Characteristics of Fractures of the Appendicular and Axial Skeletons in Rabbits and Hares: A Retrospective Study


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Summary

Background: The frequency and characteristics of fractures may vary according to the environment. Objectives: To assess fractures of the appendicular and axial skeletons in rabbits (Oryctolagus cuniculus) and hares (Lepus sp.) presented at a veterinary teaching hospital. Methods: Medical records and radiographs were retrospectively analyzed over eight years.
**Results:** A total of twenty-six pet rabbits and five free-ranging hares were enrolled in this study. Twenty-one of them had fractures in the appendicular skeleton, nine in the axial skeleton, and one in both. The fractures were related to traumatic events, such as being hit by a vehicle (22.58%), falling (12.9%), being attacked by another animal (12.9%), and having a paw stuck in a hole (3.22%); 48.38% had an unknown cause. Long bone fractures were found in the humerus (n=2), radius/ulna (n=1), femur (n=5), and tibia (n=12). Fractures involving the distal aspects of the limbs included the tarsus (n=1) and metatarsus (n=2) bones. Except for one rabbit, all of the others had unilateral fractures. Fourteen presented closed fractures and nine were open fractures. All these fractures were complete, being 56.52% simple and 43.47% multifragmental. The procedures used included osteosynthesis (42.85%), external coaptation (28.57%), amputation (14.28%), euthanasia (4.76%), and two animals died (9.52%). The fractures of the axial skeleton included vertebral column (n=6), mandible (n=3), and pelvis (n=2). Five fractures were treated conservatively, and in four cases, the rabbits were euthanized. **Conclusion:** The fractures resulted from a traumatic episode, which had an unknown origin in most of the cases, involving mainly the appendicular skeleton, being the tibia the bone most affected.

**Key words:** Bone, Lagomorphs, Radiography, Trauma

**Introduction**

Rabbits and hares belong to the Leporidae family, order Lagomorpha; however, the term hare is reserved for Lepus genera (Graham, 2015). Rabbits are a popular pet for both adults and children in a substantial number of countries throughout the world (Hillyer, 1994; Miwa and
Carrasco, 2011). Pet rabbits' life expectancy is more than seven years, reaching 11-12 years or longer (Hillyer, 1994; Harcourt-Brown, 2002; Meredith, 2016). On the other hand, wild rabbits may not survive beyond their first year (Meredith, 2016). The small breeds of rabbits are sexually mature at approximately 4-5 months of age, and larger breeds at 5-8 months of age (Harcourt-Brown, 2002).

The skeleton is equivalent to 7% to 8% of the body mass, and it is considered somewhat fragile in rabbits (Cruise and Brewer, 1994; Brewer, 2006; Miwa and Carrasco, 2011). The bones are brittle, with thin cortices (ratio of the thickness cortex/bone of 12%) and have lower density and higher mineral composition than dogs bones (Miwa and Carrasco, 2011; Guzman and Kapatkin, 2021). In addition, the muscles of the hind limbs are strong, and the locomotion is particularly based on jumping (Miwa and Carrasco, 2011; Meredith, 2016).

The cause of fracture in pet rabbits and hares is usually associated with a traumatic event (Fettinger et al., 2010; Miwa and Carrasco, 2011; Pećin et al., 2015; Sasai et al., 2015). Improper handling can induce fractures or luxation of the lumbar vertebrae or hind limbs (Brown, 1997), even in animals with normal bone density (Brown, 1997; Meredith, 2016). Fractures in rabbits are often complex with multiple fragments, but bone healing may occur quickly (Harcourt-Brown, 2002).

The principles of surgical treatment and techniques used in small animals have been used in clinical cases of fractures in rabbits and hares (Harcourt-Brown, 2002; Pećin et al., 2015; Kawamoto et al., 2018; Sasai et al., 2018; Miwa and Carrasco, 2011; Garcia-Pertierra, 2020), but there are challenges associated with the anatomy and composition of the bone tissue (Barron et al., 2010; Miwa and Carrasco, 2011; Guzman and Kapatkin, 2021). In addition, because rabbits are natural prey for many carnivores (Meredith, 2016), the stress and pain reactions are different.
from those in dogs and cats (Hillyer, 1994; Miwa and Carrasco, 2011; Guzman and Kapatkin, 2021).

