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Retrospective evaluation of bone sequestra in 21 cattle and three New World Camels – short- and long-term outcomes

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Summary

In a retrospective analysis of 24 animals (21 cattle, two alpacas and one llama) with bone sequestration in one or more extremities from 2007 to 2024, we examined clinical findings, size of sequestra, treatment, postoperative complications, outcome and postoperative survival times. The cattle had a mean age of 27.2 months (SD: 20.3) and the New World camels (NWC) of 4.4 months (SD: 5.9) at the time of diagnosis. Among the 30 sequestra diagnosed, 21 (66.5 %) were located in the metatarsal and metacarpal bones, with the remaining distributed among other limb bones. The animals had a mean locomotion score of 3.3 (SD: 1.3) out of 5 on their initial examination. The size of the sequestra varied widely, ranging from 1.5 to 10.0 cm in length, 0.5 to 4.0 cm in width and 0.2 to 1.0 cm in depth. The sizes were grouped into three categories including only cattle for statistical analysis.

Three patients were euthanized directly after diagnosis due to comorbidities and poor prognoses. Nineteen of the remaining 21 animals underwent sequestrectomy. In two of the 21 patients, small and thin sequestra were diagnosed by radiography and these resolved spontaneously. Another five of the 21 treated patients were euthanized due to postoperative complications, while 16 (76.2 %) recovered. The mean cumulative postoperative survival time for the 13 cattle was 31.1 months (SD: 26.5) and for the three NWC 89.5 months (SD: 61.0).

Zusammenfassung

Retrospektive Auswertung von Knochensequestern bei 21 Rindern und drei Neuweltkamelen – kurz- und langfristige Ergebnisse

Bei 24 Tieren (21 Rinder, 2 Alpakas, 1 Lama) mit Sequestern an einem oder mehreren Gliedmaßenknochen wurden klinische Befunde, Größe der Sequester, Behandlungsregime, postoperative Komplikationen, Behandlungserfolg und die postoperative Überlebenszeit retrospektiv analysiert (2007–2024). Zum Zeitpunkt der Diagnosestellung wiesen die Rinder ein mittleres Alter von 27,2 Monaten (± 20,3) und die Neuweltkamele von 4,4 Monaten (± 5,9) auf. Von den 30 diagnostizierten Sequestern befanden sich 21 (66,5 %) an den Metakarpal- und Metatarsalknochen, der Rest verteilte sich auf andere Gliedmaßenknochen. Bei der Erstuntersuchung wiesen die Patienten einen mittleren Locomotion-Score von 3,3 (± 1,3) von 5 auf. Die Knochensequester waren 1,5 bis 10,0 cm lang, 0,5 bis 4 cm breit und 0,2 bis 1,0 cm tief. Für die statistische Auswertung bei Rinderpatienten wurden die Sequester nach ihrer Größe in drei Gruppen eingeteilt.

Drei der 24 Patienten waren aufgrund von ernsthaften Begleiterkrankungen, und damit einer schlechten Prognose, nach der Diagnosestellung euthanasiert worden. Bei 19 Tieren wurde eine Sequestrektomie durchgeführt, und bei zwei Tieren waren radiologisch kleine

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No statistically significant correlation was found between the age at the time of sequestrum diagnosis and postoperative survival time (p=0.854), or between the size of sequestra and treatment success (p=0.77). However, we found a significant correlation in cattle between the size of sequestra and postoperative survival times (r=0.585; p=0.036). Cattle in group 3, which had the largest sequestra, had a significantly longer postoperative survival time than cattle in groups 1 and 2 (p=0.026) with smaller sequestra.

Based on the results of this study and previous research, we conclude that cattle and New World camels suffering from bone sequestra have good prospects of recovery if sequestrectomy is performed at the appropriate time, assuming that there are no other serious concomitant diseases. However, a prerequisite is that the bone sequestrum is clearly demarcated radiologically from the surrounding vital bone.

Abbreviations: AMA = Agrarmarkt Austria; BW = body weight; LCS = locomotion score; NSAIDs = nonsteroidal anti-inflammatory drugs; NWC = New World camels; SD = standard deviation

und dünne Sequester diagnostiziert worden, so dass hierbei die Resorption derselben abgewartet wurde. Fünf der 21 behandelten Patienten wurden aufgrund postoperativer Komplikationen euthanasiert und 16 Patienten (76,2 %) wurden erfolgreich behandelt. Die mittlere kumulative postoperative Überlebenszeit der 13 Rinderpatienten betrug 31,1 Monate (± 26,5) und der drei Neuweltkamele 89,5 Monate (± 61,0).

Weder zwischen dem Alter aller Patienten zur Zeit der Diagnosestellung und der postoperativen Überlebenszeit (p=0,854), noch zwischen Sequestergröße und Behandlungserfolg (p=0,77) war ein statistisch signifikanter Zusammenhang nachweisbar. Hingegen ließ sich bei Rindern ein signifikanter Zusammenhang zwischen Sequestergröße und postoperativer Überlebenszeit (r=0.585; p=0,036) feststellen. Rinder der Gruppe 3, also jene Patienten mit den größten Sequestern, hatten unerwartet eine signifikant längere postoperative Überlebenszeit, als die der Gruppen 1 und 2 (p=0,026). Aus den Ergebnissen dieser und anderer Studien lässt sich schlussfolgern, dass die Heilungschancen von Rindern und Neuweltkamelen mit Knochensequestern bei adäquater Wahl des Zeitpunktes für die Sequestrektomie - der Sequester muss im Röntgenbild sehr deutlich von allen umgebenden vitalen Knochenanteilen abgegrenzt sein - als gut einzustufen sind, sofern nicht zusätzlich schwerwiegende Begleiterkrankungen vorliegen.

Introduction

A sequestrum is a portion of bone that has been separated from its blood supply and is therefore undergoing necrosis. The involucrum is the newly formed bone wall created by the periosteum around the bone sequestrum. When sequestra develop, they are often accompanied by a fistula opening onto the skin, purulent exudate and necrotic tissue, known as cloaca (Firth 1987; Hirsbrunner et al. 1995; Valentino et al. 2000). The blood supply to the bone is often interrupted as a result of a traumatic impact to the periosteum, which can occur through a direct penetrating wound or a blunt trauma, of post-surgical demarcation of bone fragments or, in rare cases, of the haematogenous settlement of a bacterial infection in the bone (Köstlin et al. 1990; Hirsbrunner et al. 1995; Valentino et al. 2000).

In general, bone sequestra are rare in cattle and New World camels (NWC) under current husbandry conditions. However, trauma can quickly damage the periosteum, especially in the long bones of the distal limbs, where the soft tissue covering that protects the bone is particularly thin (Hirsbrunner et al. 1995; Müller 2024). When trauma prevent both the arterial and the venous bloodflow to a specific area of bone, circumscribed bone areas can die over a period of two to four weeks. Such trauma also creates excellent conditions for bacterial growth (Valentino et al. 2000; Rousseau et al. 2013; Heppelmann 2020).

Characteristic clinical symptoms in animals suffering from bone sequestra often include a non-healing, painful wound that may be several weeks old, swelling around the wound on the affected limb, fistula extending to the bone surface, purulent exudation and, depending on the extent and duration of the previous trauma, mild to severe lameness (Valentino et al. 2000; Pagliosa et al. 2019; Kusenda et al. 2024).

A suspected diagnosis of sequestration can be made with the help of a detailed medical history and orthopaedic examination. Additionally, it is often possible to trace the fistula canal with a probe to the rough bone surface, which is no longer covered with periosteum and is osteolytic (Heppelmann 2020; Kusenda et al. 2024). An ultrasound examination of the bone surface (5–8 MHz linear probe) can sometimes confirm a clinical suspicion of sequestration (Taguchi & Hyakutake 2012; Kofler et al. 2021; Kusenda et al. 2024).

The diagnostic imaging method of choice to diagnose a bone sequestrum is radiography of the affected bone in two planes (Steiner et al. 2010). If the periosteal trauma occurred only a few hours or a few days previously, it is advisable to take a follow-up radiograph approximately 14 to 20 days after the initial examination. This is because the sequestrum only becomes clearly demarcated from the rest of the bone by a broad radiolucent line two to four weeks after the periosteal trauma (Valentino et al. 2000; Steiner et al. 2010).

Very small bone sequestra can be resorbed spontaneously, but this is exceptional. Sequestra that reach a certain size must be removed surgically via sequestrectomy (Hirsbrunner et al. 1995; Valentino et al. 2000; Rousseau et al. 2013). Sequestrectomy of the mature, clearly demarcated sequestrum can be performed under general, epidural or local anaesthesia, depending upon its location on the limb. Together with the demarcated bone fragment, all necrotic and infected soft tissue must be completely removed and meticulous surgical wound debridement is necessary (Hirsbrunner et al. 1995; Valentino et al. 2000; Pagliosa et al. 2019).

The prognosis for the affected animal generally depends on the size of the sequestrum. If a large sequestrum is present, a significant piece of the load-bearing bone is missing after sequestrectomy, which may result in the worst-case scenario of a pathological fracture (Valentino et al. 2000; Rousseau et al. 2013). However, there are usually good chances of recovery after a complete sequestrectomy (Valentino et al. 2000; Rousseau et al. 2013; Kobera & Wagner 2018). It is also important to consider the extent of the soft-tissue trauma that caused the sequestrum and whether, for example, neighbouring tendons or joints were also injured. Another possible complication, in addition to a fracture or a progressive bone infection, is the development of a further sequestrum. This may occur if the first sequestrum could not be completely removed because the demarcation was not clear enough at the time of the procedure, leading to the progression of bone necrosis (Valentino et al. 2000; Rousseau et al. 2013; Heppelmann 2020).

