UNIVERSIDAD COMPLUTENSE DE MADRID

FACULTAD DE VETERINARIA

TESIS DOCTORAL

Aplicación de la fijación externa en la resolución de fracturas de pelvis y de sacro en pequeños animales: Propuesta de clasificación

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

PRESENTADA POR

José Antonio Flores Galán

DIRECTOR

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MADRID, 2023

D. JESÚS RODRÍGUEZ QUIRÓS, Profesor Contratado Doctor, perteneciente al Departamento de Medicina y Cirugía Animal de la Facultad de Veterinaria de la Universidad Complutense de Madrid,

INFORMA:

Que la Tesis Doctoral titulada **"APLICACIÓN DE LA FIJACIÓN EXTERNA EN LA RESOLUCIÓN DE FRACTURAS DE PELVIS Y SACRO EN PEQUEÑOS ANIMALES: PROPUESTA DE CLASIFICACIÓN"** realizada por **D. JOSÉ ANTONIO FLORES GALÁN**, y dirigida por el que suscribe, reúne los requisitos necesarios para su exposición y defensa, con el fin de optar al Grado de Doctor.

Y para que así conste y a los efectos oportunos, firmamos el presente informe en Madrid, a 11 de Diciembre de 2023.

D. Jesús Rodríguez Quirós

Dedicatoria

"*El entusiasmo es la madre del esfuerzo*
y sin él jamás se consiguió nada grande"
Ralph Waldo Emerson

"Hay una fuerza motriz más potente que el vapor, la electricidad o la energía atómica: la voluntad"
Albert Einstein

A mis padres, por su sacrificio e inacabable generosidad desde que Dios me trajo a este mundo. Esta tesis doctoral no hubiese sido posible sin ellos. Nunca sabré cómo agradecérselo.

A mis hijos, que con paciencia infinita han soportado mis interminables horas de estudio y tiempo delante de cualquier libro. Ojalá les sirva este esfuerzo como estímulo para perseguir objetivos que algún día les hagan más felices.

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Agradecimientos

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Abreviaturas

Abreviaturas

- DE Desviación estándar
- FE Fijación externa
- FFA Fractura de la fisis acetabular
- h hora(s)
- Kg Kilogramo (s)
- mg miligramo(s)
- ml mililitro(s)
- PMM Polimetilmetacrilato
- VAS Escalas de valoración visual (del inglés "*Visual Assessment Score*").

Resumen

1. Resumen

La presente Tesis Doctoral incluye los datos recogidos a través de tres trabajos basados en la aplicación de la fijación externa para la resolución de fracturas pélvicas y sacras en la especie canina y felina. Muchas de estas fracturas suponen un desafío para la mayor parte de los cirujanos ortopedas veterinarios, los cuales las abordan habitualmente mediante técnicas de osteosíntesis interna, con todo lo que ello supone en cuanto a invasión, tiempos de cicatrización y recuperación.

El primer estudio analiza los resultados obtenidos del tratamiento de distintas fracturas pélvicas en 32 pacientes de la especie canina mediante fijación externa. En este trabajo se empleó la fijación externa, como un sistema complementario a un sistema de osteosíntesis interna, o como método exclusivo de estabilización. Además, se ha propuesto una clasificación alfanumérica de los sistemas de fijación empleados, aportando información sobre su diseño, considerando el número y ubicación de los clavos, así como la interconexión de estos. Entre los resultados obtenidos, se destaca la buena tolerancia de los pacientes al sistema de fijación externa, así como la escasa presencia de complicaciones.

El segundo estudio se centra en el uso de la fijación externa para la resolución de fracturas de sacro en 15 pacientes caninos. En algunos casos, la fijación externa fue el único sistema utilizado, mientras que en otros se aplicó como método complementario. Este trabajo recopila los datos de cicatrización ósea y las complicaciones, utilizando escalas para evaluar la calidad de reducción de la fractura y la tolerancia del paciente al sistema. Los buenos resultados obtenidos en estos aspectos, además de la mínima invasión, versatilidad y facilidad de aplicación de la fijación externa, constituyen un argumento sólido para su utilización en fracturas sacras.

