioabsorbable screw, were discussed with owners and informed client consent forms were signed.

Radiographic diagnosis: Caudo-cranial and latero-medial projections, for MFC and proximal radius were made with an exposure of 80/70 kV and 3.2 mAs respectively, while dorsopalmar/plantar projections for the distal limb were made using 70/60 kV and 2.2 mAs. The lesions were measured in width and height on caudo-cranial and dorso-plantar/palmar projections (Figure 1A, B).

Surgical technique: All horses were pre-medicated with procaine penicillin 22,000 UI/kg IM and flunixin meglumine 1.1 mg/kg IV. Surgery was performed under general anaesthesia, maintained with inhalation of isoflurane. The horses with lesions in the radius, phalanges or carpal bone were placed in lateral or dorsal recumbency depending on the surgeon's preference, while all horses with MFC lesions were placed in dorsal recumbency. Aseptic preparation of the surgical site was done with standard techniques. Surgical treatment involved a trans-cortical extra-articular approach to the cyst to facilitate curettage, irrigation, and placement of an absorbable implant, under radiographic guidance. The technique required several radiographic views intra-operatively; fewer radiographs were required as the surgeon became comfortable with the procedure.

Surgical procedure for radius, phalanges and carpal lesions: The lesion was located with dorso-palmar and latero-medial radiographic views for phalanges and carpal lesions while cranio-caudal and medial-lateral views for the radius, using an 18G needle as a skin-marker (Figure 2A, B). Through a stab incision, a 4.5 mm drill bit was positioned as parallel as possible, to intersect the SCL, avoid penetration of the subchondral bone and articular cartilage (Figure 2C, D). Using a 2 mm Cobb curette, intra-lesional debridement was performed and the lesion was flushed with saline. To select the proper pin length, a depth gauge was used to measure the distance between the bone edge and about the centre of the cystic cavity (Figure 2E). A 4.6 mm pin was inserted, using a pin-driver and a mallet, until reaching the middle of the lesion (Figure 2F). The subcutis was sutured with absorbable monofilament suture (poliglecaprone 25 n. 2-0) and the skin incision with non-absorbable monofilament suture (nylon n. 2-0). The limb was bandaged.

Surgical procedure for MFC lesions: The lesion was located on caudo-cranial and latero-medial radiographic views using an 18G needle as a skin-marker (Figure 3A, B). A 1 cm skin incision was made directly down to the bone of the epicondylar fossa. A 4.5 mm hole was drilled across the medial condyle, cranial to the collateral ligament, and angled distally to intersect the SCL (Figure 3C, D). It was not possible to standardise the angle of entry as the lesions were found in different locations within the condyle. An 8.5 mm drill bit was used to enlarge the bone tunnel, then debridement (Cobb curette 4 mm diameter) and flushing were performed. The distance between the middle of the cyst and the bone edge was measured (Figure 3E), and a tap and a screwdriver were used to insert a 9 mm interference screw, until reaching the middle of the lesion (Figure 3F). The subcutis was sutured with absorbable monofilament suture (poliglecaprone-25 n.0) and the skin incision was closed with non-absorbable monofilament suture (nylon n.0). An adhesive patch to suture protection was applied during the recovery phase post-general anaesthesia.

Post-operative care: Antimicrobial (procaine penicillin 22,000 UI/kg IM) and anti-inflammatory (flunixin meglumine 1.1 mg/kg IV) treatment was continued once daily for 3 days post-operatively. For the lesions that were in the distal radius, phalanges and carpal bone a bandage was put on and changed 3 days after surgery and then every 4 days. For MFC and proximal radius lesions, no protective dressing was applied. In all patients, sutures were removed 12 days post-surgery and four weeks of stall-rest was recommended.

Post-operative rehabilitation: After the four weeks of stall-rest, a post-operative rehabilitation program was introduced. The protocols varied according to patient age; weanlings and yearlings were turned out in small paddocks for four weeks, and after that, in a larger pasture for four more weeks. Older horses were walked (by hand or machine) daily for four weeks; beginning with 20 minutes daily the first week and increasing 10 minutes each week. In the following four weeks, 10 minutes trotting-activity was started and increased by 10 minutes each week. All horses were returned to their routine exercise protocol after 12 weeks of restricted exercise.

Postoperative radiographic follow-up: Radiographs were taken at 30, 60, 90 and 120 days after surgery. During the first three months a "side by side" comparison of the pre-and post-operative radiographic images was used to evaluate changes of the SCL.

Morphometric analysis: To evaluate the effect of the implant, a morphometric analysis (ImageJ[2]) was performed measuring the cavity area in all radiographs at time zero and subsequently in all radiographs at 120 days after surgery. Then radiographs at 0 and 120 days were paired and changes in area, on caudo-cranial projection for MFC lesions or on dorso-plantar/palmar views for the other locations, were expressed as a percentage of the preoperative values.

Postoperative clinical follow-up: The authors or attending veterinarians recorded the presence of fever, lameness, and/or swelling at the surgical site in the first week after surgery, and then each time radiographs were taken thereafter.

Long-term follow-up: The clinical condition of patients, from 120 days post-surgery to the time of writing, were obtained by direct communications with referring veterinarians.