Since the frequency and characteristics of fractures may vary according to the environment, this study aimed to retrospectively assess fractures of the appendicular and axial skeletons in rabbits (*Oryctolagus cuniculus*) and hares (*Lepus sp.*) presented at a veterinary teaching hospital.

**Materials and Methods**

This study was approved by the Institutional Ethics Committee on Animal Use (CEUA: 074/2020). Medical records and complementary diagnostic exams (based on radiographs) of rabbits and hares with fractures, evaluated at the Center for Medicine and Research in Wild Animals (CEMPAS) from a veterinary teaching hospital, were retrospectively analyzed over a period of eight years (2013-2020). The inclusion criteria were cases whose management had been described, and plain radiographs confirmed the fracture. The exclusion criteria were descriptive cases without images.

The following information was taken into account: patient signalment (sex; body mass; age, in case of age not provided, the animal was classified as young or adult according to opened or closed physis on x-ray); cause of the fracture; involvement of one or more bones of the appendicular and/or axial skeleton; management of the case. The fractures of the appendicular skeleton bones were classified as follows: affected bone; closed or open; complete (both cortices disrupted) or incomplete (only one cortex disrupted); simple (transverse, oblique, spiral) or multifragmentary fracture (more than two fractured fragments, which can be a reducible wedge, nonreducible wedge, or segmental); location (proximal third, middle third, or distal third
(epiphysis, physis, and metaphysis). If the animal presented one or multiple fractures was also verified. Those of the axial skeleton were classified to the location and characteristics of the fracture.

The association between fracture site (appendicular or axial skeletons) and sex, and also the age (≤ 8 months age and young; > 8 months of age and adult) of the animals were compared using Fisher's exact test (two-sided). The significance level was set at 5%. The statistical analysis was performed with commercial statistical software (GraphPad Prism 8.3.1®, San Diego, CA, USA).

Results

A total of twenty-six pet rabbits and five free-ranging hares met the inclusion criteria and were enrolled in the study. Twenty-one (67.74%) of them had fractures in the appendicular skeleton (Table 1), nine (29.03%) in the axial skeleton (Table 2), and one (3.22%) in both skeletons, which represented 5.75% of all rabbit admissions in the period. One hare showed fractures that included bones in both skeletons, therefore it was not included in the Tables.

The body mass ranged from 0.6 to 3.8 kg (mean 2.1 kg ± 0.97). The average age was 1.83 years (± 1.79), calculated from rabbits whose age was known. From the animals whose age was not provided, seven were classified as young and six as adults. All rabbits were entire (unclear), being 58.06% (n=18) males, 22.58% (n=7) females and 19.35% (n=6) there was no identification. Fischer's exact test showed no significant association between fracture site and sex (p = 0.3618). Likewise, no association was observed between fracture site and age (p = 0.427).

Including only the appendicular skeleton, the causes of fractures were hit by a vehicle (14.28%; n=3), falling from the owner's arms (9.52%; n=2), being attacked by a dog (14.28%;
n=3), having the paw stuck in a hole (4.76%; n=1), and 57.14% (n=12) having an unknown cause. Including only the axial skeleton, the causes of fractures were being hit by a vehicle (33.33%; n=3), falling from a height or cage (22.22%; n=2), being attacked by another rabbit (11.11%; n=1), and 33.33% (n=3) having an unknown cause. Including both skeletons, one hare was hit by a vehicle.

