Received: 18 February 2022 | Revised: 6 September 2022 | Accepted: 28 September 2022

DOI: 10.1002/vetr.2344

VetRecord

ORIGINAL RESEARCH

Treatment options, complications and long-term outcomes for limb fractures in pet rabbits

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Abstract

Background: Limb fractures represent the most common orthopaedic disease in pet rabbits. However, only a few studies have evaluated therapeutic details of limb fractures. There are no data available for long-term outcomes of limb fracture treatment.

Methods: The medical records of six institutions were reviewed retrospectively to identify cases of traumatic limb bone fractures in pet rabbits between 1999 and 2020. The medical records (n = 387) were analysed for details of fracture prevalence, aetiology, therapy protocols, treatment complications, outcome and long-term effects. In addition to the retrospective data evaluation, 13 rabbits were re-evaluated in person in recent clinical analyses, including orthopaedic examination, radiography and computed-tomographic imaging. Details of long-term effects of fracture treatment were requested over the telephone for a further 232 animals using a standardised questionnaire.

Results: Long bone fractures accounted for the majority of all fractures (296/387; 76.5%). Hindlimb fractures (301/387; 77.7%) were more common than forelimb fractures (86/387; 22.2%), and tibial fractures and combined fractures of the tibia and fibula (119/387; 30.8%) were observed most frequently. Most fracture treatments were based on osteosynthesis procedures (243/328; 74.1%). Treatment complications occurred in 130 out of 328 (39.6%) cases. A high bodyweight ($p = 0.047$) and an older age ($p = 0.01$) were found to be significant risk factors for the emergence of therapy complications. Overall, 75.4% of animals (175/232) had a satisfactory long-term outcome. Limb posture anomalies were evaluated in 61 cases (26.3%).

Limitations: The multi-centre approach led to the inclusion of various institutions, veterinarians, treatment protocols and rabbit populations that might have influenced the results. The medical records were reviewed retrospectively, so there were some data that were lacking or could not be collected in a standardised manner. Furthermore, rabbit owners' evaluation of long-term outcomes might be prone to error, despite the use of a standardised interview questionnaire.

Conclusion: Limb fractures are a common orthopaedic issue in pet rabbits. The patient's bodyweight and age are significant risk factors for the emergence of complications during the fracture treatment process. Long-term orthopaedic effects, such as abnormal limb posture and permanent lameness of the affected limb, were observed regularly.

KEYWORDS
fracture, orthopaedics, rabbit, radiography, trauma

INTRODUCTION

Long bone fractures are a common reason for the presentation of pet rabbits in veterinary practice.[1,2] Compared to other mammals, the skeletal structure of rabbits is light, comprising 7%–8% of the total bodyweight.[3] Low bone density, large muscle mass and behavioural characteristics predispose rabbits to limb fractures.[4] Fracture aetiologies are diverse, including accidents related to handling or equipment, blunt trauma or behaviour.[5,6] Only a few studies have compared diagnostic and therapeutic details of limb fractures in rabbits,[7–9] acquiring different results for outcome and complication rate associated with fracture therapy. Treatment modalities can be broadly classified into conservative and surgical options. Surgical methods commonly used for cats and dogs may not be necessarily appropriate for rabbits.[10,11] Therefore, it is essential to adjust methods to the specific needs of rabbits.[5,8,12] Primarily depending on the fracture location and type, different surgical methods such as external skeleton fixation systems, intramedullary pinning, cerclage wiring, bone plating or combinations of these techniques have been described.[7,13–16] The main purpose of this retrospective study was to review the fracture aetiologies, therapy options and treatment outcomes in six veterinary hospitals specialised in small mammal medicine. Furthermore, the patients' long-term clinical follow-ups were analysed.

MATERIAL AND METHODS

The medical records of six institutions were reviewed to identify cases of traumatic limb bone fractures in pet rabbits between 1999 and 2020. Participating veterinary institutions are listed in Table 1.