Performance analysis: Performance data were recorded using electronic database (france-galop.com; letrot.com; ippicabiz.it; equibase.com). The number of races before and after surgery and whether the horses raced at the age of two or three years old after surgery were recorded. In addition, the number of wins and/or placement were recorded. The number of subjects that raced in relation to the anatomical locations of the SCLs were documented. In unraced horses, details of training were obtained by direct communication with referring veterinarians, owners, horsemen, and trainers.

Results

Thirty-eight horses met the inclusion criteria. There were 25 Thoroughbreds and 13 Standardbreds, 21 females and 17 males. Horses were between the ages of 10 and 24 months (mean 15 months; median 10 months) at the time of surgery (Table S1).

Radiographic diagnosis: In one horse, bilateral lesions (proximal phalanx) were observed leading to a total of 39 SCLs. Twenty-eight out of 39 (72%) lesions had a diameter of 9 mm or larger. SCLs were located in the distal MFC in 22 horses (57%), in the radius in seven horses (18%), in the proximal phalanx in five horses (six limbs; 13%), in the middle phalanx in three horses (8%) and one horse had a lesion in the fourth carpal bone (2%) (Table S1).

Mean operating time: The mean operating time was 25 minutes (range 20-30) for SCLs of the MFC, 22 minutes (range 15-40) for SCLs of the radius, 27 minutes (range 20-45) for SCLs of the proximal phalanx, 25 minutes (range 15-30) for SCLs of the middle phalanx group and 10 minutes for the SCL of the fourth carpal bone (Table S1).

Surgical complications: In one case (n5, MFC), the implant was found to be dislodged from the bone tunnel and located between the bone and overlying fascia on the 30 day radiographs. There were no signs of radiographic healing (Figure 4A) and three months later, the horse underwent a second surgery with the insertion of a new implant. In case n.18, radiography at 30 days showed that the implant was inserted too far into the MFC joint. The implant was removed during arthroscopy and the horse did not enter race training (Figure 4B).

Post-operative radiographic findings: Up to 60 days after surgery, the gross shape of all composites of the implant was preserved and its radiopacity appeared unchanged (Figure 2F, Figure 6B-C). The radiographic exam demonstrated radiopacity of the implant and radiolucency of the unfilled PLLA. In some horses with SCLs type 2B of the MFC (i.e. large dome shape lesion extending down to a large articular surface defect), the radiographs at 120 days showed a residual defect (Wallis type 1, Santschi grade 2) [1,11] however, it was reduced at 240 days postoperatively (Figure 6).

Morphometric findings: In 38 out of 39 SCLs treated, independent of the location or size of the lesion, a filling of the cystic cavity was observed and the morphometric analysis at 120 days showed an average area reduction of 77% (range 0-100%). In particular, 84% in the MFC (range 0-100%), 82% in the radius (range 61-99%), 70% in the proximal phalanx (range 50-99%), 82% in the middle phalanx (range 76-90%) and 68% in the fourth carpal bone (Table S1).

Postoperative clinical follow-up: Soft tissue reaction around the surgical site occurred in about 30% of cases and disappeared spontaneously between 30 and 60 days after surgery. No other specific treatments for SCLs following surgery were performed. According to referring veterinarian evaluation at 120 days, 36 out of 38 horses (94%) were not lame when compared to the pre-surgical evaluation.

Long-term follow-up: Follow up duration was mean 37 months (range 28-46). Case n.3 (MFC) developed a recurrence of the lesion 10 months later, a lameness of 3/5 degree was evident, and it was retired. No infection relating to the implants, no persistent cosmetic defects, and no foreign body reaction were reported.

Performance analysis: Twenty-seven horses (27/38; 71%) raced after surgery and among them, 21 horses (78%) won prize money; 13/27 (48%) horses operated at weanling/yearling age, started racing at 2 years old (Table S2). Considering SCLs anatomical location, 16/22 patients with SCLs in the MFC, 4/7 with lesions in the radius, 6/6 with lesions in the proximal phalanx, 1/3 with SCLs in the middle phalanx and one horse with SCL in the fourth carpal bone started racing after surgery. Six unraced horses (6/38) were in training at the time of writing, while three horses entered training but were retired due to tendon injury or reasons independent of SCLs. Two horses (case n.3 and n.18) were retired for breeding (Table S2).

Discussion

This study describes successful placement of a bioabsorbable implant for treatment of SCLs in 38 young racehorses. We found that use of the implant led to resolution of lameness in 36/38 horses and was associated with an average of 77% radiographic filling of the lesion. Within this group of patients, 71% of horses raced after surgery with 48% of horses racing in their 2-year-old year. These results are comparable to the percentage of horses, without cystic lesions, that raced at two and three years old as observed by Pérez-Nogués *et al*. in their study [20].