Fracture classifications in appendicular and axial skeletons are given in Tables 1 and 2, respectively. The exception was the hare that had fractures in the axial skeleton (right mandible body - closed, complete, transverse; right pelvic floor and ischium) and appendicular skeleton (right femur – closed, transverse, complete). Long bone fractures were found in the humerus (n=2), radius/ulna (n=1), femur (n=5), and tibia (n=12). Fractures involving the distal aspects of the limbs included the tarsus (n=1) and metatarsus (n=2) bones. Except for one rabbit that showed fractures of the right and left tibia, all the others had unilateral fractures. A total of 14 fractures were closed (60.86%) and nine open (39.13%). All these fractures were complete, being 56.52% (n=13) simple and 43.47% (n=10) multifragmentary fracture. The procedures used in the fractures of the appendicular skeleton included osteosynthesis (42.85%; n=9), external coaptation (n=6; 28.57%), amputation (14.28%; n=3), euthanasia (n=1; 4.76%), and two animals died (n=2; 9.52%) (Figures 1 and 2).

The fractures of the axial skeleton (n=11) included vertebral column (54.54%; n=6), mandible (27.27%; n=3) and pelvis (18.18%; n=2). All of them were closed fractures. Five fractures of the axial skeleton were treated conservatively, and in four cases, the rabbits were euthanized due to poor prognosis at presentation (Figure 3).

The hare whose fractures included bones of both skeletons was euthanized.
Discussion

Fractures accounted for 5.75% of the total rabbit admissions over the eight years, being 67.74% in the appendicular skeleton, 29.03% in the axial skeleton, and 3.22% in both skeletons. The fractures in this study were non-neoplastic and related to traumatic events, mainly due to being hit by a vehicle (22.58%), falling (12.9%), being attacked by another animal (12.9%), having a paw stuck in a hole (3.22%), and 48.38% had an unknown cause. On the other hand, in a retrospective study with 210 pet rabbits, 24.8% of the fractures were due to accidental falls as a result of human error, 22.9% were related to other causes, and 16.7% the cause was unknown (Sasai et al., 2015). In another retrospective study with 28 pet rabbits, 70% had unknown causes and 17% were related to a known trauma (Garcia-Pertierra, 2020). All hares in the present study were free-ranging, and most of them had been hit by a vehicle. However, the hares are game species in some countries, and femur fractures have been related to shots (Fettinger et al., 2010).

The mean age of the rabbits was 1.83 years. A study verified that one year was the age that most fractures happened, supposedly due to the sexual maturity of the rabbits (Sasai et al., 2015). Also, in another study that evaluated long-bone fractures in rabbits, 75% had aged less than two years and the others were under six months (Garcia-Pertierra, 2020). The clinical and radiographic exams did not detect fractures related to neoplasia in the present study, probably because most were young rabbits. Fractures due to metastasis of uterine adenocarcinoma, osteosarcoma, and rhabdomyosarcoma have been observed in rabbits (Sasai et al., 2015).

The percentage of males (58.06%) was higher than females (22.58%), but 19.35% were unknown. Another study found 54.8% males and 45.2% females; however, in fractures associated with neoplasms, female rabbits were considered more likely to have a fracture (Sasai et al., 2015).
Including all fractures, the three fracture sites more frequent were the tibia (35.29%), vertebral column (17.64%), and femur (14.70%). On the other hand, the vertebral column (23.2%), tibia (22.7%), and femur (13.1%) were the most affected, considering non-neoplastic fractures in a study with 198 rabbits (Sasai et al., 2015). Different types of traumatic events may influence the differences in findings. Considering only the appendicular skeleton, the tibia followed by the femur were the most fractured, as observed in other pet rabbit studies (Sasai et al., 2015; Sasai et al., 2018). On the opposite, in a retrospective study with 28 pet rabbits, the femur followed by the tibia were the most fractured (Garcia-Pertierra, 2020). The highest proportion of fractures in the hind limbs verified in this study and the others (Sasai et al., 2015; Garcia-Pertierra, 2020) has been attributed to a considerable force exerted by the rabbits on the hind limbs (Sasai et al., 2015).

The tibia fractures comprised 58.33% simples and 41.66% multifragmental, being 66.66% open fractures. A study in the rabbit’s tibia showed that an oblique loading induced diaphyseal fracture and short duration loading induced comminuted fracture (Hirsch et al., 1954). The simple fractures in the present study included short oblique (n=3), long oblique (n=1), transverse (n=2) and spiral (n=2) fractures. In mature rabbits, angulatory forces in the tibia caused transverse and oblique fractures with more damage to soft tissues than the spiral forces, which caused spiral fractures (Oni et al., 1988). This fact probably justifies two short oblique fractures and one transverse that had been open in the present study.