Our objective was to analyse the medical records of a larger number of patients diagnosed with a bone sequestrum in their limbs. We aimed to answer the following questions: What was the success rate following sequestrectomy? What was the mean postoperative survival time for patients successfully treated for bone sequestra? Are there any statistical correlations between the size of the bone sequestra and treatment success and postoperative survival time? Is there a statistical correlation between patient age and postoperative survival time?

Materials and Methods

Stationary cattle and NWC patients were included in this retrospective study if they had documented records in the Animal Hospital Information System (TIS) and had been hospitalized at the Clinic for Ruminants of the University of Veterinary Medicine Vienna for bone sequestra on the limbs between June 2007 and June 2024. Cattle and NWC diagnosed with sequestra in other anatomical locations were excluded. The medical records of 24 patients that met these criteria were available. Study data included all findings, such as species, age, breed, pregnancy status, localization, cause, results of clinical, ultrasonographic and radiographic examinations, size of sequestra, presence of concurrent disease, treatment methods, complications, duration of hospitalization and outcome.

The study was reviewed and endorsed by the Ethics and Animal Welfare Committee of the University of Veterinary Medicine Vienna for compliance with Good Scientific Practice and national legislation (ETK-23/02/2024).

Diagnosis of bone sequestra

Gait assessment was conducted on all animals using locomotion scoring upon arrival at the clinic and again at discharge, according to Sprecher et al. (1997). Additionally, a general clinical examination was performed. To inspect and palpate the affected limb thoroughly, patients were usually placed in lateral recumbency on a hydraulic surgical table for easy access to the fistula opening. The hair in the area of interest was shaved and the surrounding area carefully cleaned.

Ultrasonographic examination of evident soft tissue swelling on the affected limb was also performed with the patient restrained on the surgical table. After applying contact gel, the entire soft tissue swelling was examined in longitudinal and transverse planes from proximal to distal using a 5–8 MHz linear probe (Mindray® DP 30Vet, Mindray Bio-Medical Electronics Co. Ltd, Shenzhen, China). Attention was focused on the appearance of the bone surface (smooth, rough, irregular) and on the presence of deep bone defects and periosteal proliferation (Taguchi & Hyakutake 2012; Kofler et al. 2021).

Radiographs of the affected region were taken for all the patients in at least two planes: dorso-plantar/palmar and the corresponding cranio-caudal planes, as well as in latero-medial/medio-lateral planes. If necessary, oblique planes were also used (Steiner et al. 2010). All radiographs were acquired with portable X-ray units of similar power but from different manufacturers and the images processed using a CR or a DR system (Fujifilm Corporation, Tokyo, Japan).

Treatment plan

Patient preparation

For the surgical removal of the sequestrum, all cattle patients were sedated with xylazine (0.05–0.1 mg/kg BW, IM; Sedaxylan® 20 mg/ml, Eurovet Animal Health BV, Bladel; The Netherlands) and placed in lateral recumbency on the surgical table. Cows in late pregnancy, starting from the seventh month, received isoxsuprine hydrochloride (200 mg/animal, IM, Degraspasmin®, Dr. E. Graeub AG; Bern, Switzerland) ten minutes before sedation to prevent unwanted uterine contractions and potential abortion.

General anaesthesia was used in two of the three NWC. All three NWC were administered xylazine (0.1 mg/kg BW, IM, Sedaxylan® 20 mg/ml, Eurovet Animal Health BV, Bladel, The Netherlands) and butorphanol (0.2 mg/kg BW, IM, Butomidor® 10 mg/ml, Richter Pharma AG, Wels, Austria) as premedication. Anaesthesia was induced in two NWC with ketamine (3 mg/kg BW, IV, Ketamidor®, Richter Pharma AG, Wels, Austria) to prepare them for intubation and general anaesthesia was maintained using isoflurane (Vetflurane®, Virbac, Opfikon, Switzerland) and oxygen.

One alpaca cria with two sequestra in a metatarsal bone underwent surgical treatment under sedation and local anaesthesia. All patients with bone sequestra treated surgically under sedation also received local anaesthesia. Intravenous regional anaesthesia was used, or, in cases of severe swelling and in NWC, infiltration anaesthesia (ring block) was applied 15 to 20 cm proximal to the swelling. Before local anaesthesia, the surgical area was thoroughly shaved and cleaned with iodine soap solution (Jodosept® PVP jodhältige Flüssigseife, Vetoquinol GmbH, Ismaning, Germany). For intravenous regional anaesthesia, an elastic tourniquet was placed above the surgical site, typically near the tarsus/carpus. A limb vein (radial vein; common digital plantar/palmar vein IV or II, common digital dorsal vein III, cranial or caudal branch of the lateral saphenous vein; lateral plantar metatarsal vein) was then punctured below the tourniquet after disinfecting the site with iodine alcohol. A volume of 20–40 ml of 2 % procaine hydrochloride (Procamidor® 20 mg/ml, Richter Pharma AG, Wels, Austria) was injected into the vein.

For infiltration (ring block) anaesthesia, several continuous injections of 2 % procaine hydrochloride (40–80 ml) were placed subcutaneously in a ring around the entire limb, approximately 15–20 cm proximal to the surgical field, ensuring that all nerves in the area were fully anaesthetized. Once the local anaesthesia was administered, the surgical site was disinfected.

Sequestrectomy

Surgery began with a spindle-shaped skin incision around the wound or fistula. Infected and necrotic skin and subcutaneous and fascial tissue were resected with a scalpel to give access to the bone surface. In cases where the sequestrum was surrounded by large bone sclerosis, some of this proliferative bone tissue had to be removed using a rongeur or chisel and hammer before the sequestrum could be extracted. If the bone sequestrum had not been completely demarcated radiographically from the rest of the bone, it was carefully mobilized and removed at the detectable demarcation line using a chisel and hammer. Next, the wall of the bone cavity was thoroughly curetted using a sharp spoon until only vital bone was visible. To ensure all small bone fragments and debris were removed from the wound, the cavity was rinsed with 500–1,000 ml of sterile 0.9 % saline solution (Valentino et al. 2000; Heppelmann 2020). Finally, an antibiotic was instilled into the wound, using the preparation that had been administered systemically. A drain composed of either sterile gauze or sterile soft foam (Ligasano®, Ligamed medical products GmbH, Cadolzburg-Wachendorf, Germany) was placed in the cavity. After removing the sequestrum, the skin of four patients (two cattle, one alpaca and one llama) was closed with U-sutures, leaving a small, approximately 2 cm wide opening for drainage. In all other surgically treated patients, secondary wound healing was attempted.

Wound dressings and bandages

For wound dressing, either three layers of sterile gauze or a 1 cm thick piece of sterile polyurethane soft foam (Ligasano®, Ligamed medical products GmbH, Cadolzburg-Wachendorf, Germany) were used. Three-to-four layers of cotton wool were wrapped for padding and secured with gauze bandages (Raucolast®; Lohmann & Rauscher GmbH & Co. KG; Rengsdorf; Germany). By pulling firmly on the gauze, a pressure bandage could be applied to achieve haemostasis at the surgical wound and protect it from contamination. The final layer consisted of a self-adhesive elastic bandage (Vetrap®; 3M Österreich GmbH, Vienna, Austria) and a textile adhesive tape (Tesa Textilband®, 5 cm wide; Henry Schein Animal Health, Vienna, Austria), which completely covered the outside surface of the dressing in two to three layers.

In 13 cases, the surgeon suspected an increased risk of fracture of the affected bone due to the large size of the bone sequestrum that was removed. In these cases, a fiberglass cast (Cellacast® Longuette 12 cm; Lohmann & Rauscher, Vienna, Austria) or splints made of vertically sectioned PVC pipes were applied over the protective bandage. The PVC splints were held together with textile adhesive tape (Tesa Textilband®, 5 cm wide; Henry Schein Animal Health, Vienna, Austria) and completely encircled the neighbouring proximal joint on the forelimb. In cases of sequestra in the middle and proximal metatarsal regions, a cast was applied that extended from the claws up to the mid-tibia.

Intra-, peri- and postoperative medication and aftercare

The following antibiotics were administered systemically: penicillin-streptomycin (4 ml/100 kg BW, IM; Peni-Strepto® 1 mg/ml, Virbac Österreich GmbH, Vienna, Austria), amoxicillin (15 mg/kg BW, IM; Vetrimoxin® 150 mg/ml, Ceva Tiergesundheit GmbH, Düsseldorf, Germany), ampicillin (0.1 ml/kg BW, IM; Ampivet® 10 % ad us vet, Virbac S.A., Carros, France), cefquinome (1 mg/kg BW, IM; Cobactan® 2.5 %; Intervet Deutschland GmbH, Unterschleißheim, Germany) and procaine-benzylpenicillin (20,000 I.U./kg BW, IM,

Procaine-penicillin Suspension® 300 mg/ml; Dechra Veterinary Products Deutschland GmbH, Aulendorf, Germany).