El tercer trabajo se fundamenta en el tratamiento quirúrgico basado en el uso de la fijación externa de una fractura fisaria bilateral acetabular en un gato de 5 meses de edad. El manejo de este tipo de fracturas, poco documentado en la literatura, representa un desafío quirúrgico importante debido a su naturaleza articular, especialmente en un paciente tan joven y de pequeño tamaño. El uso de la fijación externa permitió tratar esta doble fractura de forma mínimamente invasiva, contribuyendo positivamente en la reducción de los tiempos de cicatrización y de recuperación postoperatoria. En un paciente de estas características, un enfoque quirúrgico abierto habría sido dificultoso y lesivo, con un incremento notable del tiempo anestésico, aspecto importante en un paciente tan joven. Al igual que los resultados obtenidos en los otros dos estudios, las complicaciones registradas fueron muy bajas y el grado de confort presentado por el paciente fue muy alto, aspecto crucial en el tratamiento de este tipo de fracturas en animales pequeños.

Los resultados obtenidos de estos estudios respaldan el uso de la fijación externa como sistema de estabilización de fracturas pélvicas y sacras en la especie canina y felina. Sus características aportan un alto grado de adaptabilidad, independientemente del tipo de fractura. Adicionalmente, la fijación externa es un sistema sencillo, de fácil aplicación (una vez se comprenden sus fundamentos básicos) y mínimamente invasivo. Sin embargo, es crucial tener un profundo conocimiento de los corredores seguros, los cuales se describen en los tres estudios incluidos en esta Tesis Doctoral, y utilizar la fluoroscopia debido a la complejidad anatómica de los huesos afectados. La fijación externa ha demostrado también ser compatible con sistemas internos cuando se trataron fracturas complejas y sumamente inestables, donde se requirió una combinación de ambos sistemas. En estas situaciones, ambas opciones fueron posibles al mismo tiempo, lo que subraya la versatilidad del sistema externo.

Por lo tanto, estos estudios tienen como objetivo aportar resultados y conocimientos entorno a un sistema de fijación pocas veces empleado para la resolución de fracturas pélvicas y sacras en pequeños animales.

Palabras claves: Fijación externa, clasificación sistemas, fractura pelvis, fractura sacro, pequeños animales

Summary

2. Summary

This Doctoral Thesis presents data compiled from three studies based on the application of external fixation for resolving pelvic and sacral fractures in both canine and feline species. Many of these fractures are challenging for most veterinary orthopedic surgeons, who often managed them using internal osteosynthesis techniques, with all the implications in terms of invasiveness, healing periods and recovery.

The first study analyzes the outcomes of treating pelvic fractures in 32 canine patients using external fixation. In this work, external fixation was employed as a complementary system to an internal osteosynthesis system or as an exclusive method of stabilization. Moreover, it introduces an alphanumeric classification for the fixation systems used, offering insights into their design based on the number and location of pins, and their interconnection. The results obtained highlight the good tolerance of patients to the external fixation system, as well as the low incidence of complications.

The second study focuses on the use of external fixation to resolve sacral fractures in 15 canine patients. External fixation was either the primary or complementary method used in these cases. This research compiles data regarding bone healing and complications, utilizing scales to evaluate fracture reduction quality and patient tolerance to the system. The study emphasizes the positive results in these aspects, underlining the minimal invasiveness, versatility, and simplicity of external fixation, as a compelling option for managing sacral fractures.

The third study focuses on the surgical management of a bilateral acetabular physeal fracture in a 5-month-old cat using external fixation. Managing this type of fracture, poorly documented in the literature, represents a significant surgical challenge due to its articular nature, especially in a small and young patient. The use of external fixation allowed for the minimally invasive treatment of this bilateral fracture, significantly reducing healing and postoperative recovery times. Furthermore, an open surgical approach would have been difficult and harmful, with a significant increase in anesthesia time, an important aspect to be taken in account in very small patients. Similar to the outcomes in the other two studies, recorded complications remained minimal, and the level of comfort presented by the patient was very high, a crucial aspect in the treatment of such fractures in small animals.

The results obtained from these studies support the use of external fixation as a stabilization technique for pelvic and sacral fractures in both canine and feline species. Its characteristics provide a high level of adaptability, regardless of the type of fracture. Additionally, external fixation stands out for its simplicity, ease of application (once fundamental principles are grasped), and minimal invasiveness. However, it is important to have a deep understanding of the safe corridors, which are described in the three studies included in this Doctoral Thesis, and the use fluoroscopy are essential due to the anatomical complexity of the affected bones. External fixation has demonstrated compatibility with internal systems, particularly in managing complex and highly unstable fractures, where a combination of both systems was required. In these situations, the simultaneous use of both systems was possible simultaneously, highlighting the versatility of the external system.

Therefore, these studies aim to provide results and knowledge about a fixation system rarely used for the resolution of pelvic and sacral fractures in small animals.