All femur fractures were closed, being two Salter-Harris Type 1, two multifragmental, and one transverse. A study showed that the force required to induce femoral fracture in rabbits was smaller than tibia fracture, which was attributed to the femoral shape (Hirsch et al., 1954). Comminuted fractures may occur in rabbits due to traumatic events of high energy and impacts.
of low energy (Miwa and Carrasco, 2011). Just one animal had a tarsal fracture, which is generally associated with the category of low-energy fractures; closed, slight soft tissue trauma, and preservation of the blood supply (Harcourt-Brown and Chitty, 2013).

In the axial skeleton, vertebral fractures were the most frequent (54.54%), being the lumbar region the most affected. The lumbosacral region (L6–L7) is a common site of fracture or luxation in rabbits; the force applied by hind limbs during the escape can over-flex the vertebral column inducing the lesion (Fisher et al., 2021). However, another study found L5 the site most affected by fractures (Sasai et al., 2015). These patterns were not verified in the current study since the fractures occurred at different sites from L4 onwards. However, most rabbits and hares were euthanized due to injury severity. Regarding the mandible fractures, one was caused by falling, and the other had an unknown cause in rabbits. One hare had a fracture due to being hit by a vehicle. In general, mandibular fractures in rabbits have been more frequently associated with dropping or leaping from the owner's arms (Harcourt-Brown, 2002).

Although this study was not focused on fracture treatments, surgical treatment was used only in long bone fractures. Internal fixation methods, such as those used in the current study, have been used in rabbits and hares, but species-specific guidelines for fracture treatment are still lacking (Harcourt-Brown and Chitty, 2013; Pećin et al., 2015; Garcia-Pertierra, 2020). A study has successfully used sheep xenograft and low-level laser therapy to treat segmental bone defects induced in rabbits (Nazht et al., 2021). Because of the financial constraints, conservative methods or even euthanasia were used in some cases. Additionally, the amputation was done in three pet rabbits with severe open fractures of the tibia. Limb amputation has been cited as an economical solution for complex fractures, being well-tolerated more frequently when performed on the thoracic limb (Harcourt-Brown, 2002). However, a study (n= 32) detected nineteen chronic
complications and six deaths after a limb amputation in client-owned rabbits (Northrup et al., 2014).

The primary limitation of this study was the incomplete data in medical records, which reduced the number of animals in the inclusion criteria. Another limitation was that the breed was not provided. However, the findings in the study helped to understand the frequency and characteristics of fractures in the species.

In conclusion, the fractures resulted from a traumatic episode, which had an unknown origin in the most, involving mainly the appendicular skeleton, being the tibia the bone most affected.

Acknowledgements

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Conflicts of interest

The authors declare no conflict of interest.