Postoperatively, each bovine received systemic nonsteroidal anti-inflammatory drugs (NSAIDs) such as ketoprofen (3 mg/kg BW, IM/IV; Rifen®, 100 mg/ml, Richter Pharma AG, Wels, Austria). New World camels were administered carprofen (1.4 mg/kg BW, SC; Carprodolor® 50 mg/ml, Le Vet Beheer B.V., TV Oudewater, The Netherlands). The drugs were first administered approximately one hour before surgery. In individual patients, anti-inflammatory medication was continued twice daily using metamizole sodium (20–40 mg/kg BW, IV; Novasul® 500 mg/ml, Richter Pharma, Wels, Austria).

All three NWC were also administered a single dose (3,000 I.U. SC) of tetanus antitoxin (Equilis® Tetanus Serum, Intervet GmbH, Vienna, Austria) on the day of surgery and were administered 4 mg/kg BW omeprazole orally (Equinor® 370 mg/g, Norbrook Laboratories Ltd, Monaghan, Ireland) once daily until discharge.

After surgical treatment, patients were kept in a dry, straw-padded sick box until they were discharged from the hospital. Two days after sequestrectomy, the dressing was first changed under local anaesthesia. The interval between changes of dressing was then extended to two-to-three days and as the healing process advanced to every four-to-six days. During each change, the skin around the wound area was disinfected with iodine alcohol, the surgical wound was rinsed with 500–1,000 ml of 0.9 % saline solution, antibiotics were topically instilled into the wound cavity and the gauze or soft foam drain was replaced.

In animals that had a cast applied postoperatively, the cast was cut open in the middle, laterally and medially with an oscillating saw to change the dressing. The cast halves were pushed apart to the front and back and removed. After a new dressing was applied over the surgical wound, the cast halves were replaced over the dressing and secured with a textile adhesive Tesa tape. This method allowed the original cast to be used until the end of the treatment.

Drains were completely removed when no more exudate was observed. When skin had been primarily sutured, stitches were removed after fourteen days. Once the drainage opening had closed with vital, plane and thick granulation tissue, the animals were released to their home farms.

Duration of hospitalization

The duration of hospitalization was defined as the period from the day of initial admission until the day of discharge from the clinic. It was only calculated for patients that were successfully treated.

Determination of postsurgical survival time

To calculate the postsurgical survival time of the animals that were still alive at the time of the retrospective evaluation, we set 20 June 2024 as the cut-off date. The date of culling of patients was determined by cross-referencing the Agrar-Markt-Austria (AMA) database with individual ear-tag numbers. By combining this information with the date of discharge from the clinic, we could determine the postoperative survival time of successfully treated patients and whether the animals were still alive at that time (cumulative postoperative survival time). In the three NWC, the postoperative survival time was determined by a telephone call with the owners.

Statistical analysis

The data were analysed using the SPSS statistical program, v29 (IBM SPSS Statistics®, SPSS Inc., Armonk, NY, USA) to produce descriptive and inferential statistics in cattle and NWC patients. We used Excel (Excel 365®, Microsoft Corp., Redmond, WA, USA) to calculate mean values, standard deviations, medians and minimum and maximum values.

The size of the sequestra (length, width, depth) was measured in the surgically treated patients after sequestrectomy with a measuring rule. In non-operated patients, the sizes of the sequestra were determined from radiographs. Bone sequestra were divided into three groups:

Group 1: sequestra up to a length or width of 2.5 cm,
Group 2: sequestra with a length or width of 2.6–4 cm,
Group 3: sequestra that were longer or wider than 4 cm.

Due to the small number of cases, we used non-parametric tests. The data set contains two interval-scaled variables: age and postoperative survival time. Kolmogorov-Smirnov tests were used to check for normal distribution. Both variables showed a significant deviation from normal distribution (age: $p=0.006$; postoperative survival time: $p<0.001$).

We analysed the impact of the size of the bone sequestra (categorized into three groups) on treatment success using the chi-square test for all patients. Differences in postoperative survival times between the groups (groups 1 and 2 were combined) were assessed in cattle patients only using Kaplan-Meier analysis (log rank test) and the Mann-Whitney test. Cumulative survival times were graphically presented using Kaplan-Meier survival plots.

We used Spearman's rank correlation coefficient to assess correlations between patient age and postoperative survival times, as well as between locomotion scores on initial examination and locomotion scores on discharge for all patients. We used the chi-square

test to determine whether there was a higher incidence of sequestra in cattle younger than 14 months than in cattle aged 23.5 months and older. The Wilcoxon test was employed to assess whether locomotion scores on initial examination and on discharge in all patients showed any significant differences. For all statistical tests, a p-value of less than 5 % ($p<0.05$) was considered significant.

Tab. 1: Distribution of sequestra by location on forelimb and hindlimb bones / Verteilung der Sequester nach Lokalisation an den Knochen der Vorder- und Hintergliedmaßen

Affected bone	Number of sequestra (n)	Percent (%)
Metatarsus	13	43.3
Metacarpus	7	23.3
Tibia	3	10.0
Radius	2	6.7
Calcaneus	2	6.7
Coxal tuberosity	1	3.3
Femur	1	3.3
Pedal bone	1	3.3

Results

We evaluated the case records of 24 animals, including 21 cattle, two alpacas and one llama diagnosed with limb bone sequestra. The cattle belonged to the following breeds: Fleckvieh (n=14; 58.3 %), Holstein-Friesian (n=5; 20.8 %), Red-Holstein (n=1; 4.2 %) and Murbodner Blondvieh (n=1; 4.2 %). The NWC included two alpacas (8.3 %) and one llama (4.2 %).

The 24 patients comprised 19 females (79.2 %) and five males (20.8 %). Among the 19 females, four were pregnant (21.0 %) and 15 were non-pregnant (79.0 %). Upon admission, the mean age of the 21 cattle patients with sequestra was 27.2 months (SD: 20.3; median: 13.4; min: 0.1; max: 78.2). The mean age of the three NWC with sequestra was 4.4 months (SD: 5.9; median: 1.3; min: 0.8; max: 11.2).

Clinical findings

The orthopaedic examination on the day of admission determined a mean locomotion score (LCS) of 3.3 (out of 5) (SD: 1.3; median: 3.0; min: 1.0; max: 5.0) for the 24 patients. Three patients (12.5 %) showed no lameness (LCS 1) on initial examination, while eleven animals (45.8 %) had a LCS≥4.

Upon discharge from the clinic, the 16 successfully treated patients had a mean LCS of 1.5 (SD: 0.6; median: 1; min: 1; max: 3). Ten animals (62.5 %) were

Fig. 1: Dorsal view of the right metatarsal region of a four-year-old Fleckvieh cow showing a chronic, fistulating wound immediately distal to the tarsometatarsal joint / Vorderansicht der rechten Metatarsalregion einer 4-Jahre alten Fleckvieh-Kuh mit einer chronischen, eiternden Wunde knapp distal des Tarsometatarsalgelenkes

Tab. 2: Size of the sequestra in the 24 patients divided into three groups: Group 1 (green): sequestra up to 2.5 cm long/wide; Group 2 (yellow): sequestra 2.6 to 4 cm long/wide; Group 3 (orange): sequestra larger than 4 cm in length/width. The right column indicates the animals that were successfully treated and those that were euthanized. Red letters indicate that the animals were euthanized immediately after diagnosis, while blue letters indicate that the animals were euthanized due to postoperative complications / Größe der Sequester bei den 24 Patienten eingeteilt in drei Gruppen: Gruppe 1 (grün): Sequester bis zu 2,5 cm lang/breit; Gruppe 2 (gelb): Sequester 2,6 bis zu 4 cm lang/breit; Gruppe 3 (Orange): Sequester größer als 4 cm in Länge/Breite. In der rechten Spalte ist angeführt, welche Tiere erfolgreich therapiert und welche euthanasiert wurden. Rot markiert bedeutet, dass die Tiere sofort nach der Diagnosestellung euthanasiert wurden; blau markiert bedeutet, dass die Tiere aufgrund von postoperativen Komplikationen euthanasiert wurden

Patient	Length in cm	Width in cm	Depth in cm	Therapy / Euthanasia
1	7.5	3.0	1.0	Euthanasia
2	4.0	1.5	0.2	Therapy
3	3.0	1.0	0.2	Therapy
	3.0	1.5	0.2	
4	3.0	2.0	0.2	Therapy
5	2.0	3.0	0.5	Therapy
6	9.0	3.0	0.8	Euthanasia
7	5.0	0.8	0.2	Therapy
8	5.5	2.5	0.8	Therapy
9	3.0	2.0	1.0	Therapy
10	4.6	2.0	0.8	Therapy
11	5.0	1.0	0.8	Therapy
12	7.0	3.0	1.5	Euthanasia
13	6.5	3.2	0.8	Therapy
14	7.0	3.4	0.8	Therapy
15	1.5	1.5	0.5	Therapy
16	10.0	3.0	0.8	Euthanasia
17	8.0	4.0	0.8	Therapy
18	2.0	1.0	0.5	Euthanasia
19	2.5	0.7	0.5	Euthanasia
20	2.0	2.0	0.1	Therapy
	5.0	0.8	0.6	
	4.0	0.5	0.5	
21	8.0	4.0	0.4	Therapy
	8.0	3.0	0.4	
22	3.0	2.0	0.3	Euthanasia
	4.0	1.0	0.4	
	4.0	3.0	0.5	
23	2.0	0.5	0.5	Therapy
24	6.5	1.8	0.6	Euthanasia

free of lameness, five (31.3 %) had a LCS of 2 and one (6.3 %) a LCS of 3.