Key words: External fixation, classification systems, pelvic fracture, sacral fracture, small animals

Introducción

3. Introducción

Las fracturas pélvicas en pequeños animales representan aproximadamente el 25% de los casos diagnosticados en la práctica diaria (Harasen, 2007; Fathy et al., 2018). En su mayoría, estas fracturas en perros son el resultado de accidentes de tráfico, caídas o impactos, siendo menos frecuentes las fracturas patológicas (Innes y Butterworth, 1996). Aunque algunos estudios han mostrado resultados exitosos con el tratamiento conservador (Bouabdallah et al., 2020), éste generalmente conlleva una reducción inadecuada y un prolongado tiempo de recuperación (Fitzpatrick y Hamilton, 2012). En la mayoría de los casos, el tratamiento quirúrgico se considera la opción estándar debido a sus tiempos de recuperación más cortos, una cicatrización más rápida, una menor incidencia de enfermedades relacionadas con la estenosis del canal pélvico y mejores resultados funcionales (Lee, 2012).

Entre las opciones de tratamiento quirúrgico descritas están las placas de osteosíntesis (Kenzig et al., 2017; Moi et al., 2022), las placas transilíacas (Mills, 2009), los tornillos interfragmentarios (Vangundy et al., 1988) y fijación interna con tornillos y polimetilmetacrilato (PMM) (Burton, 2011). En la literatura veterinaria, algunos estudios han explorado el uso de la fijación externa (FE) en el tratamiento de fracturas pélvicas, destacando su seguridad y una buena tolerancia por parte de los pacientes, con un bajo índice de complicaciones (Fitzpatrick y Hamilton, 2012; Graville et al., 2018; Bouabdallah et al., 2020). Las complicaciones más comunes encontradas en el uso de la FE aplicada en fracturas pélvicas incluyen el aflojamiento de implantes y la infección local en los orificios de entrada de los clavos (Palmer et al., 1997; Bouabdallah et al., 2020).

Las fracturas de sacro en pequeños animales son poco frecuentes, siendo más habituales en la especie canina que en la especie felina (Anderson y Coughlan, 1997; Wilson, 2015). Aproximadamente, estas fracturas corresponden el 3% de las que se producen en el esqueleto axial en pequeños animales (Paré et al., 2001; Bali et al., 2009), siendo su origen principal el atropello del paciente (Kuntz et al., 1995; Anderson y Coughlan, 1997; Paré et al., 2001; Kudnig y Fitch, 2004; Wilson, 2015; Nell et al., 2017; Stecyk et al., 2021). Suelen asociarse con daños neurológicos, provocando dolor y distintos grados de afectación neurológica, comprometiendo funciones como la micción y la defecación (Sharp et al., 2005; Mills, 2009), así como la capacidad de sostén con uno o ambos miembros pélvicos (Mills, 2009). La intervención quirúrgica se considera la principal opción para su tratamiento, especialmente cuando coinciden con otras lesiones pélvicas (Paré et al., 2001; Sharp et al., 2005; Mills, 2009; Stecyk et al., 2021). Sin embargo, en casos de leve disfunción neurológica o poco desplazamiento en el foco de fractura, se puede considerar el tratamiento conservador (Mills, 2009; Wilson, 2015; Nell et al., 2017).

Aunque el tratamiento quirúrgico habitualmente emplea placas, tornillos o clavos con PMM para fracturas vertebrales (Wong y Emms, 1992; Garcia et al., 1994; Sturges et al., 2003; Weh y Kraus, 2007; Nell et al., 2017; Gougeon y Meheust, 2021; Bitterli et al., 2022), en el caso de fracturas sacras es más frecuente el uso de tornillos de compresión (DeCamp et al., 2016), placas de osteosíntesis con bloqueo (Mills, 2009; Nell et al., 2017), agujas transilíacas (Kudnig y Fitch, 2004) o agujas para la fijación transarticular lumbosacra (Paré et al., 2001; Mills, 2009). No obstante, el sistema de FE, inicialmente desarrollado para fracturas vertebrales (Otto et al., 2000; Walker et al., 2000) destaca en estos casos debido a sus ventajas en seguridad, simplicidad, tolerancia del paciente y resultados finales (Burton, 2011; Schuetze et al., 2022).