The records needed to be complete (including at least major signalment data, clinical condition and initial therapy result) and fully comprehensible in order to be available for this study. Rabbits that were euthanased without therapy were included in this study as long as complete records were available. Detailed data pertaining to the patients' signalment and husbandry, fracture aetiology and characteristics (classified according to Brinker et al.[17]), treatment, complications and outcome were tabulated after reviewing the medical records. Complications relating to the fracture therapy were classified as 'no', 'major' and 'minor', as adopted by Cook et al.,[18] and their occurrence was classified into three different time periods; intraoperative, within 48 hours of initial treatment and between day 3 of the initial treatment and the time complete healing with regained limb functionality was achieved. Lethal anaesthesia events were defined as deaths occurring perioperatively (ie, between the start of anaesthesia and complete awakening of the patient). Fractures with a suspected pathological origin[19–21] were excluded from this study.

TABLE 1 The list of veterinary institutions participating in this multi-centre study with their respective number of cases

Veterinary institution	Number of cases
University of Veterinary Medicine Hannover, Foundation, Germany	124
Freie Universität Berlin, Germany	106
University of Zurich, Switzerland	13
Veterinary Clinic Haar, Germany	100
Veterinary Clinic Posthausen, Germany	35
Veterinary Clinic Northeim, Germany	9

In addition to the retrospective data evaluation, 13 rabbits were re-evaluated in person at the Department of Small Mammal, Reptile and Avian Diseases, University of Veterinary Medicine Hannover, Germany. The examination of these animals was performed according the German Animal Welfare Act of 2006, which regulates against animal suffering and pain infliction. All examinations were kept short and performed as gently as possible, with and no sedation/anaesthesia needed. After a detailed anamnesis with the animal owner, clinical and orthopaedic examinations as well as digital radiography and computed-tomographic imaging were obtained to evaluate the long-term effects of fracture treatment.

A total of 232 animals could not be presented for a follow-up examination. Following a standardised questionnaire (see Supporting information), the owners of these rabbits were requested by telephone to specify any long-term changes they had observed in limb posture, lameness and restriction of motion after the end of the fracture therapy. In addition, the owners were asked to grade the treatment results and indicate whether they would agree to the elected therapy again in future cases.

A total of 142 patients were evaluated by reviewing their medical records alone.

Statistical analysis

Statistical analyses were performed by a specialist in veterinary epidemiology, using Microsoft Excel (Microsoft, Redmond, WA, USA) and the commercial software 'Statistical Analysis System' (version 9.3, SAS Institute, Cary, NC, USA). Categorical data were reported as number and percentage. Logistic regression analysis was used to determine if there were significant ($p < 0.05$) risk factors (signalment, treatment, location of injury and fracture characteristics) for both complication rate and therapy outcome.

TABLE 2 Details of fracture aetiologies and husbandry conditions in 387 rabbits with limb fractures

	Number of rabbits (%)
Fracture aetiology	
Handling-related accidents (owner)	65 (16.8%)
Enclosure equipment	57 (14.7%)
Room equipment	43 (11.1%)
Other animals (e.g., dogs)	26 (6.7%)
Companion animals	12 (3.1%)
Handling-related accidents (veterinarian)	6 (1.5%)
Unknown (not reported)	92 (23.8%)
Not identified by the owner	86 (46.0%)
Housing form	
Inside (room)	123 (31.8%)
Permanently outside	80 (20.7%)
Inside (cage)	44 (11.4%)
Inside + outside	27 (7.0%)
Not identified	113 (29.2%)

RESULTS

Signalment data

Of the 387 rabbits included in this study, 210 (54.2%) were male and 175 (45.2%) were female. Bodyweight ranged from 0.2 to 9.5 kg, with a median of 1.72 kg. Patients were divided into three weight classes for further analysis: group 1 (140 animals, weighing less than 1.5 kg), group 2 (216 animals, weighing between 1.5 and 3 kg) and group 3 (31 animals, weighing more than 3 kg).

Rabbits presented with fractures were aged between 1 and 166 months (median 25 months). All animals were assigned to three age classes for further statistical analysis. Altogether, 117 fractures (30.2%) occurred in rabbits younger than 1 year, 185 (47.8%) in rabbits 1–6 years old and 85 (22.0%) in rabbits older than 6 years.

Fracture aetiology

Detailed data relating to fracture aetiologies and enclosure equipment are summarised in Table 2. Handling-related traumas were seen most frequently. The majority of patients (293/387; 75.7%) were presented within 24 hours of trauma occurrence.