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<table>
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<tr>
<th>Age (years)</th>
<th>Sex</th>
<th>Fracture site</th>
<th>Cause</th>
<th>Fracture classification</th>
<th>Treatment</th>
</tr>
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<tr>
<td>adult</td>
<td>-</td>
<td>left humerus (middle third)</td>
<td>attack by a dog</td>
<td>closed, multifragmental, reducible wedge</td>
<td>one intramedullary pin</td>
</tr>
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<td>3,0</td>
<td>M</td>
<td>left humerus (distal third)</td>
<td><em>fall from owner's arms</em></td>
<td>closed, multifragmental, reducible wedge</td>
<td>one intramedullary pin</td>
</tr>
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<td>right radius/ulna (middle third)</td>
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<td>conservative - external fixator</td>
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<td>6</td>
<td>M</td>
<td>left femur (proximal third)</td>
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</tr>
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<td>conservative - external fixator</td>
</tr>
<tr>
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<td>right tibia (middle third)</td>
<td>unknown</td>
<td>open, complete, transverse</td>
<td>euthanasia</td>
</tr>
<tr>
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<td>left tibia (distal third)</td>
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<td>amputation</td>
</tr>
<tr>
<td>adult</td>
<td>M</td>
<td>left tibia (distal third)</td>
<td><em>fall from owner's arms</em></td>
<td>closed, complete, spiral</td>
<td>one intramedullary pin</td>
</tr>
<tr>
<td>0,7</td>
<td>F</td>
<td>left tibia (distal third)</td>
<td>attack by a dog</td>
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<td>amputation</td>
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<td>amputation</td>
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<td>right tibia (distal third)</td>
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<td></td>
<td>2</td>
<td>right tibia (distal third)</td>
<td>hit by a vehicle</td>
<td>left: closed, complete, short oblique</td>
<td>external fixator and conservative - external fixator and euthanasia</td>
</tr>
<tr>
<td>young</td>
<td>-</td>
<td>right tibia (distal third)</td>
<td>unknown</td>
<td>open, complete, short oblique</td>
<td>deamputation</td>
</tr>
<tr>
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<td>M</td>
<td>right tibia (epiphysis distal)</td>
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<tr>
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<td>M</td>
<td>right tarsus</td>
<td>foot stuck in a hole</td>
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<td>right 3rd metatarsal bone (proximal third)</td>
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<td>right 1st, 2nd, 3rd metatarsal bone (proximal third)</td>
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<td>open, complete, short oblique</td>
<td>conservative - external fixator</td>
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*hare; M: Male; F: Female.*
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<tr>
<th>(kg)</th>
<th>Mass</th>
<th>Age</th>
<th>Sex</th>
<th>Event</th>
<th>Injury Details</th>
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<td>young</td>
<td>M</td>
<td>fall from a height of 5 m</td>
<td>left mandible body</td>
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<tr>
<td>2</td>
<td>-</td>
<td>3</td>
<td>M</td>
<td>unknown</td>
<td>right and left mandibular rami</td>
<td>complete, transverse</td>
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<tr>
<td>3*</td>
<td>adult</td>
<td>-</td>
<td>hit by a vehicle</td>
<td>iliac wing</td>
<td>multifragmental, reducible</td>
<td></td>
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<tr>
<td>4</td>
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<td>attack by another rabbit</td>
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<td>vertebral body compression</td>
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<td>2.6</td>
<td>adult</td>
<td>F</td>
<td>unknown</td>
<td>vertebral column (L4)</td>
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<td>0.9</td>
<td>2</td>
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<td>fall from cage</td>
<td>vertebral column (caudal epiphysis of L6)</td>
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</tr>
<tr>
<td>7</td>
<td>1.7</td>
<td>adult</td>
<td>M</td>
<td>unknown</td>
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<td>vertebral body compression</td>
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<td>8*</td>
<td>-</td>
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<td>F</td>
<td>hit by a vehicle</td>
<td>vertebral column (L3, L4, L5)</td>
<td>L3: caudal articular process L4: vertebral body and transverse L5: transverse process Luxation between L3 and L4</td>
</tr>
<tr>
<td>9*</td>
<td>3.3</td>
<td>adult</td>
<td>M</td>
<td>hit by a vehicle</td>
<td>vertebral column (T8, T10, T11)</td>
<td>T11: vertebral arch T8 and T10: spinous processes Luxation between T11 and T10</td>
</tr>
</tbody>
</table>

Table 2: Fractures of the axial skeleton in rabbits and hares

*hare; M: Male; F: Female
Figure 1: Mediolateral (a, c) and craniocaudal (d, e) radiographic views of the left tibia of a rabbit (no. 8). Long oblique fracture (a, b) treated with external coaptation due to financial constraint, showing malunion in part compensated for by remodeling of the bone (c, d) 35 days after surgery.
Figure 2: Mediolateral (a, c) and craniocaudal (d, e) radiographic views of the left femur of a rabbit (no. 5). Salter-Harris (type I) distal femur fracture stabilized with two Kirschner wires, showing advanced bone healing on the 15th day after surgery.

Figure 3: Lateral (a) and ventrodorsal (b) radiographic views of the vertebral column of a rabbit (no. 4). Observe the vertebral compression fracture of L6.