Research on absorbable materials has been described in the literature since the 1970s but there have been substantial advancements over time. The literature, mostly in laboratory animals and human surgery, has documented that absorbable materials offer many advantages such as osteoconduction, osteoinduction and bioabsorption. The biomechanical properties, including elasticity and stiffness similar to that of the cortical bone, assure a bending strength for six months after surgery and consequent bone stabilisation [21]. The osteoconductive and osteoinductive properties stimulate the filling of the defects, while the biomechanical properties assure bone stability; these factors are important in resolution of lameness and possibly long-term preservation of the joint. The rationale for our surgical technique was to combine the properties of this implant with a minimally invasive, transcortical approach allowing debridement of the cavity and provide contact of the implant with the surrounding bone. In addition, insertion through an extra-articular approach minimises risk to articular cartilage and preserves the articular growth cartilage and physis, important in young horses. In the human literature several authors reported encouraging findings using μ-HA-PLLA for the management of several cavitary defects, resulting from bone tumour and/or cyst resection [21]. In these patients with resection of chondrosarcoma or osteoblastoma, involving the sub-articular space of distal femur, the reconstruction with μ-HA-PLLA implant provided an excellent recovery of knee function [21]. Block and Thorn [17] in a review study reported a success rate of 78-90% in solitary bone cyst lesions and 100% success in benign bone tumour cases treated in different anatomical locations, without recurrence in subjects treated with curettage followed by cavity packing with μ-HA-PLLA. It was observed that their relatively slow resorption may be preferable in treating bone cysts where quickly resorbing implants are contraindicated. In these patients, new bone surrounding the μ-HA-PLLA implant was typically evident at 10 weeks post-surgery. A histologic study in rabbits, revealed the formation of new bone around the implant even at three weeks, at eight weeks bone lamellar construction was visible and at 25 weeks the bone surrounding the composites became normal trabecular bone [22]. Furukawa *et al*. [22] and Shikinami *et al*. [23] documented the complete process of absorption and total bone replacement of this specific implant inserted in the distal femoral condyle in rabbits; while Higashi *et al*. [24] used the same implant as a bone filler in rat femur and demonstrated that µ-HA incorporated with PLLA play an active role in new bone formation. The absorption mechanism of implant in horses is unknown. In animal models it has been demonstrated that the degradation depends on shape and size of the implant, as well as vascularity and implantation site, and is facilitated by the µ-HA crystals that are ground down to an average diameter of 3–5 µm. This size range of particles is suitable for triggering phagocytosis, for incorporation into the PLLA matrix, to exhibit effective bioactivity and for reinforcing the composite [23]. Assuming that the structure and physiology of the horse's bone are similar to that of other mammals tested animals, at least 3 years should be considered a reasonable time frame for complete degradation by macrophages [23,25,26].

In our experience, the bone density of SCL area started to increase after 60 days and the morphometric analysis demonstrated an average filling of 77% after 120 days (Figure 5A-L). These results are consistent with those reported in human and animal studies. The implant with the radiolucent PLLA, once inserted, does not alter the radiopacity of SCLs enabling us to evaluate changes in radiopacity using serial radiography (Figure 6).

Study limitations: This study has some limitation. Firstly, we have no information about resorption in our patients because it was not possible to perform a histological investigation and no necropsies were available. Secondly, it would have been interesting to perform computed tomography or magnetic resonance at two/three years after surgery; unfortunately, this is not a practical goal with horses that are in race-program or are sold in an auction sale. Finally, since the radiographic controls were performed sometimes in hospital and sometimes at the farm or training stable, possible minor variations in technique and positioning occurred.

Conclusions

In conclusion, subchondral cystic lesions in young horses intended for auction and athletic performance are an important problem in the equine industry and clearly a common cause of economic loss [4,20,27]. This surgical procedure allowed early rehabilitation and resulted in progressive healing of the lesions; in addition, it makes it unnecessary to plan or perform a second surgery for implant removal and the synthetic nature of the implant eliminates the need for a second procedure to harvest autologous tissue (i.e. osteochondral grafts). Moreover, the u-HA/PLLA materials do not cause artifacts that can interfere with a computed tomography or magnetic resonance examination of the lesion, preserving the ability to assess it or different lesions if needed. The implant was well tolerated, the technique is feasible in different anatomical locations and the μ-HA-PLLA implant can offer an alternative to current techniques for the management of SCLs in young horses.

Authors' declarations of interest

No competing interests have been declared.

Ethical animal research

Research ethics committee oversight not required by this journal: retrospective study of clinical records.

Informed consent

Explicit owner informed consent for inclusion of animals in this study was not stated.

Data accessibility statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Sources of funding

This study was unfunded.

Acknowledgements

The authors gratefully acknowledge Dr Dean W. Richardson DVM, DACVS (Charles W. Raker Professor of Surgery, Chief of Large Animal Surgery, New Bolton Center, University of Pennsylvania) for his intellectual support and valuable supervision during manuscript drafting. The authors are thankful to Dr John Halley (Fethard Equine Hospital, Ireland) and Mr J.Ph. Dubois (Owner breeder and trainer of racehorses, France) for having believed first in this technique.

Authorship

P. Ravanetti conceived, executed the study, the surgery and prepared the manuscript. A. Lechartier executed the study. M. Hammon contributed to cases materials. E. Zucca prepared the manuscript. All authors approved the final version of the manuscript and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Manufacturers' addresses

[1] Takiron CO., Osaka, Japan; M.I.T distributors, Piacenza, Italy.

[2] U.S. National Institutes of Health, Bethesda, Maryland, USA.

FIGURES

Figure 1: **A**) Caudo-cranial projection of MFC. The red lines measure width and height of the cyst. **B)** Dorso-palmar projection of distal proximal phalanx. The red lines measure width and height of the cyst. **C)**: A, Pin-driver; B, Interference screw 9.0 mm; C, Pin 4.6 mm.

Figure 2: Surgery of a SCL located in the distal part of the proximal phalanx. **A)** Dorsopalmar and **B)** Latero-medial projections; the needle shows the optimal surgical approach to the SCL. **C**) Dorso-palmar projection showing a 4.5 mm drill bit directed toward the SCL. **D)** Latero-medial projection showing the 4.5 mm bone hole (red arrow). **E)** The depth-gauge reached the middle cavity to measure the correct length of the implant. **F**) The pin was positioned in the middle of the cavity (red arrow).