Fracture characteristics

Table 3 describes the fracture details of all 387 rabbits, including fracture location, type of fracture and joint involvement. We found 38 open fractures (9.8%) and 49 fractures involving joints (12.7%). Four patients were presented with multiple limb fractures. No significant correlation between the rabbits' sex, weight or age and the affected bone was noted for the different fracture locations.

Fracture therapy

Of the 387 cases available to review, 20 had incomplete treatment records and 39 were euthanased without treatment. In total, 26 rabbits (6.7%) were euthanased due to poor prognosis for recovery and severity of additional findings. In this group, there were seven tibial/fibular fractures, five femoral, four humeral and four multiple long bone fractures. Fractures were classified as open in five cases (19.2%) and comminuted in nine cases (34.6%). Another 13 animals (3.4%) were euthanased for financial reasons.

The majority of fractures were treated by osteosynthesis techniques (243/328; 74.1%), and 14 (4.3%) rabbits underwent initial partial/complete limb amputation. Comparatively, the proportion of surgically treated cases was higher in open fractures (30/38 cases; 78.9%) and joint-involving fractures (42/49 cases; 85.7%). A total of 71 animals (21.6%) were treated conservatively with cage confinement and exercise restriction, either with (19 cases; 26.8%) or without (52 cases; 73.2%) splinting. The number of animals managed conservatively was significantly higher for rabbits with fractures involving the distal part of the limb (32/66 cases; 48.5%) compared to patients with long bone fractures (27/250; 10.8%). In addition, all 12 (100%) pelvic fractures were treated conservatively.

The comparison made between the different age groups revealed that surgical therapies were more common in younger rabbits. Eighty-six of 117 (73.5%) patients younger than 1 year were treated surgically, whereas 44 of 85 (51.8%) rabbits older than 6 years underwent surgery. Table 4 summarises the treatment details.

Therapy complications

Altogether, 34 animals died due to complications related to the surgical procedure (most notably 13 lethal anaesthesia events and nine deaths occurring postsurgically) and two patients were euthanased intraoperatively due to further fracturing during surgery. Another 22 animals did not survive the rehabilitation period: 11 patients died between days 3 and 18 after surgery. A further 11 animals were euthanased during rehabilitation. The reasons for this decision were ongoing reduced condition postsurgery (seven cases), refractures of the affected bone (two cases), implant failure (two cases), wound healing problems (one case) and osteomyelitis (one case).

Complications were identified in 130 of 328 cases (39.6%; 98 major and 32 minor). The most frequently reported complications were (delayed) wound healing issues, seen in 42 out of a total of 257 surgically treated patients (16.3%). The percentage rate of such complications was higher in open fractures (11/38 cases;

TABLE 3 Details of fracture classification in 387 rabbits

Affected bone	Number of rabbits (%)	Fracture location: Diaphyseal (no., %)	Fracture location: Epi-/metaphyseal (no., %)	Fracture type: Closed (no., %)	Fracture type: Open (no., %)	Joint involvement: Extra-articular (no., %)	Joint involvement: Intra-articular (no., %)
Humerus	15 (3.9%)	13 (86.6%)	2 (13.4%)	15 (100%)	0 (0%)	15 (100%)	0 (0%)
Radius/ulna	62 (16.0%)	59 (95.2%)	3 (4.8%)	61 (98.4%)	1 (1.7%)	60 (96.8%)	2 (3.2%)
Metacarpus	6 (1.6%)	5 (83.3%)	1 (16.6%)	6 (100%)	0 (0%)	5 (83.3%)	1 (16.6%)
Phalanges	3 (0.7%)	1 (33.3%)	2 (66.6%)	3 (100%)	0 (0%)	1 (33.3%)	2 (66.6%)
Forelimb	86 (22.2%)	78 (90.7%)	8 (9.3%)	85 (98.8%)	1 (1.2%)	81 (94.2%)	5 (5.8%)
Pelvis	17 (4.4%)	16 (94.1%)	1 (5.9%)	17 (100%)	0 (0%)	16 (94.1%)	1 (5.9%)
Femur	96 (24.8%)	78 (81.2%)	18 (18.8%)	95 (99.0%)	1 (1.0%)	83 (86.4%)	13 (13.6%)
Tibia/fibula	119 (30.7%)	100 (84.0%)	19 (16.0%)	99 (83.2%)	20 (16.8%)	104 (87.4%)	15 (12.6%)
Calcaneus	31 (8.0%)	26 (83.8%)	5 (16.1%)	19 (61.2%)	12 (38.7%)	26 (83.8%)	5 (16.1%)
Metatarsus	28 (7.2%)	20 (71.4%)	8 (28.6%)	25 (89.2%)	3 (10.8%)	21 (75.0%)	7 (25.0%)
Phalanges	6 (1.5%)	3 (50.0%)	3 (50.0%)	5 (83.3%)	1 (16.6%)	3 (50.0%)	3 (50.0%)
Multiple fractures	4 (1.0%)	4 (100.0%)	0 (0%)	4 (100%)	0 (0%)	4 (100%)	0 (0%)
Hindlimb	301 (77.7%)	247 (82.1%)	54 (17.9%)	264 (87.7%)	37 (12.3%)	257 (85.4%)	44 (14.6%)
Total	387 (100%)	325 (84.0%)	62 (16.0%)	349 (90.2%)	38 (9.8%)	338 (87.3%)	49 (12.7%)