Patients with bone sequestra in their limbs often exhibited mild-to-moderate swelling in the affected area (n=19; 63.3 %), painful reactions to palpation (n=12; 40.0 %), chronically infected wounds with mild hypergranulation and purulent exudation (n=18; 60.0 %). In one case, a newly contaminated wound (3.3 %) was observed. The most common causes of sequestrum formation were trauma penetrating to the periosteum (n=19; 79.2 %) (Fig. 1) and previous fractures (n=3; 12.5 %). In two patients, the cause could not be determined.

Of the 30 sequestra diagnosed, 21 (66.5 %) were on the metatarsal and metacarpal bones (Figures 1, 3, 4). The remaining nine sequestra (33.5 %) were distributed among other proximal limb bones (Figs. 2, 5, 6); a pedal bone in a forelimb was involved in one case (Table 1). The bone sequestra ranged from 1.5 to 10.0 cm in length, 0.5 to 4.0 cm in width and 0.2 to 1.0 cm in depth (Table 2).

Reasons for euthanasia after diagnosis

Three of the 24 animals (12.5 %) with a sequestrum were euthanized immediately after diagnosis. In one of these cases, a Red Holstein cow, 6.5 years old and non-pregnant for over six months, had a sequestrum that was over 50 % of the width of the metacarpus and 8 cm long. The risk of a postoperative fracture was considered high, so it was decided to euthanize the cow, also for economic considerations.

The second animal, a four-month-old Murbodner Blondvieh calf, had a 6.5 cm long sequestrum on the cranial aspect of the radius. It also had transverse fractures in the humerus of the ipsilateral forelimb and the proximal femur of a hindlimb. Due to the poor prognosis, the animal was euthanized. The sequestrum in the radius was an incidental

Fig. 2: Medio-lateral radiograph of the left antebrachial region of a four-month-old Murbodner Blondvieh calf showing a sequestrum on the cranial aspect of the radius, which is only demarcated from the vital by a small radiolucent line. The radiolucent line does not extend to the cranial surface of the compacta. At this stage, the demarcation is not yet sufficient for a successful sequestrectomy. / Medio-laterale Röntgenaufnahme der linken Unterarmregion eines vier-Monate alten Murbodner Blondvieh Kalbes; der Sequester kranial am Radius ist zwar vom vitalen Knochen durch eine dünne Aufhellungslinie abgegrenzt, die Aufhellungslinie reicht aber nicht bis an die kraniale Kompakta des Radius. Dieses Stadium der Demarkation ist jedoch für eine erfolgreiche Sequestrektomie noch nicht ausreichend.

finding as no wound or swelling was clinically detectable on the radius (Fig. 2).

The third animal, a three-year-old Fleckvieh cow, had a sequestrum in the pedal bone of the medial claw of the right forelimb that resulted from a penetrating injury caused by a nail. This cow also had a white-line abscess in the lateral claw of the left hindlimb and chronic *Staphylococcus aureus*-mastitis. Due to the impact of

Fig. 3: Oblique, dorsolatero-plantaromedial radiograph of the metatarsal region of the four-year-old Fleckvieh cow in Figure 1 showing a clearly demarcated sequestrum dorsally and moderate periosteal bone / Oblique, dorsolaterale-plantaromediale Röntgenaufnahme der Metatarsalregion der 4-Jahre alten Fleckvieh-Kuh aus Abb. 1 mit einem deutlich demarkierten Sequester dorsal und mittelgradiger periostaler Knochenproliferation

the diseases on multiple organ systems and for economic reasons, the cow was not treated but was euthanized after diagnosis.

Results for treated animals

Treatment was performed in 21 (87.5 %) patients, with sequestrectomy performed on 19 (90.5 %) animals (Fig. 6d). In the remaining two (9.5 %) animals, the bone sequestra were so small that self-resorption was awaited under accompanying systemic antibiotics.

Treatment was successful in 16 patients (76.2 %). One of the 16 animals was a calf with two bone sequestra on the right metatarsal bone, which showed undisturbed healing after the sequestrectomy. Half (50 %) of group 1 with small sequestra (<2.5 cm), 83.3 % of group 2 (size from 2.6 to 4 cm) and 72.7 % of group 3 (>4 cm) were discharged after successful treatment. Five (23.8 %) of the 21 treated animals were euthanized due to complications during treatment.

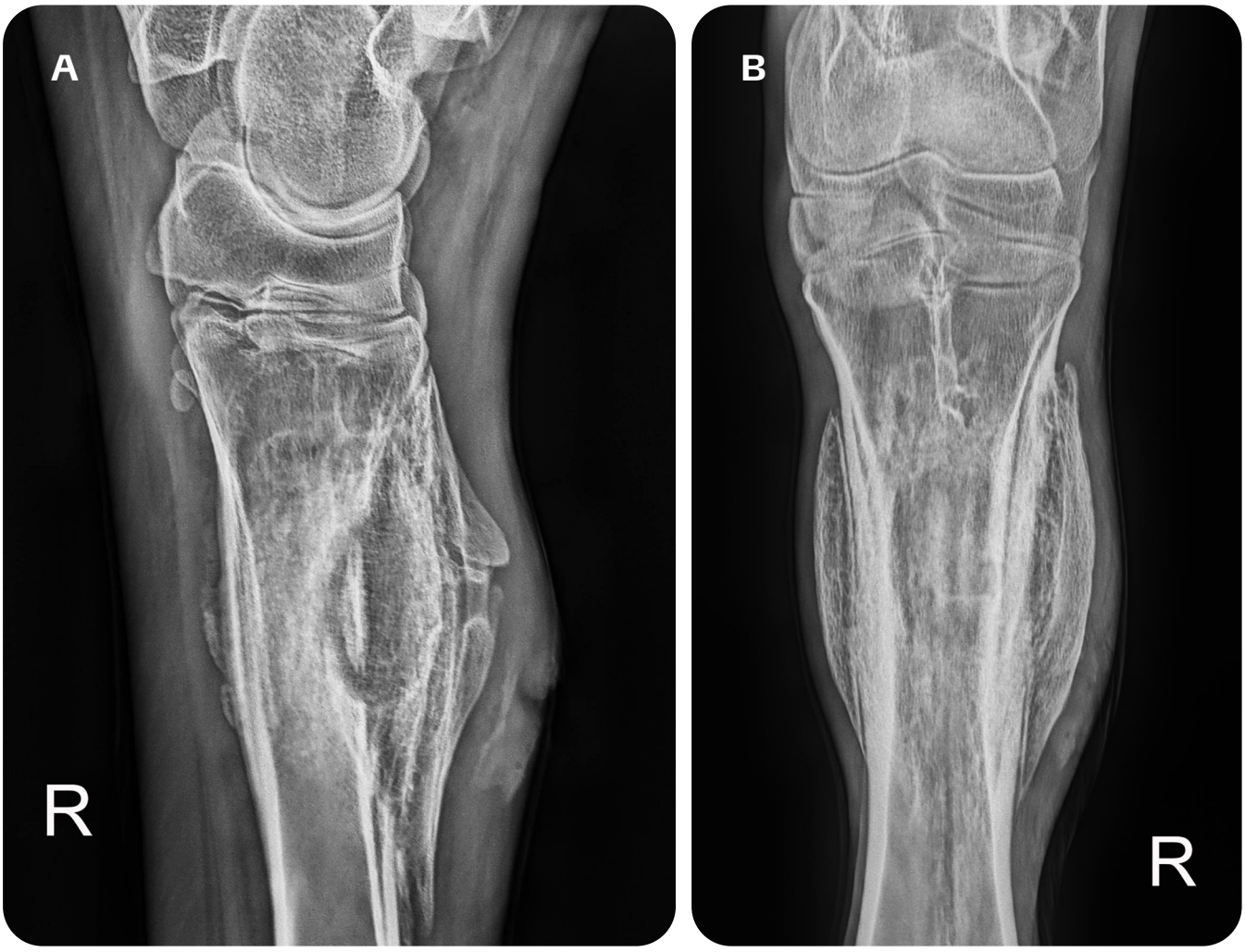


Fig. 4a,b: Latero-medial (a) and dorso-plantar (b) radiographs of the right metatarsal region of a four-month-old Fleckvieh calf showing a clearly demarcated sequestrum cranially on the proximal metatarsal bone and several periosteal growths. The trauma that initiated the alterations in this calf occurred eight weeks previously. / Latero-mediale (a) und dorso-plantare (b) Röntgenaufnahmen der rechten Metatarsalregion eines 4 Monate-alten Fleckvieh-Kalbes mit einem deutlich demarkierten Sequester kranial am proximalen Metatarsus sowie hochgradigen periostalen Zubildungen. Das ursächliche Trauma lag bei diesem Kalb bereits 8 Wochen zurück.

Postoperative complications

In six of the 21 treated animals (28.6 %), further surgical interventions were necessary after sequestrectomy to remove infected bone parts that were not adequately demarcated during the initial surgery. Three animals (14.3 %) required one additional bone curettage, one animal (4.8 %) required two and two animals (9.5 %) required three. One of them was an alpaca that had a total of three sequestra on two cannon bones. Despite the additional procedures, all six patients had successful outcomes.