En relación a las fracturas pélvicas en gatos, éstas representan el 22-32% de todas las fracturas del sistema esquelético (Langley-Hobbs et al., 2007; Krebs et al., 2014). Dentro de este grupo, las fracturas acetabulares constituyen el 14-43% del total (Boswell et al., 2001; Haine et al., 2019). A pesar de su frecuencia, existen escasas referencias bibliográficas relacionadas con fracturas no traumáticas, y en particular con las fracturas de la fisis acetabular (FFA) (Kudnig y Fitch, 2004: Langley-Hobbs et al., 2007). La fisis acetabular se cierra entre las 20 y 24 semanas de edad en la especie felina (Langley-Hobbs et al., 2007), y se desconoce si las FFA tiene un origen similar al "*Síndrome de Displasia Epifisaria Felina*", donde se describen fracturas espontáneas de la cabeza femoral en pacientes machos, habitualmente castrados tempranamente, obesos (McNicholas et al., 2002; Lafuente et al., 2011; Schwartz, 2013; Borak et al., 2017) y/o hipotiroideos (Diehm et al., 2019). No obstante, aún no hay datos en la literatura que respalden esta teoría sobre el origen de las FFA.

Históricamente se ha considerado el tratamiento conservador de las fracturas acetabulares como una opción terapéutica en pacientes inmaduros (Meeson et al., 2017). Sin embargo, las opciones no quirúrgicas no son la mejor elección para este tipo de fracturas (Boswell et al., 2001; Langley-Hobbs et al., 2007; Lafuente et al., 2011; Krebs et al., 2014; Meeson et al. 2017; Haine et al., 2019; Schuetze et al., 2022), ya que la complicación más común es el desarrollo de osteoartritis debido a reducciones inadecuadas del foco de fractura (Orrenius, 2019). Según Piana y colaboradores (2020), los desplazamientos de más de 3 mm en la reducción de la fractura se asocian con un mayor riesgo de osteoartritis en la articulación afectada. No obstante, otros autores argumentan que esta decisión es más una cuestión biomecánica, donde factores como el nivel de actividad del paciente y el peso corporal son determinantes para optar por el tratamiento conservador o quirúrgico (Roberts et al., 2021). Otras complicaciones observadas en fracturas acetabulares desplazadas y no reducidas incluyen el estrechamiento del canal pélvico con el consecuente estreñimiento, déficit neurológico y dolor (Boswell et al., 2001).

Existen diversas técnicas descritas para el tratamiento de fracturas acetabulares en pequeños animales, siendo las placas de pequeños fragmentos o las placas bloqueadas las más utilizadas (Hardie et al., 1999; Boswell et al., 2001; Amato et al., 2008; Piana et al., 2020; Roberts et al., 2021; Murugarren et al., 2023), junto la combinación de tornillos con PMM o cerclajes (Beaver et al., 2000; Voss et al., 2009; Haine et al., 2019; Blakely et al., 2019; Schuetze et al., 2022). En aquellos casos donde la reparación quirúrgica no es posible, se puede considerar el empleo de procedimientos paliativos como la ostectomía de cabeza y cuello femoral para la eliminación del dolor y el mantenimiento de una buena funcionalidad del miembro (Scott y McLaughling, 2007). Hasta la fecha, no se ha descrito en la bibliografía el uso de la FE como único método de estabilización en el tratamiento de FFA en gatos inmaduros. Esta técnica se ha documentado solo en un caso en la especia canina como método complementario a otro sistema de osteosíntesis (Haine et al., 2019), a diferencia de medicina humana, donde se considera una técnica muy útil en pacientes pediátricos con fracturas acetabulares traumáticas (Amorosa et al., 2014; Guillaume et al., 2020).

El fundamento de la FE en el tratamiento de fracturas es proporcionar estabilidad al foco de fractura con la mínima interacción posible con el tejido blando, teniendo como objetivo mantener la longitud, alineación y rotación de la fractura (Bible y Look, 2015). En ciertos casos el uso de la FE puede emplearse como un sistema de estabilización complementario a un sistema de fijación interna (Ben-Amotz et al, 2009).

La fisiología de la consolidación de la fractura depende en gran medida del modo de fijación y del nivel de estabilidad (Palmer et al., 1992). Una estabilidad absoluta de la fractura, como la lograda con placas de osteosíntesis, conduce a una consolidación primaria del hueso mediante la formación de hueso intramembranoso. En contraste, la estabilidad relativa de la fractura proporcionada por la FE resulta en una consolidación secundaria mediante hueso endocondral. Sin embargo, esta opción permite modificar la construcción de la estructura inicial para hacer la fractura más o menos estable según las necesidades (Bible y Look, 2015)