TABLE 4 Fracture treatment methods for 328 rabbits

Affected bone	Number of rabbits	Cases with a sufficient medical record	Conservative therapy Exercise restriction (complications)	External coaptation (complications)	Surgical therapy Intramedullary pinning (complications)	External fixation systems (complications)	Other techniques (complications)	Amputations Amputation (Complications)
Humerus	15	10	1 (0)	1 (1)	3 (3)	2 (1)	0 (0)	3 (0)
Radius/ulna	62	55	6 (1)	5 (1)	18 (6)	23 (14)	2 (2)	1 (0)
Metacarpus	6	6	3 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (0)[a]
Phalanges	3	3	3 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Forelimb	86	74	13 (1)	6 (2)	21 (9)	25 (15)	2 (2)	7 (0)
Pelvis	17	12	12 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Femur	96	84	12 (0)	1 (0)	20 (12)	32 (17)	17 (7)	2 (0)
Tibia/fibula	119	101	1 (0)	0 (0)	23 (10)	66 (27)	8 (5)	3 (1)
Calcaneus	31	28	2 (0)	9 (4)	10 (5)	6 (1)	0 (0)	1 (0)
Metatarsus	28	24	8 (0)	3 (1)	8 (7)	3 (2)	2 (1)	0 (0)
Phalanges	6	5	4 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)[a]
Multiple fractures	4	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Hindlimb	301	254	39 (1)	13 (5)	61 (34)	107 (47)	27 (13)	7 (1)
Total	387	328	52 (2)	19 (7)	82 (43)	132 (62)	29 (15)	14 (1)

Note: Numbers in brackets indicate the number of patients with complications during therapy.
[a]In these cases, an amputation was performed only for the affected toe/digit.

28.9%) compared to closed fractures (31/219 cases; 14.2%). A total of 239 animals were treated with one or more implants. Implant failure was identified in 33 (13.8%) of these cases. Refractures of the affected bone were seen in 32 of 306 (10.5%) patients with 31 occurring in treatments using osteosynthesis techniques (31/235; 13.2%) and one developing during conservative therapy (1/71; 1.4%).

Further complications included osteomyelitis (10/257; 3.9%), implant-related bone growth issues (4/239; 1.7%), prolonged paralysis symptoms of the affected bone (3/328; 0.9%) and emergence of pseudarthrosis (2/328; 0.6%).

Table 5 illustrates the most commonly observed complications and their rates for the main surgical fracture therapies. Fracture location neither had a

TABLE 5 The three most common types of complications and their corresponding rates for the main surgical therapy techniques

Surgical technique	Complication	Complication rate
Implants 39/73 (53.4%)	Implant failure	14/73 (19.2%)
	Refracture	10/73 (13.7%)
	Wound healing issue	9/73 (12.3%)
Tie-in external fixation systems 46/93 (49.5%)	Wound healing issue	14/93 (15.1%)
	Refracture	12/93 (12.9%)
	Implant failure	6/93 (6.5%)
External fixation systems without tie-in 17/39 (43.6%)	Implant failure	3/39 (7.7%)
	Refracture	3/39 (7.7%)
	Wound healing issue	3/39 (7.7%)

TABLE 6 The two most common types of complications and their corresponding rates for the three animal weight classes