Five patients (23.1 %) had to be euthanized during treatment. Two animals (9.5 %) experienced a fracture of the affected metatarsus after sequestrectomy: in one animal the bone fractured on the same day as the sequestrectomy, while the bone fractured four days later in the other. Both animals had received a postoperative cast. The sequestra in these two animals were 7.5 x 3 x 1 cm and 9 x 3 x 0.8 cm. In another two patients (9.5 %), bone infection continued to progress after sequestrectomy and bone curettage, despite antibiotic treatment. These patients were ultimately euthanized 12 days postoperatively. The fifth animal was a three-day-old Holstein calf that had sustained a comminuted fracture of the tibia. The fracture had been treated with internal fixation but an infection developed postoperatively in the fracture zone, leading to demarcation of one large sequestrum and two smaller sequestra in the tibia, causing instability. Sequestrectomy was not possible, so the calf was euthanized despite repeated curettage and irrigation four weeks after treatment of the fracture and one week after diagnosis of the sequestrum.

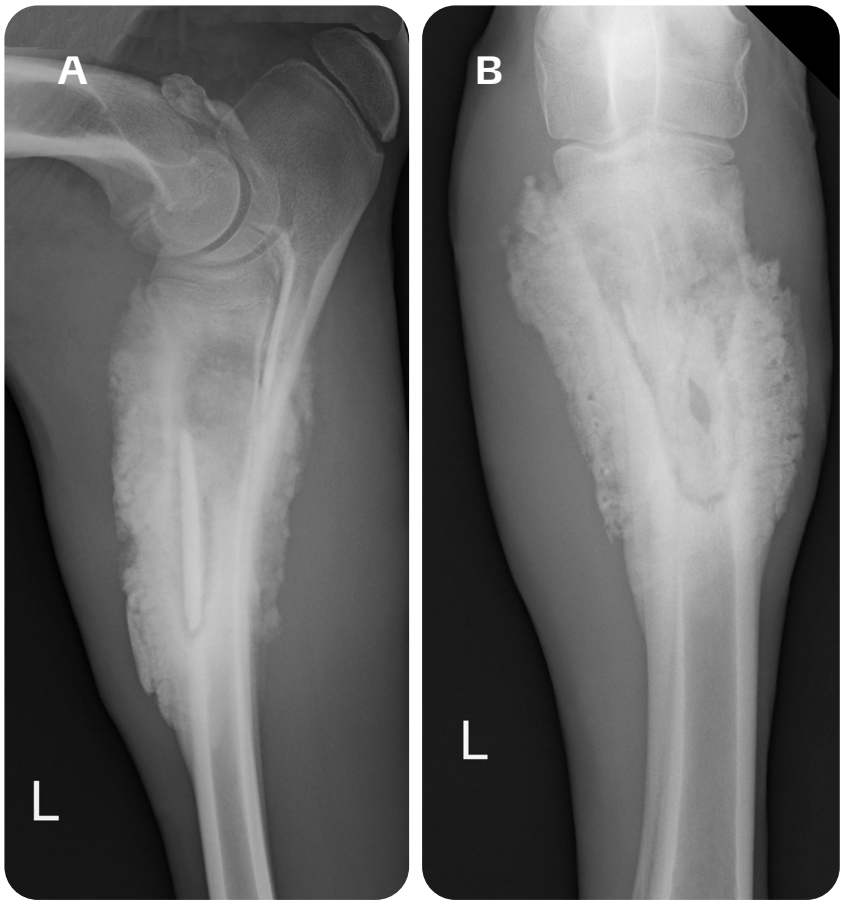


Fig. 5a,b: Medio-lateral (a) and cranio-caudal radiographs (b) of the left antebrachial region of a three-month-old Alpaca cria showing a clearly demarcated sequestrum on the cranial aspect of the radius and severe periosteal growths / Medio-laterale (a) und kranio-kaudale Röntgenaufnahmen (b) der linken Unterarmregion eines 3 Monate-alten Alpaca Crias mit einem deutlich demarkierten Sequester kranial am Radius und hochgradigen periostalen Zubildungen

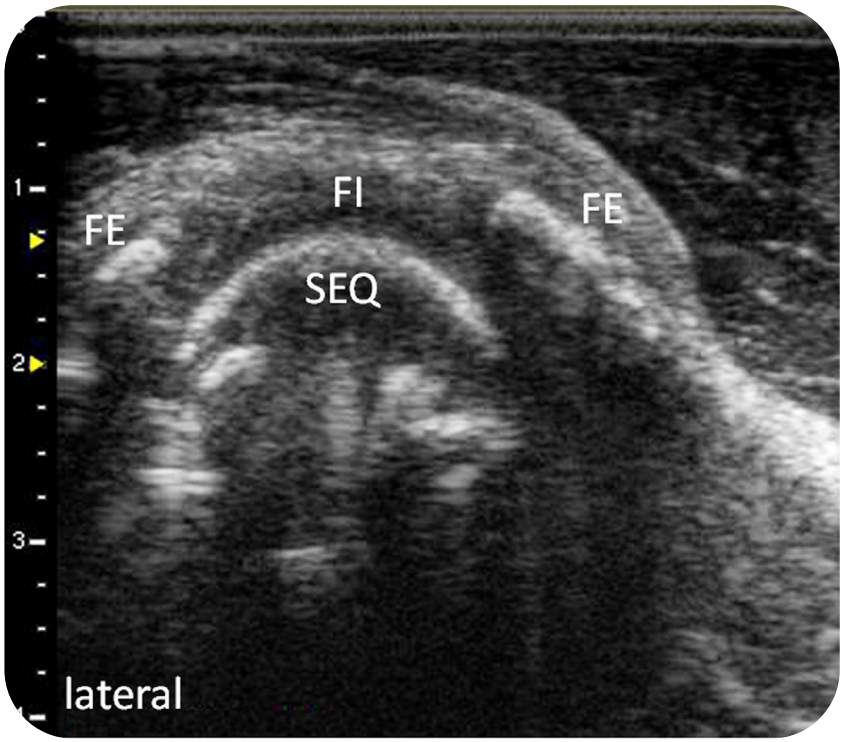


Fig. 6a: Transverse sonogram (7.5 MHz linear probe) of the left proximal femoral region showing a sequestrum in a twelve-month-old alpaca stallion; SEQ: demarcated sequestrum; FE: physiological, smooth, hyperechoic contour of the femur extending lateral and medial to the fistula canal (FI) into the depth of the image / Transversales Sonogramm (7,5 MHz Linearschallkopf) der linken proximalen Femurregion mit Darstellung eines Sequesters bei einem 12-Monate alten Alpaca-Hengst; SEQ: demarkierter Sequester; FE: physiologische, glatte, hyperechogene Kontur des Femurs lateral und medial des Fistelkanals (FI) in die Tiefe verlaufend

Duration of systemic medication and hospitalization

Systemically administered antibiotics were given as part of the treatment for an average of 7.9 days (SD: 2.8; median: 7; min: 3 days; max: 14 days). For peri- and post-operative anti-inflammatory treatment, ketoprofen was administered to cattle for an average of 5.4 days (SD: 3.8; median: 5.5; min: three days; max: 15 days). Carprofen was administered to the NWC for an average of four days (SD: 4.2; median: 1; min: three days; max: ten days) and metamizole for an average of 4.3 days (SD: 1.7; median: 4; min: three days; max: seven days). The 16 successfully treated patients had a mean hospitalization time of 29.6 days (SD: 10.1; median: 28.5; min: 14; max: 49).

Postoperative survival time

Sixteen animals were released to their farms of origin after successful treatment. Five of these 16 patients were still alive at the time of evaluation; they had a postoperative survival time of 7.0, 26.7, 102.5, 23.1 and 143.0 months at that time. The final three survival times refer to the three NWC, resulting in a mean cumulative survival time of 89.5 months (SD: 61.0; median: 102.5; min: 23.1; max: 143.0). The mean cumulative survival time of the 13 cattle was 31.1 months (SD: 26.5; median: 26.7; min: 7.0; max: 143.0). The mean postoperative survival time of the 13 cattle patients in the three groups based on size of the sequestra were: 13.3 months for group 1 (SD: 8.8; min: seven; max: 19.5), 18.9 months for group 2 (SD: 10.3; min:

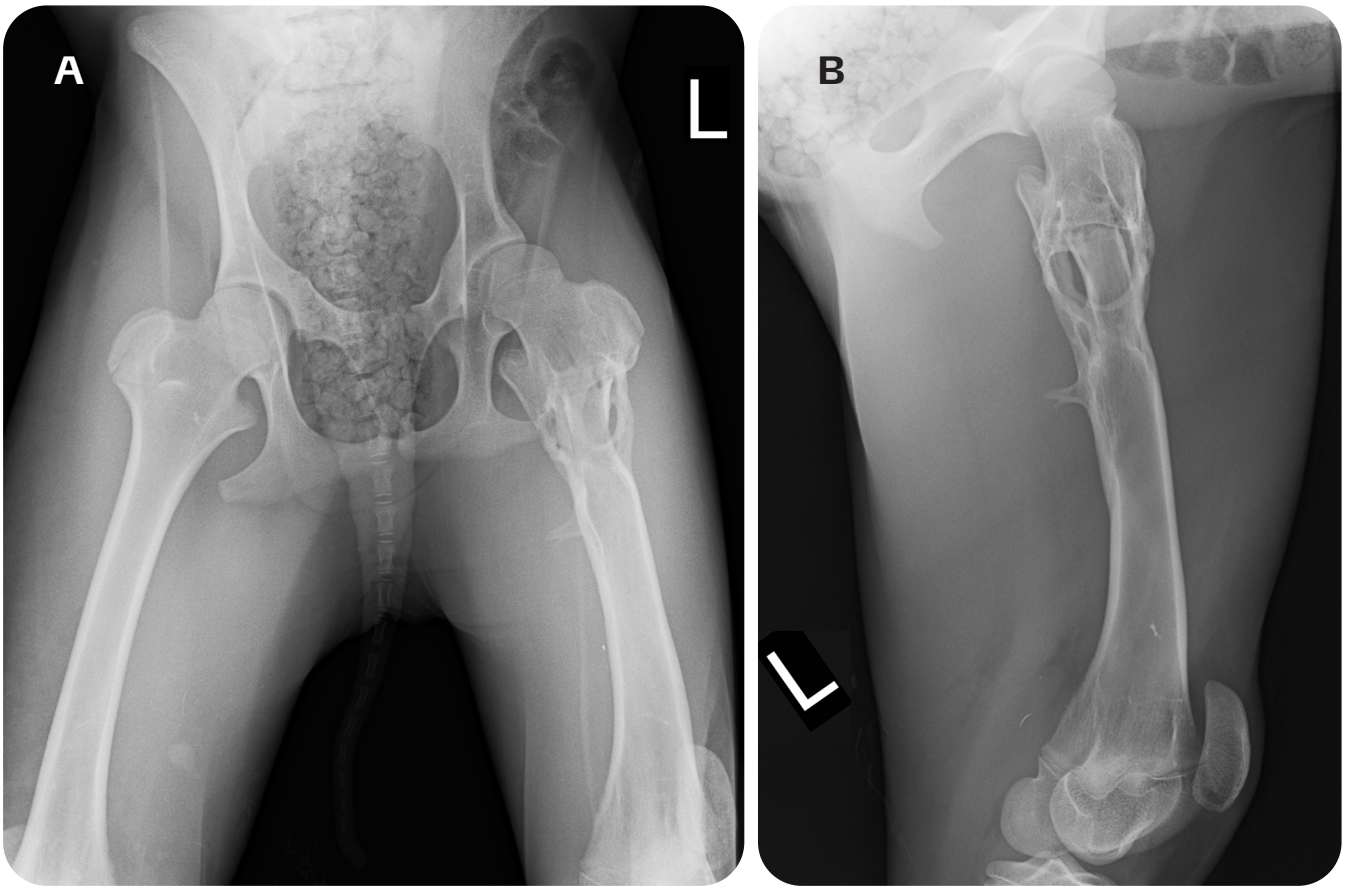


Fig. 6b,c: Ventro-dorsal (a) and medio-lateral radiographs (b) of the pelvic region and both femurs showing a sequestrum proximal on the left femur, just distal to the greater trochanter. The absence of periosteal bone proliferation is striking. / Ventro-dorsale (a) und medio-laterale Röntgenaufnahme (b) der Beckenregion und der beiden Oberschenkelknochen mit einem Sequester proximal am linken Femur knapp distal des Trochanter major. Auffällig ist das Fehlen einer periostalen Knochenproliferation.

6.1; max: 30.2) and 47.3 months for group 3 (SD: 33.8; min: 11.8; max: 108.1).

Statistical analysis

Due to the small sample size in group 1, the animals were combined with those in group 2 for statistical calculations. Table 3 provides a summary of the statistical analysis.

There was no statistically significant correlation between the age of the patients at the time of clinic presentation and postoperative survival time (r=0.050; p=0.854). Similarly, we found no statistically significant difference between cattle younger than 14 months (n=10) and those older than 23.5 months (n=11) in relation to the occurrence of limb sequestra (p=0.827). The three NWC with sequestra ranged in age from 0.8 to 11.2 months with a mean of 4.4 months.

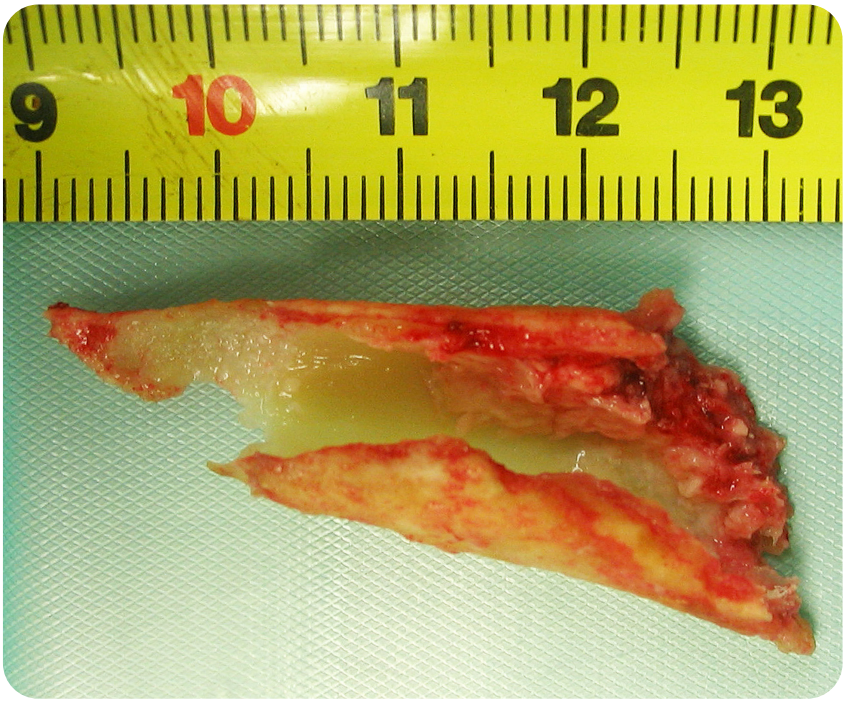
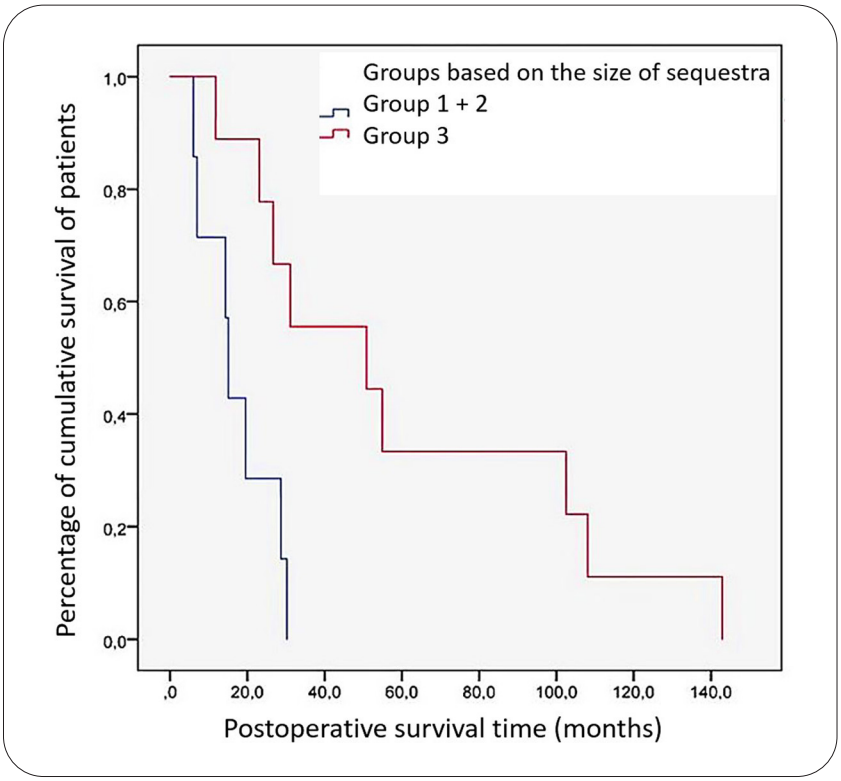


Fig. 6d: View of the sequestrum from the left proximal femur of the alpaca after sequestrectomy, measuring 4.2 x 1.5 cm / Ansicht des 4,2 x 1,5 cm großen Sequesters aus dem linken proximalen Femur des Alpacas nach der Sequestrektomie

Tab. 3: Results of the statistical analysis, including trial correlations, differences, the test, p values and correlation coefficients; LCS: Locomotion Score / Ergebnisse der statistischen Analysen mit den überprüften Korrelationen/Differenzen, den verwendeten Tests, den errechneten p-Werten und Korrelationskoeffizienten.

Statistical evaluations	Test	p-value
Correlation between age of the patients and postsurgical survival time	Spearman-Rank correlation	r=0.050 0.854
Association between age of the patients and occurrence of sequestra	Chi-Square test (Pearson)	0.827
Association between size of sequestra and treatment success	Chi-Square test (Pearson)	0.77
Correlation between size of sequestra in cattle and post-surgical survival time	Spearman-Rank correlation	r=0.585 0.036
Difference in postsurgical survival time of patients between groups 1+2 and group 3	Mann-Whitney test	0.017
Difference between LCS on initial examination and LCS at discharge in patients of groups 1 and 2	Wilcoxon test	0.038
Difference between LCS on initial examination and LCS at discharge in patients of group 3	Wilcoxon test	0.011



There was no significant correlation between the size of the sequestra and treatment success (p=0.77). However, there was a significant correlation between the size of the sequestra and postoperative survival time in cattle patients (r=0.585; p=0.036). Cattle in group 3 with the largest sequestra had a significantly longer postoperative survival time than those in groups 1+2 (p=0.026) (Fig. 7). There was also a statistically significant difference between the LCS of patients at clinic admission and discharge, both for patients in groups 1+2 (p=0.038) and for those in group 3 (p=0.011).