Figure 3: SCL of the MFC. **A**) Caudocranial and **B)** Lateral-medial projections; the needle shows the optimal surgical approach to the SCL. **C**) Caudo-cranial **D)** Latero-medial projections show a 4.5 mm drill bit within the cyst. **E)** Caudo-cranial projection shows the depth-gauge positioned in the middle cavity to measure the correct length of the implant. **F**) Placement of the interference screw within the cyst (red arrow).

Figure 4: **A**) Caudo-cranial projection of a SCL in the MFC (case n.5) showing migration of the implant between bone and fascia (red arrow).

B) Intraoperative arthroscopic image (case n.18) showing a portion of the implant inserted within the medial femoro-tibial joint.

Figure 5: Radiographs of subchondral cystic lesions treated with pins (A-H) and with interference-screw (I-L). Side by side comparison of radiographic images pre-operatively and 120 days post-operatively. **A-B)** Distal radius lesion; **C-D)** Proximal radius lesion (elbow); **E-F)** Proximal middle phalanx lesion; **G-H)** Distal proximal phalanx lesion; **I-L)** MFC lesion.

Figure 6: Caudocranial projections of a MFC showing progression of SCL improvement from pre-operatively to 240 days post-operatively. Radiopacity can be monitored monthly. Changes in radiopacity can be noted monthly. Condylar flattening was evident from 30-120 days post-operatively (red arrows) but was reduced at 240 days.

Supporting information

Data S1: Clinical locations.

Table S1: Pre- and post-surgery findings of 38 cases treated with an absorbable implant in five different anatomical locations.

Table S2: Long-term follow-up of 38 cases treated with an absorbable implant in five different anatomical locations.