	Complication (with rate)		
Bodyweight (kg)	Wound healing issue	Refracture	Total complication rate*
<1.5	11/128 (8.6%)	7/128 (5.5%)	39/128 (30.5%)
1.5–3	18/193 (9.3%)	8/193 (4.1%)	82/193 (42.5%)
>3	4/27 (14.8%)	4/27 (14.8%)	15/27 (55.6%)

*The overall complication rates for the weigh groups one and three differ significantly ($p = 0.047$)

TABLE 7 Selected complications and their corresponding rates for the three animal age classes

	Complication (with rate)		
Animal age (years)	Prolonged postsurgical reduction	Refracture	Total complication rate*
<1	0/108 (0%)	7/108 (6.5%)	32/108 (29.6%)
1–6	4/171 (2.3%)	8/171 (4.7%)	70/171 (40.9%)
>6	11/69 (15.9%)	5/69 (7.2%)	34/69 (49.3%)

*The overall complication rates for the age classes one and three differ significantly ($p = 0.01$).

considerable influence on the general complication rate nor on specific complications such as wound healing issues, implant failure or refractures. In addition, joint involvement and implant handling method (removal/retention) did not alter the occurrence of complications. Nevertheless, notable differences were revealed for the rehabilitation management of external fixation systems. In total, external fixation was used in 132 cases in this study. Rehabilitation protocols including a dynamisation of fracture healing by a piecewise removal of external implants were used for the treatment of 24 long bone fractures and resulted in a lower complication rate (4/24; 16.7%) compared to rehabilitation management without dynamisation (58/108 cases; 53.7%).

The rehabilitation period between day 3 and the point of complete functional limb recovery after the initial fracture treatment was revealed as a critical timeframe for emerging complications, with 88 of 130 (67.7%) complications arising in this period. In comparison, 26 (20.0%) complications occurred within 48 hours postoperatively and 16 (12.3%) complications arose during surgery as anaesthesia events.

An increased bodyweight ($p = 0.047$) and an advanced age ($p = 0.01$) were significant risk factors for the occurrence of therapy complications. Tables 6 and 7 illustrate the details.

Initial therapy outcome

Of the 328 rabbits with a sufficient medical record, 18 animals were not included in the assessment of the final treatment result due to missing case history details, leaving 310 patients for evaluation of the initial therapy outcome. A positive treatment result with a functional recovery of the affected limb was observed in 237 cases (76.5%). A total of 15 amputations (4.8%) were performed after the initial therapy failed. These rabbits had a median age of 2.8 years and a median bodyweight of 1.52 kg. Reasons for electing amputation were severe wound healing problems (eight cases), implant failure (five cases) and refractures of the affected bone (two cases). Altogether, limb amputation was performed in 25 rabbits and led to a successful therapy outcome in 20 cases (80%). A total of 58 rabbits (18.7%) did not survive the treatment period. Table 8 shows the outcomes for the different fracture locations.

TABLE 8 Outcome of fracture therapy for 310 rabbits

Affected bone	Cases with a known therapy outcome	Cases with a functional recovery of the limb (%)	Amputation (%)	Number of deceased rabbits (%)[a]
Humerus	10	7 (70.0)	1 (10.0)	2 (20.0)
Radius/ulna	52	42 (80.8)	3 (5.8)	7 (13.5)
Metacarpus	3	3 (100)	0 (0)	0 (0)
Phalanges	3	3 (100)	0 (0)	0 (0)
Forelimb	68	55 (80.9)	4 (5.9)	9 (13.2)
Pelvis	12	11 (91.7)	0 (0)	1 (8.3)
Femur	80	53 (66.3)	3 (3.8)	24 (30.0)
Tibia/fibula	93	68 (73.1)	5 (5.4)	20 (21.5)
Calcaneus	28	24 (85.7)	3 (10.7)	1 (3.6)
Metatarsus	24	21 (87.5)	0 (0)	3 (12.5)
Phalanges	5	5 (100)	0 (0)	0 (0)
Multiple fractures	0	0 (0)	0 (0)	0 (0)
Hindlimb	242	182 (75.2)	11 (4.5)	49 (20.2)
Total	310	237 (76.5)	15 (4.8)	58 (18.7)

[a]Rabbits that were either euthanased or died during therapy.