Discussion

Bone sequestra occur at varying frequencies in cattle and NWC. Treatment of the affected animal can be very complex depending upon the location and size of the sequestrum (Hirsbrunner et al. 1995; Valentino et al. 2000; Kusenda et al. 2024). There have been only three retrospective studies of the causes, diagnosis and treatment of bone sequestra in a large number of cattle: ten cases by Hirsbrunner et al. (1995), 77 cases by Firth (1987) and 110 cases by Valentino et al. (2000). Retrospective studies with case numbers of nine, twelve and 36 patients are also available on sequester treatments in NWC (Huber 2011; Rousseau et al. 2013; Kobera & Wagner 2018). However, most other studies relate to case reports of one or two bovines (Squire et al. 1990; Hooper et al. 1991; Clerc et al. 2005; Jaeger & Mueller 2008; Taguchi & Hyakutake 2012; Pagliosa et al. 2019; Heppelmann 2020; Kusenda et al. 2024; Müller 2024) and individual alpacas (Debney et al. 2011; Oman et al. 2021).

In Austria, no detailed retrospective evaluation of a large number of cattle

Fig. 7: Kaplan-Meier survival plots of 13 successfully treated cattle patients, divided into two groups based on the size of the sequestra: group 1+2 (combined) and group 3. Animals in group 3, with the largest sequestra, had a longer postoperative survival time (p=0.026) / Überlebensfunktionskurve (nach Kaplan-Meier) der 13 erfolgreich therapierten Rinderpatienten, eingeteilt je nach Größe der Sequester in die Gruppen 1+2 (zusammengefasst) und Gruppe 3; Tiere in der Gruppe 3 mit den größten Sequestern zeigten eine statistisch signifikant längere postoperative Überlebenszeit (p=0,026)

and NWC with bone sequestra in their limbs has taken the postoperative survival time into consideration. A case report from a few years ago provided a detailed description of the surgical procedure for sequestrectomy of a 7 cm x 3.4 cm x 0.8 cm sequestrum in the metatarsus of a cow (Pagliosa et al. 2019). There was also a review of short-term treatment outcomes for twelve animals with sequestra, although three of them were located in the mandible (Kofler 2017).

We evaluated the medical records of 24 animals with a total of 30 bone sequestra in their limbs. Two thirds (66.5 %) of the bone sequestra diagnosed were in the metatarsal and metacarpal bones, which aligns with findings from other researchers (Firth 1987; Hirsbrunner et al. 1995; Valentino et al. 2000; Clerc et al. 2005; Taguchi & Hyakutake 2012; Rousseau et al. 2013; Pagliosa et al. 2019; Müller 2024). The increased occurrence of bone sequestra in the cannon bones can be attributed to the thin soft-tissue mantle cover of the limbs distal to the carpus and tarsus, which provides little protection to the periosteum against trauma (Taguchi & Hyakutake 2012; Pagliosa et al. 2019; Heppelmann 2020).

In the majority of patients (almost 80 %) in our study, sequestrum formation was caused by direct traumatic impact to the bone. This observation is consistent with reports that periosteal trauma leads to impaired blood circulation in the surrounding bone areas. After a certain delay, necrosis of the surrounding bone occurs (Valentino et al. 2000; Rousseau et al. 2013; Heppelmann 2020). Much less common is osteomyelitis secondary to haematogenous spread, which can also lead to ischaemia of the periosteum due to bacterial emboli and ultimately to sequestrum formation (Valentino et al. 2000; Kusenda et al. 2024). Sequestrum formation can also be a complication following conservative or surgical fracture treatment (Köstlin et al. 1990; Squire et al. 1990).

Particularly in NWC, haematogenous spread can be a more frequent cause of bone sequestra. In such cases, there is no clinical evidence of trauma to the affected limb, which can lead to sequestra that are only diagnosed at a late stage in lame alpacas and llamas (Debney et al. 2011; Huber 2011; Rousseau et al. 2013; Kobera & Wagner 2018; Oman et al. 2021). Three (12.5 %) of the 24 animals in our study were NWC. Trauma (penetrating and blunt) was identified as the cause of the sequestra through medical history and clinical examination.

Trauma to the limb bones, along with associated periosteal damage and development of a sequestrum, typically results in lameness (Hirsbrunner et al. 1995; Valentino et al. 2000; Rousseau et al. 2013). This was evident in our patients, as 41.7 % of the 24 animals with a sequestrum exhibited mild to moderate lameness in the initial examination. Severe lameness (45.8 %) was observed in patients whose original trauma had occurred only a few hours or days before the initial examination. Only three out of 24 patients (12.5 %) with sequestra in their limbs showed no signs of lameness on initial examination, despite having evident swelling and a chronic fistulating wound on a limb.

The presence of a bone sequestrum delays wound healing because necrotic bone elicits a foreign body reaction. The organism continuously tries to demarcate it from the surrounding vital, blood-supplied tissue (Hirsbrunner et al. 1995). When inspecting and palpating the limb, there is frequently a fistula with purulent discharge running from the sequestrum to the skin surface. This purulent exudation cannot be treated with systemic antibiotic administration alone, as the bone sequestrum continues to endure for a longer period, depending on the size of the necrotic bone (Gift & DeBowes 1989; Hirsbrunner et al. 1995; Heppelmann 2020). Soft-tissue inflammation and more slowly bone proliferation will also develop around the affected bone area. If these symptoms are present in a limb, a sequestrum should always be considered as a differential diagnosis and further diagnostic procedures, ideally radiographs, should be performed (Valentino et al. 2000; Steiner et al. 2010).

The clinical manifestation of bone sequestra in NWC differs from that in cattle and horses, particularly in relation to the age of the affected animals and the presence of detectable local trauma (Gift & DeBowes 1989; Hirsbrunner et al. 1995; Valentino et al. 2000). Sequestra have been observed in NWC up to 30 months old and can develop without signs of local trauma (Rousseau et al. 2013; Kobera & Wagner 2018). The risk of developing a bone sequestrum in cattle aged six months to two years is significantly higher, with an odds ratio of 2.6, compared to cattle under six months of age (Valentino et al. 2000). In the present study, the three NWC with sequestra were younger than twelve months, while cattle diagnosed with a limb bone sequestrum had a mean age of 27.2 months, with eleven of the 21 cattle 23.5 months and older. This result corroborates previous observations on the age of animals suffering from sequestra (Kobera & Wagner 2018; Rousseau et al. 2013; Valentino et al. 2000). Previous work considered a larger number of patients but we found no statistically significant difference ($p=0.827$) in the frequency of sequestra for cattle of different ages. Again, the limited patient numbers may have influenced the result.

A definitive diagnosis of a bone sequestrum can only be made following a radiographic examination of the affected limb region (Valentino et al. 2000; Steiner et al. 2010). This was performed in all animals in this study. In cases where a sequestrum is clearly demarcated, a broad radiolucent line can be seen on the radiograph. This results from osteolysis and gradually separates the sequestrum from the surrounding healthy bone. Extensive periosteal growths surrounding the sequestrum are often observed, depending on how long the sequestrum has been present (Valentino

et al. 2000; Steiner et al. 2010; Heppelmann, 2020). The formation of a sequestrum after periosteal trauma takes a certain amount of time and its clear demarcation from vital tissue usually only occurs after two to four weeks (Hirsbrunner et al. 1995; Heppelmann 2020). It is therefore advisable to take radiographs even in patients that are presented just a few hours or days after a penetrating periosteal trauma to minimize the risk of overlooking any small bone lesions or small fractured bone fragments (Steiner et al. 2010). In any case, radiographic examination of the affected region in such patients must be repeated after two to four weeks. Only after this period can the very clearly demarcated bone sequestrum be detected, if one has formed at all (Valentino et al. 2000; Debney et al. 2011; Kobera & Wagner 2018; Heppelmann 2020; Kusenda et al. 2024).

Veterinarians in livestock practice may find the definitive diagnosis of a sequestrum challenging, as a mobile radiographic unit is typically not available in bovine practice (Kobera & Wagner 2018; Pagliosa et al. 2019; Kusenda et al. 2024). Sequestrum formation can also be imaged using ultrasonography with a 5–8 MHz linear probe, provided that there is not yet high-grade periosteal bone formation around the fistula canal. Portable ultrasound units are now standard equipment for many livestock practitioners and are primarily used for pregnancy examinations in cattle. Ultrasonography can often visualize the associated fistula and the demarcated bone fragment. However, a major disadvantage of diagnostic ultrasound is the lack of an overall view, making it difficult to determine the degree of demarcation and the true magnitude of the sequestrum, especially if periosteal growths hinder or prevent imaging of the underlying lesion (Taguchi & Hyakutake 2012; Pagliosa et al. 2019; Kofler et al. 2021).