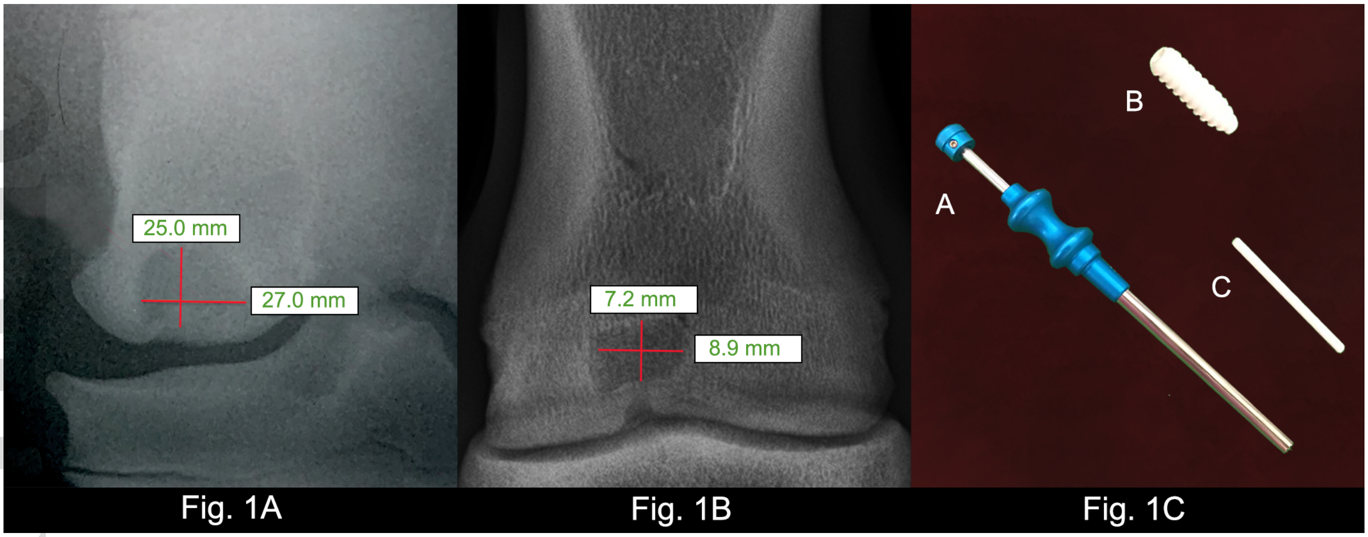
References

1. McIllwraith, C.W. (2016) Suchondral Cystis Lesions. In: *Joint Disease in the Horse* 2nd edn. Eds: C.W. McIllwraith, D.D. Frisbie, C.E. Kawcak and R. Van Weeren. Elsevier, St. Louis, Missouri. pp 85–90.
2. Janes, J.G., Garrett, K.S., McQuerry, K.J., Waddell, S., Voor, M.J., Reed, S.M., Williams, N.M. and MacLeod, J.N. (2015) Cervical Vertebral Lesions in Equine Stenotic Myelopathy. *Vet. Pathol.* **52**, 919–927.
3. Sherlock, C. and Mair, T. (2011) Osseous cyst-like lesions/subchondral bone cysts of the phalanges. *Equine Vet. Educ.* **23**, 191–204.
4. Whitman, J.L., Morehead, J.P., Prichard, M.A., Hance, S.J. and Santschi, E.M. (2006) Radiographic Lucencies in the Medial Femoral Condyle of Thoroughbred Sale Yearlings: A Preliminary Investigation of the Effect on Race Records. In: *AAEP*. pp 416–419.
5. Kold, S.E., Hickman, J. and Melsen, F. (1986) An experimental study of the healing process of equine chondral and osteochondral defects. *Equine Vet. J.* **18**, 18–24.
6. Rechenberg, B., Guenther, H., McIlwraith, C.W., Leutenegger, C., Frisbie, D.D., Akens, M.K. and Auer, J.A. (2000) Fibrous Tissue of Subchondral Cystic Lesions in Horses Produce Local Mediators and Neutral Metalloproteinases and Cause Bone Resorption in Vitro. *Vet. Surg.* **29**, 420–429.
7. Ray, C.S., Baxter, G.M., McIlwraith, C.W., Trotter, G.W., Powers, B.E., Park, R.D. and Steyn, P.F. (1996) Development of subchondral cystic lesions after articular cartilage and subchondral bone damage in young horses. *Equine Vet. J.* **28**, 225–232.
8. Tsuchiya, H., Abdel-Wanis, M.E., Uehara, K., Tomita, K., Takagi, Y. and Yasutake, H. (2002) Cannulation of simple bone cysts. *J. Bone Joint Surg. Br.* **84-B**, 245–248.
9. Fürst, A. and Jackson, M.A. (2018) What is the current best approach to treatment of subchondral cyst-like injuries. *Proc. BEVA Congress* pp 122–123.
10. Ortved, K.F., Nixon, A.J., Mohammed, H.O. and Fortier, L.A. (2012) Treatment of

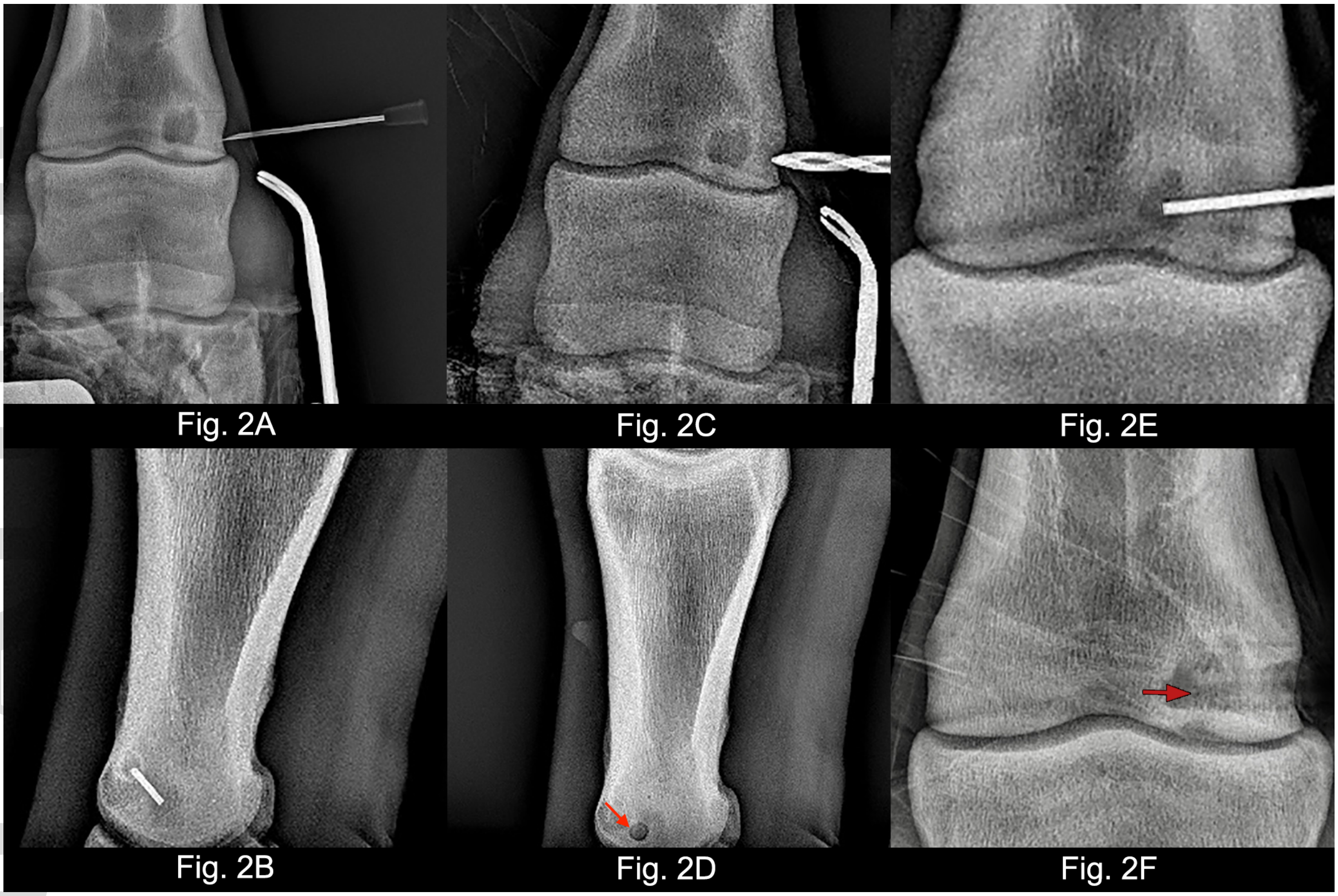
subchondral cystic lesions of the medial femoral condyle of mature horses with growth factor enhanced chondrocyte grafts: A retrospective study of 49 cases. *Equine Vet. J.* **44**, 606–613.