Long-term therapy results

In total, 13 of 387 patients (3.4%) were reviewed on the basis of detailed clinical examinations, which have been performed recently for this study. In 11 of these 13 cases, orthopaedic anomalies relating to the affected limb were assessed by palpation. In four cases, abnormal limb posture was identified during clinical examination, and in three of these cases the owner had noted the abnormality. Compared to previous radiographic examinations of all 13 rabbits, diagnostic imaging showed articular mineralisation associated with the joints adjacent to the fractured bone in 12 of 13 cases. Additionally, extra-articular ossification was noted in three cases. Measurement of the fractured bones revealed a shortening in 10 out of 13 cases. Detailed data relating to long-term consequences of fracture treatment were collected for 232 animals over the telephone. The rabbit owners were asked to provide data for the time period between rehabilitation and the telephone interview (ranging between 3 and 138 months).

A positive long-term treatment result was reported by 175 of 232 owners (75.4%). A total of 20 owners (8.6%) indicated lameness in their rabbits, and 41 (17.7%) reported permanent abnormal limb posture. Lameness of the affected limb occurred more often in conservatively treated rabbits (9/71; 12.7%) compared to surgical cases (11/161; 6.8%), whereas abnormal limb posture was noted more frequently for surgical therapies (30/161; 18.6%) compared to conservatively treated rabbits (11/71; 15.5%). A total of seven animals (232; 3.0%) were reviewed by their owners to have permanent restrictions of motion due to limb issues. Table 9 displays further results of this survey.

TABLE 9 Long-term treatment effects in 232 rabbits with limb fractures

Bone	Cases with a sufficient medical record available	Abnormal limb posture	Lameness	Permanent restrictions of motion due to limb problems
Humerus	8 (2)	1 (1)	3 (1)	2 (0)
Radius/ulna	42 (11)	8 (2)	5 (1)	0 (0)
Metacarpus	3 (3)	0 (0)	0 (0)	0 (0)
Phalanges	3 (3)	0 (0)	0 (0)	0 (0)
Forelimb	56 (17)	9 (3)	8 (2)	2 (0)
Pelvis	11 (11)	2 (2)	0 (0)	0 (0)
Femur	50 (13)	7 (4)	2 (1)	0 (0)
Tibia/fibula	66 (1)	15 (0)	3 (1)	1 (0)
Metatarsus	20 (11)	0 (0)	1 (1)	2 (1)
Calcaneus	24 (13)	8 (2)	6 (4)	2 (0)
Phalanges	5 (5)	0 (0)	0 (0)	0 (0)
Hindlimb	176 (54)	32 (8)	12 (7)	5 (1)
Total	232 (71)	41 (11)	20 (9)	7 (1)

Note: Numbers in brackets indicate the number of conservatively treated cases.

Overall the majority of interviewed rabbit owners (166/232; 71.6%) stated that they would decide to repeat the initially elected therapy in future cases. A total of 33 owners (14.2%) were indecisive, and 29 (2912.5%) stated that they would decline repeating the elected therapy. Reasons given for not choosing the therapy again were the expense/stress of treatment process (51.7%), an unsatisfactory therapy result (17.2%), financial reasons (17.2%) and an unsatisfactory medical briefing before surgical therapy (13.8%).

DISCUSSION

There is little published literature covering the topic of limb fractures in pet rabbits. To our knowledge, this study is the first multi-centre approach analysing fracture aetiology and treatment as well as complications and long-term outcomes in pet rabbits.

The prevalence of limb bone fractures was comparable to previous studies examining limb fracture occurrence in rabbits,[7,9] cats and dogs.[22–24] The percentage of open fractures was similar to that in a study by Garcia-Pertierra et al.,[9] but lower than that reported by Sasai et al.[7]

Incorrect handling by the animal owners as well as the rabbits' natural behaviour, including powerful and fast limb movements together with comparably light bones accounting for only 6%–8% of total body mass,[3,25] predispose pet rabbits to limb fractures. Depending on the housing form, regularity of animal control by the owners and individual signs of pain,[26,27] an early recognition of limb fractures might be difficult. By continuously using an injured limb, initially closed fractures can develop into open traumas where additional damage of soft tissues and skin appears.[11,28]