The preferred treatment for a bone sequestrum is surgical removal of the avital bone fragment and all surrounding necrotic tissue. If a suitable restraining device, such as a hydraulic tilting table used for hoof trimming, can be arranged, a sequestrectomy can be performed in any practical setting as long as the surgeon is sufficiently skilled (Kusenda et al. 2024). If no radiography support is available, it is recommended that patients with a history of penetrating periosteal trauma and suspected sequestrum formation be referred to a well equipped clinic (Pagliosa et al. 2019; Kusenda et al. 2024; Müller 2024).

Sequestrectomy can be performed under general anaesthesia, as in two NWC in this study, or under sedation and additional epidural or local anaesthesia on the affected limbs (Pagliosa et al. 2019; Heppelmann 2020; Kusenda et al. 2024), as in the remainder of surgically treated patients. General anaesthesia is only required for the removal of a sequestrum in cattle and NWC in cases when the bone sequestrum is in very proximal bones, so that effective and safe local anaesthesia can no longer be applied (Valentino et al. 2000; Debney et al. 2011; Rousseau et al. 2013; Kobera & Wagner 2018). To ensure a good and unobstructed view of the surgical field during surgery, a tourniquet should always be placed sufficiently proximal to the necessary surgical bone access (Gift & DeBowes 1989; Valentino et al. 2000; Pagliosa et al. 2019; Heppelmann 2020).

The correct timing of the surgical procedure is crucial for the success of a sequestrectomy. If a surgeon attempts to remove the sequestrum too soon, before it is sufficiently demarcated from vital bone tissue, the border to the healthy, vital bone can often be very difficult or even impossible to identify during surgery. This poses a risk for unnecessary resection of vital bone and the result may be an incomplete removal of the sequestrum (Hirsbrunner et al. 1995; Huber 2011; Kobera & Wagner 2018; Heppelmann 2020; Kusenda et al. 2024). The crucial factor in determining the correct timing for sequestrectomy is ultimately the findings from repeated radiography. Ideally, the radiographs should illustrate the bone sequestrum completely demarcated from vital bone by a broad radiolucent line (Valentino et al. 2000; Heppelmann 2020; Kusenda et al. 2024). At this 'ideal' time for surgery, medium-to-high-grade periosteal growths are often present (Hirsbrunner et al. 1995; Pagliosa et al. 2019; Kusenda et al. 2024). In our study, surgery probably took place too early in six animals, resulting in the need for a subsequent surgical intervention.

All patients with sequestra that underwent surgery, as well as the two patients where the resorption of the small bone sequestra was anticipated, were treated with systemic antibiotics and NSAIDs, as reported by others (Valentino et al. 2000; Rousseau et al. 2013; Kobera & Wagner 2018). The duration of systemic antibiotic treatment was between seven and ten days. The choice of antibiotic agent should be based on the results of resistance testing, which are usually only available about three days after the swab sample has been taken. Until then, a broad-spectrum antibiotic is usually administered, as was the case in this study. Suitable broad-spectrum antibiotics include ampicillin, amoxicillin, penicillin-streptomycin etc., which are not considered reserve antibiotics (Kobera & Wagner 2018; Pagliosa et al., 2019; Kusenda et al., 2024). The systemic administration of reserve antibiotics as adjunctive medication from the day of sequestrectomy, as described in older publications (Valentino et al. 2000; Clerc et al. 2005; Jaeger & Mueller 2008; Debney et al. 2011; Rousseau et al. 2013), does not correspond to the current guidelines for the responsible use of these agents (Aigner 2018). NSAIDs were applied for at least three days but many patients received them for significantly longer (on average 5.4 days) due to prolonged pain symptoms (Hirsbrunner et al. 1995; Valentino et al. 2000; Jaeger & Mueller 2008; Rousseau et al., 2013; Heppelmann 2020; Kusenda et al. 2024).

In two Fleckvieh cows, a two-year-old and a four-year-old, the sequestra were so small or thin (2 x 0.5 x

0.5 cm and 5 x 0.8 x 0.2 cm) that they were not surgically removed and were absorbed. In such instances, it is recommended to administer systemic antibiotic therapy for up to four weeks to prevent the progression of an infection in the surrounding bone (Gift & DeBowes 1989; Valentino et al. 2000; Heppelmann 2020; Oman et al. 2021). However, exclusive systemic medication is not advised in the presence of a large bone sequestrum. The presence of necrotic tissue surrounding the sequestrum, in which there is insufficient or no blood supply, makes it unlikely that the concentration of the antibiotic in the tissue will reach the minimum level for inhibition (Heppelmann 2020).

Minor complications after sequestrectomy, such as the need for a second bone curettage to remove remaining minor bone fragments, have also been described by others but only led to a short delay in healing (Rousseau et al. 2013; Kusenda et al. 2024). A serious complication in an animal with a bone sequestrum is the fracture of the affected bone before or after sequestrectomy. This occurs when the bone loses stability or when there is no large piece of supporting bone to bear the normal weight (Valentino et al. 2000; Huber 2011). In the present study, 13 animals showed an increased risk of postoperative bone fracture due to the size of the sequestrum. As a prophylactic measure, an immobilizing support bandage was applied after surgery, either a fiberglass cast or vertically sectioned PVC half-tubes of appropriate length and width, as reported elsewhere (Valentino et al. 2000; Pagliosa et al. 2019; Kusenda et al. 2024). Another benefit of temporarily immobilizing the limb is that restricting movement in the wound area promotes wound healing (Hirsbrunner et al. 1995; Valentino et al. 2000; Müller 2024). Despite this measure, a stress fracture in the presence of a large sequestrum or after a sequestrectomy occurred in two bovines in this study, an occurrence that has also been documented by other authors (Valentino et al. 2000; Huber, 2011). Valentino et al. (2000) reported fractures of long bones and the sternum in a total of ten out of 113 cattle (8.8 %) with sequestra, while Huber (2011) observed fractures in two out of nine NWC (22.2 %). This complication invariably necessitates euthanasia.

In the present study, 16 of 21 animals with sequestra were successfully treated, corresponding to a success rate of 76.2 %. Previous studies have reported slightly higher cure rates of 78.0 % in cattle (Valentino et al. 2000) and 88.0 % in NWC (Rousseau et al. 2013) after sequestrectomy. In three of the 24 animals, two or three bone sequestra were diagnosed on one or two different limbs. Two of these animals were discharged from the clinic after complete healing, while the third case developed bone sequestra due to infection following internal fixation of a tibial fracture. Due to the small number of patients with multiple sequestra, we are unable to assess the influence of the number of sequestra per animal on the likelihood of recovery and postoperative survival times.

Cattle, as livestock, generally have a significantly different life expectancy than NWC, which are often kept as hobby animals (Valentino et al. 2000; Rousseau et al. 2013), so we only considered cattle patients for the statistical calculations of the relationship between the size of the sequestra and postsurgical survival time. We found no statistically significant correlation between the size of sequestra and treatment success. However, there was a significant correlation between the size of sequestra and postoperative survival time in cattle. Cattle patients in group 3, with the largest sequestra, unexpectedly had significantly longer postoperative survival times than animals in groups 1 and 2 with smaller sequestra. However, the validity of this seemingly contradictory result is uncertain due to the relatively small sample size of 13 treated cattle patients.

The relationship between the size of bone sequestra, success rate and postoperative survival time has not been explored by others (Valentino et al., 2000; Huber 2011; Rousseau et al. 2013; Kobera & Wagner 2018). The mean cumulative postoperative survival time of the successfully treated cattle patients was 31.1 months. The long-term results after sequestrectomy in cattle are similar to those previously reported (Hirsbrunner et al. 1995). In this previous report, cattle no longer exhibited lameness four to 44 months after surgery, although follow-up radiographs revealed mild-to-severe thickening of the cannon bone in eight of nine patients. All three NWC in our study were still alive on the cut-off day of the postoperative survival survey and had cumulative postoperative survival times of 23.1, 102.5 and 143 months. The long postoperative survival times are consistent with a previous report of a median of 7.7 years of postoperative survival in 24 NWC (Rousseau et al. 2013). Our statistical analysis showed no correlation between the age of the animals at the time of treatment, the size of the sequestrum and postoperative survival times.

Conclusions

Based on our results and on other retrospective studies involving a large number of patients, choosing the correct time for sequestrectomy is crucial. Sequestrectomy should be performed when there is clear demarcation of the sequestrum from all surrounding vital bone radiographically, as indicated by a broad radiolucent rim around the sequestrum and at least minor bony periosteal proliferations. With adequate aftercare, the chances of recovery are generally favourable, provided that there are no serious concomitant diseases.

Fazit für die Praxis:
Aus den Ergebnissen dieser Arbeit und retrospektiven Studien anderer Autoren mit großen Patientengruppen kann der Schluss gezogen werden, dass die Wahl des richtigen Zeitpunkts für die Sequesterresektion entscheidend für den Operationserfolg ist. Diese soll erfolgen, wenn eine klare Demarkation des Sequesters vom umgebenden vitalen Knochengewebe besteht, was sich im Röntgenbild als breite Aufhellungszone um den Sequester und als zumindest kleinere periostale Zubildungen zeigt. Bei geeigneter Nachsorge sind die Erfolgsaussichten generell gut, sofern keine Begleiterkrankungen vorliegen.

Conflict of interest
The authors declare no conflict of interest.

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