11. Santschi, E.M., Williams, J.M., Morgan, J.W., Johnson, C.R., Bertone, A.L. and Juzwiak, J.S. (2015) Preliminary Investigation of the Treatment of Equine Medial Femoral Condylar Subchondral Cystic Lesions With a Transcondylar Screw. *Vet. Surg.* **44**, 281–288.
12. Jackson, M., Fürst, A., Koch, S., Rechenberg, B. von and Richards, P. (2017) Effect of recombinant human bone morphogenetic protein 2 (rhBMP-2) on equine bone formation: A preliminary in vitro and in vivo evaluation. *Pferdeheilkunde* **33**, 424–432.
13. Bodo, G., Hangody, L., Modis, L. and Hurtig, M. (2004) Autologous Osteochondral Grafting (Mosaic Arthroplasty) for Treatment of Subchondral Cystic Lesions in the Equine Stifle and Fetlock Joints. *Vet. Surg.* **33**, 588–596.
14. Mageed, M., Steinberg, T., Drumm, N., Stubbs, N., Wegert, J. and Koene, M. (2018) Internal fixation of proximal fractures of the 2nd and 4th metacarpal and metatarsal bones using bioabsorbable screws. *Aust. Vet. J.* **96**, 76–81.
15. Pyles, M., Garcia Alves, A., Hussni, C., Thomassian, A., de Mello Nicoletti, J. and Watanabe, M. (2007) Bioabsorbable screws in the healing of experimentally induced fractures of the proximal sesamoid bone in horses. *Ciência Rural. St. Maria* **37**, 1367–1373.
16. Wall, R.A., Robinson, P. and Adkins, A.R. (2010) The use of an absorbable bone screw as a transphyseal bridge for the correction of fetlock varus deviations in six foals. *Equine Vet. Educ.* **22**, 571–575.
17. Block, J.E. and Thorn, M.R. (2000) Clinical indications of calcium-phosphate biomaterials and related composites for orthopedic procedures. *Calcif. Tissue Int.* **66**, 234–238.
18. Komiya, S., Minamitani, K., Sasaguri, Y., Hashimoto, S., Morimatsu, M. and Inoue, A. (1993) Simple bone cyst. Treatment by trepanation and studies on bone resorptive factors in cyst fluid with a theory of its pathogenesis. *Clin. Orthop. Relat. Res.* **287**, 204–211.
19. Anonymous (1991) Lameness scale. Definition and classification of lameness. In: *Guide for veterinary service and judging of equestrian events* 4th edn. Ed: American Association of Equine Practitioners, Lexington, Kentucky. pp 19.
20. Pérez-Nogués, M., Derham, A., Marmion, J. and True Baker, W. (2020) Progression of shallow medial femoral condyle radiographic lucencies in Thoroughbred repository radiographs and their influence on future racing careers. *Equine Vet. J.* doi:

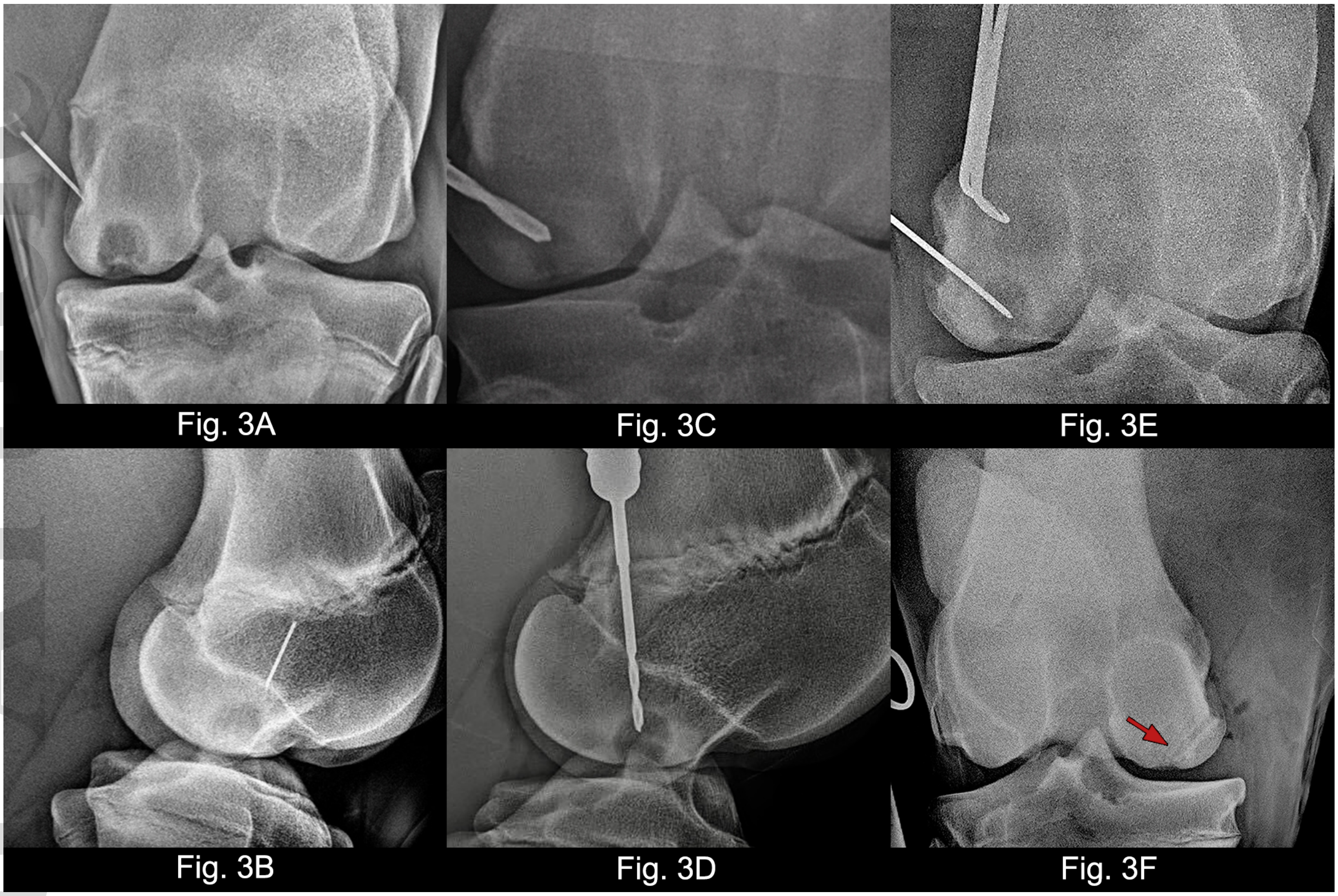
10.1111/evj.13298
21. Sakamoto, A., Okamoto, T. and Matsuda, S. (2020) Implanted β -Tricalcium Phosphate Blocks Can Function as a Placeholder in Recurrent Giant Cell Tumor of Bone. *Case Rep. Orthop.* **2020**, doi:10.1155/2020/2571940
22. Furukawa, T., Matsusue, Y., Yasunaga, T., Nakagawa, Y., Okada, Y., Shikinami, Y., Okuno, M. and Nakamura, T. (2000) Histomorphometric study on high-strength hydroxyapatite/poly(L-lactide) composite rods for internal fixation of bone fractures. *J. Biomed. Mater. Res.* **50**, 410–419.
23. Shikinami, Y., Matsusue, Y. and Nakamura, T. (2005) The complete process of bioresorption and bone replacement using devices made of forged composites of raw hydroxyapatite particles/poly L-lactide (F-u-HA/PLLA). *Biomaterials* **26**, 5542–5551.
24. Higashi, S., Yamamuro, T., Nakamura, T., Ikada, Y., Hyon, S. and Jamshidi, K. (1986) Polymer-hydroxyapatite composites for biodegradable bone fillers. *Bi* **7**, 183–187.
25. Kzhyshkowska, J., Gudima, A., Riabov, V., Dollinger, C., Lavalle, P. and Vrana, N.E. (2015) Macrophage responses to implants: prospects for personalized medicine. *J. Leukoc. Biol.* **98**, 953–962.
26. Jackson, M., Vizard, A., Anderson, G., Clarke, A., Mattoon, J., Lavelle, R., Lester, N., Smithenson, T. and Whitton, C. (2009) *A Prospective Study of Presale Radiographs of Thoroughbred Yearlings*. RIRDC Publication.
27. Hasegawa, Y., Sakano, S., Iwase, T. and Warashina, H. (2002) The long-term behavior of poly-L-lactide screws in a minipig fracture model: preliminary report. *J. Biomed. Mater. Res.* **63**, 679–685.