The majority of all fractures and long bone fractures were treated with osteosynthesis techniques, which is consistent with a previous study.[9] Nonetheless, Sasai et al.[7] observed a higher percentage of surgically treated long bone fractures in pet rabbits and reported that long bone fractures were treated by external skeletal fixation in more than 80% of cases. In the present study, we found a higher diversity of surgical techniques implemented for the treatment of long bone fractures. The comparably high number of veterinary surgeons involved in this study may have led to this difference. In addition, the absence of further studies investigating the best therapy results for each fracture location might have contributed to this result. Conservative treatment was mainly seen in trauma cases including the distal aspect of the limb and pelvic fractures. This differs from results for pelvic fracture therapy in dogs and cats, where Lohr[29] reported that more than 66% of the investigated patients with pelvic fractures were treated surgically. Animal size, major differences relating to the anatomy and physiology of locomotion and different fracture aetiologies resulting in varying traumas might explain this disparity.

Limb amputation was tolerated well by the majority of animals that underwent this procedure. Apart from two patients that died postoperatively, complications (wound healing problems) were rarely observed, contrasting with the results from a previous study that reported a higher percentage of chronic complications after limb amputation in rabbits.[30] In this former study, both the median age (5.5 years) and median bodyweight (2.2 kg) of the rabbits differed distinctly from that of the rabbits in the current study, which may have led to the different complication rate.

Wound healing issues were the most common therapy complication. The rabbits' behaviour, including cleaning behaviour,[5] might be a possible cause of this frequent occurrence. In a comparable study on cats and dogs,[22] wound infections were also seen regularly. However, implant failure was the most common problem in this survey.

Increased anaesthesia risks in small mammals are well documented,[31,32] and common complications such as hypothermia and respiratory depression need to be considered.[31,33] However, the comparably high number of anaesthetic events in this study might be connected to possible comorbidities, either chronic disorders or acute clinical signs following severe traumatic incidents.[34,35] Brodbelt et al.[32] found similar numbers for overall risk of anaesthetic and sedation-related mortality in sick rabbits (7.4%), whereas figures for healthy patients were considerably lower (0.7%). In our study, the majority of rabbits with anaesthesia emergencies underwent surgery on the day of trauma occurrence. This might indicate that stabilisation of trauma patients and pre-anaesthetic analgesics are crucial before surgery.

The frequent occurrence of complications within the rehabilitation period contrasts with the findings of a study evaluating complications of fracture therapy in rabbits,[9] but correlates with the results of studies analysing complications in cats and dogs.[22,36,37] Optimising the patient's postsurgical rehabilitation is the key to reducing major and minor complications and achieving better overall treatment results. There are numerous rehabilitation protocols for other pet animals aiming at facilitating healing time. Passive range of motion, stretching, superficial heat, electrical stimulation, aquatic therapy and cryotherapy have proved useful in dogs.[38] However, it is of great importance to apply varying supportive treatment techniques to appropriate stages of healing.[39,40] Also, the compliance of animal owners is an important contributor to this circumstance, as adequate housing equipment, exercise restriction, wound management (including periodic bandage renewals) and application of oral drugs play a key role during the rehabilitation process.[38] Furthermore, the veterinarian in charge should provide a constant assessment of the animal's improvements or complications and adjust therapy plans to optimise a quick but sustainable return to function.[41] Relating to this, notable differences were revealed for rehabilitation management of external fixation systems in this study. The therapy plan of one institution used dynamisation of the external fixation system on a comparatively common basis. The group of rabbits treated with this procedure had a lower complication rate. Dynamisation is well-documented and often used for fracture therapy protocols.[39] However, a combination of dynamisation factors, such as timing and degree, is important for the recovery of the fractured bone.[40]

By comparison, the overall complication rate was the highest for rabbits with a bodyweight of more than 3 kg. This finding corresponds to a well-documented correlation between heavyweight and obese patients and an increased risk of therapeutical complications seen in other pet animals.[42,43]

The overall complication rate of surgically treated patients is comparable to a previous report on perioperative complications in pet rabbits.[9] However, Diehm[22] found considerably lower figures for dogs (16.6%) and cats (9.2%).

Conservative protocols had a lower complication rate in this study. However, it has to be taken into consideration that, for many fractures, conservative therapy was not a suitable treatment option. Multiple complications, such as wound healing problems or implant failures, can only occur in surgical therapies. Therefore, a comparison of surgical and conservative treatment methods was not feasible in our study.

The percentage of treatments with a positive outcome was comparable to the results of a previous report by Garcia-Pertierra et al.,[9] who found a positive therapy outcome in 76.9% of all treated rabbits. However, Sasai et al.[7] found a higher number of positive therapy outcomes (86.0%). Again, the different outcome numbers might have been influenced by heterogenous animal groups and data, as well as the multi-centre character of this study with various institutions and veterinarians involved.

There was a higher number of animals evaluated by their owners to have long-term limb alterations (limb posture and lameness) compared to data published in a study focusing on small animal fractures, where permanent lameness in 4.0% of the dogs and 0.9% of the cats was reported.[22] Owner-identified pain-related changes in pet behaviour can provide valuable information.[44] Nevertheless, these data need to be interpreted with care as the assessment of lameness can be difficult. Differential diagnoses for this clinical sign in rabbits are diverse,[45] and lameness may have had other causes in some cases. Differentiation between actual lameness and other alterations in limb posture (seen by 41 animal owners) might be challenging, especially for owners.[46,47] Interestingly, the proportion of animals with limb posture anomalies is comparable for the group of rabbits reviewed over the telephone and the group of re-presented at the clinic. However, the detailed re-examinations of 13 rabbits revealed high prevalences for long-term orthopaedic complications such as (extra-) articular ossification and bone shortening. Using re-examinations, a higher number of rabbits were identified with limb abnormalities in comparison with the animal owners' anamnestic specifications. This might indicate an even higher percentage of rabbits dealing with long-term effects than is reported by the owners in this study. Routine re-examinations of fracture patients might therefore be reasonable after the conclusion of fracture therapy in order to detect and treat possible orthopaedic long-term effects. However, the majority of all interviewed owners noted a satisfactory long-term result and would opt for the elected therapy in future cases. When contrasting these findings with the number of complications and outcome results found in this study, most rabbit owners seemed to be aware of possible negative issues relating to the therapy and, at least in some cases, a guarded prognosis. However, communication skills play a major role for veterinarians, especially when working with companion animals.[48–51] It should be of great interest to every veterinary institution to minimise the percentage of clients dissatisfied with an insufficient medical briefing prior to therapy.

There are several limitations to this study. The multi-centre approach led to the inclusion of various institutions, veterinarians, treatment protocols and rabbit populations that might have influenced the results to a different extent. As medical records were reviewed retrospectively, some data were lacking or could not be collected in a standardised manner. The evaluation of long-term results by the rabbit owners might be prone to error, despite the use of a standardised interview questionnaire.

CONCLUSION

Limb fractures are a common orthopaedic issue in pet rabbits. Careful handling by animal owners is crucial, as owner-related trauma is the main cause of limb fractures. The patient's bodyweight and age are significant risk factors for complications occurring during fracture treatment. Orthopaedic long-term effects, such as abnormal limb posture (17.7%) and permanent lameness (8.6%) of the affected limb, were assessed regularly. Further studies are required to find out which fracture therapies are most successful.

AUTHOR CONTRIBUTIONS

Planning of the study design was conducted by Johannes Hetterich, Maximilian Reuschel and Michael Fehr. The patients' medical records were reviewed and classified by Johannes Hetterich, Diana Joos, Pia Cigler, Jean-Michel Hatt, Christian Hackenbroich, Kerstin Müller and Milena Thöle. Martin Beyerbach calculated the statistical analysis plan. Figures and tables were designed by Johannes Hetterich and Maximilian Reuschel.

ACKNOWLEDGEMENTS

Open access funding enabled and organized by Projekt DEAL.

CONFLICTS OF INTEREST

The authors declare they have no conflicts of interest.

FUNDING INFORMATION

The authors received no specific funding for this work.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

Ethical approval was obtained from the Committee of Animal Welfare and Animal Experimentation of the Federal State of Lower Saxony (TVA-2019-V-69).

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SUPPORTING INFORMATION

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

How to cite this article: Hetterich J, Joos D, Beyerbach M, Cigler P, Hackenbroich C, Hatt J-M, et al. Treatment options, complications and long-term outcomes for limb fractures in pet rabbits. Vet Rec. 2023;e2344. https://doi.org/10.1002/vetr.2344