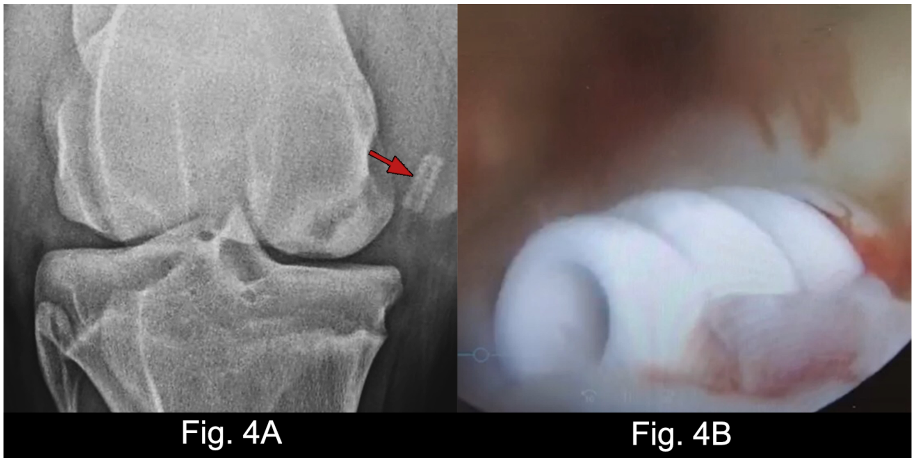
evj_13428_f1.tiff



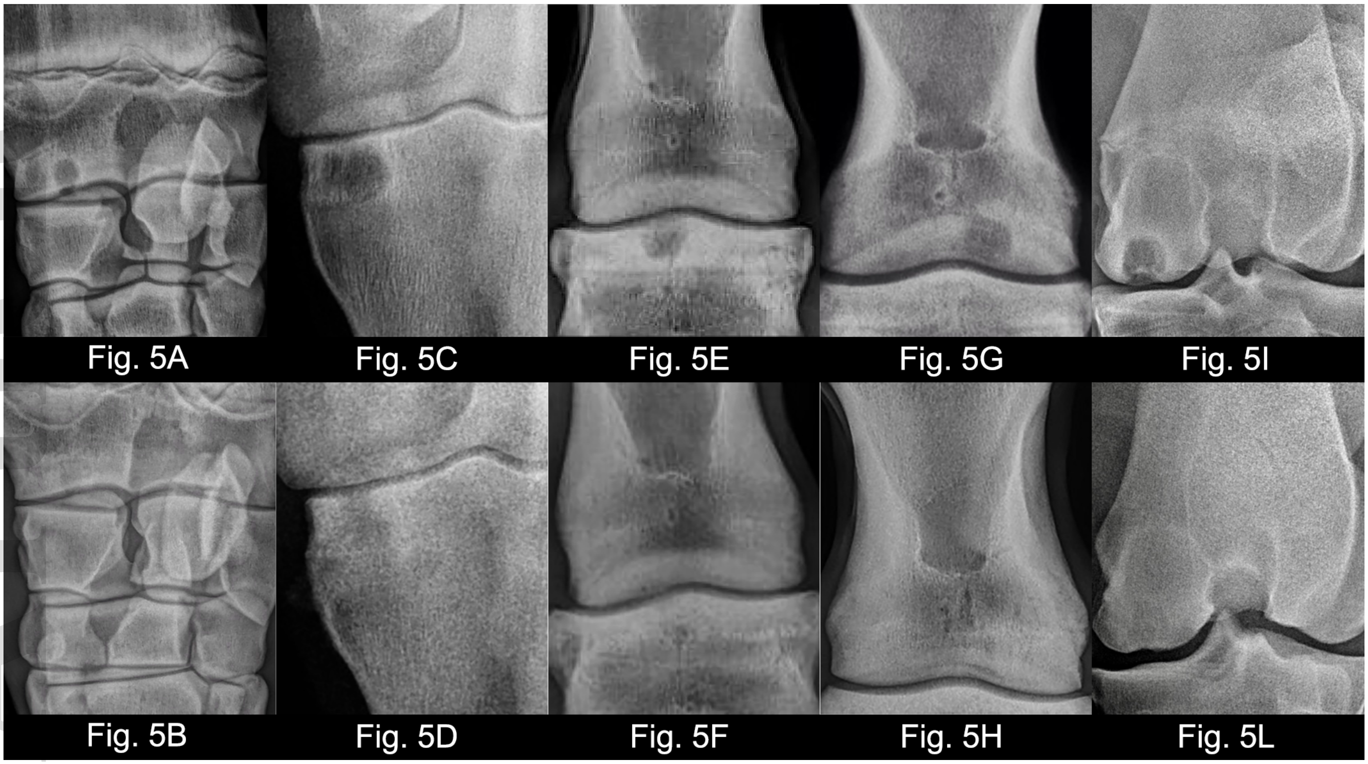
evj_13428_f2.tif



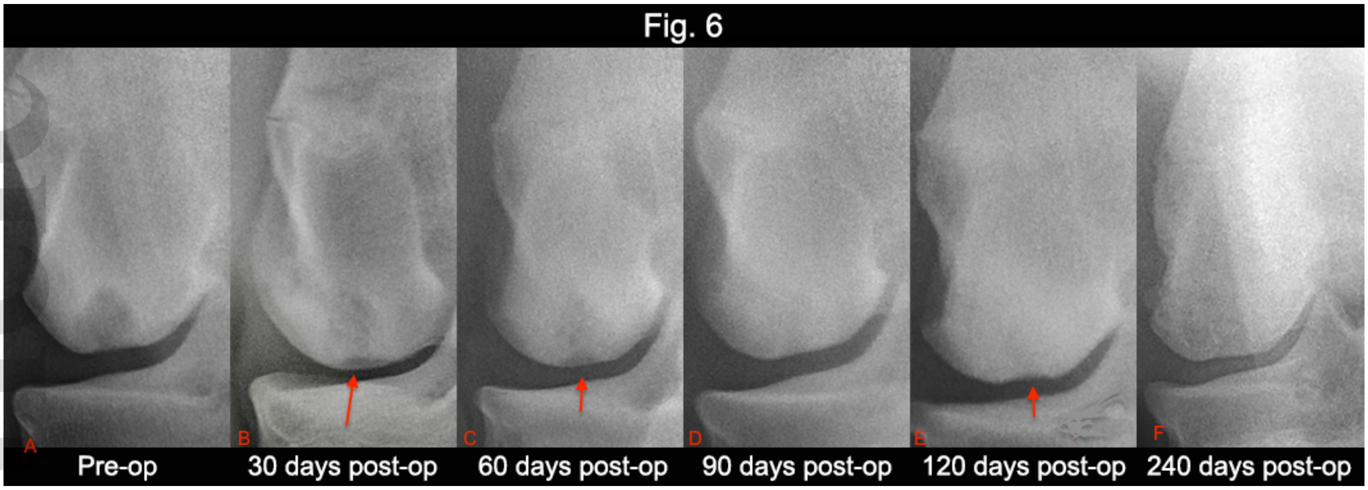
evj_13428_f3.tif



evj_13428_f4.tif



evj_13428_f5.tif



evj_13428_f6.tif