En cuanto a la nomenclatura de las distintas configuraciones de FE, las clasificaciones descritas por Roe (1992) son las comúnmente aceptadas en la actualidad, donde se incluyen la mayoría de las configuraciones empleadas en los sistemas lineales de FE. La clasificación de los fijadores externos ha evolucionado desde sencillos nombres de dispositivos hacia un sistema más descriptivo basado en la configuración de todo el sistema. Actualmente se utilizan dos sistemas de clasificación para categorizar los fijadores. En uno de ellos, se definen como fijadores de tipo I, tipo II o tipo III. En el segundo sistema de clasificación, las categorías son más descriptivas. Los fijadores se definen ampliamente como unilaterales o bilaterales, y dentro de cada una de estas categorías existen sistemas de uno o dos planos. En traumatología veterinaria, se añade información adicional cuando está disponible, especialmente relacionada con las rótulas o las barras de conexión. Muchas configuraciones no son fácilmente definibles, ya que a veces son necesarios complejos diseños para adaptar con éxito el sistema al hueso fracturado (Roe, 1992).

En medicina humana, existen clasificaciones de características similares para sistemas lineales y circulares (Hadeed et al., 2023), con aplicaciones en huesos de distinta morfología y localización. Sin embargo, no se ha descrito una nomenclatura descriptiva de fijadores externos exclusiva para su aplicación en fracturas pélvicas. A pesar de ello, sí se describe el uso de determinados diseños o configuraciones específicas para este tipo de fracturas (Rieger et al., 1996).

En resumen, la FE representa un sistema de estabilización altamente versátil con importantes beneficios, como son su mínima invasión, lo que reduce el daño al suministro vascular de los tejidos, previene retrasos en la cicatrización ósea (Johnson et al., 1999; Palmer, 2012), y reduce el dolor postoperatorio (Egger, 1991; Hudson et al., 2020). Sin embargo, la técnica requiere una comprensión sólida de los principios de aplicación para evitar complicaciones. A pesar de este dato, la FE destaca por su baja tasa de complicaciones y su facilidad de aplicación (Majeed, 1990; Mitchell et al., 2016; Stewart et al., 2019).

Hipótesis y objetivos del estudio

4. Hipótesis y objetivos del estudio

4.1. Hipótesis de trabajo

El objeto de este estudio es evaluar el tratamiento quirúrgico de fracturas pélvicas y sacras en las especies canina y felina mediante el uso de fijación externa, ya sea como elemento único de estabilización o como sistema complementario. Las hipótesis planteadas se enfocan en diferentes aspectos:

1. La primera hipótesis se centra en determinar si un conjunto de fracturas pélvicas y sacras tratadas con fijación externa presentaría resultados favorables en términos de reducción y cicatrización ósea, tratando de establecer si esta alternativa terapéutica superaría a los tradicionales sistemas de fijación interna.

2. La segunda hipótesis pretende desarrollar una propuesta de clasificación para los distintos diseños de fijación externa utilizados en fracturas pélvicas.

3. La tercera hipótesis se centra en evaluar la tolerancia y el confort del paciente hasta el momento de la explantación de estos sistemas, buscando determinar si presentan niveles adecuados en este aspecto.

4. La última hipótesis analiza las posibles complicaciones asociadas con el uso de fijación externa en el tratamiento de las fracturas de pelvis y sacro, comparando los inconvenientes relacionados directamente con el implante con aquellos encontrados en el uso de sistemas de fijación interna, con el fin de establecer si son igual de bajos o incluso más bajos.

4.2. Objetivos del estudio

El objetivo general de este estudio es evaluar la eficacia de la técnica a través de la evolución clínica de la consolidación ósea y la funcionalidad de las extremidades una vez realizada la estabilización de las fracturas de la pelvis y de sacro con fijadores externos en pequeños animales.

Los objetivos específicos propuestos para la demostración de las hipótesis planteadas son los siguientes:

a) Demostrar la eficacia mediante la obtención de estudios radiológicos hasta el momento de cicatrización ósea.
b) Establecer una propuesta de clasificación para las distintas configuraciones de fijación externa aplicadas en fracturas pélvicas y sacras.
c) Evaluar la tolerancia y el confort del paciente mediante evaluaciones basadas en escalas de valoración visual.
d) Registrar las complicaciones directamente vinculadas al sistema durante todo el tiempo de tratamiento.
e) Registrar los posibles daños iatrogénicos como consecuencia de la aplicación de la fijación externa.

Los objetivos específicos de cada uno de los artículos presentados en esta Tesis Doctoral son:

ESTUDIO 1: Retrospective Assessment of Thirty-Two Cases of Pelvic Fractures Stabilized by External Fixation in Dogs and Classification Proposal. *Vet. Sci.* 2023, 10, 656. doi: 10.3390/vetsci10110656

a) Mostrar resultados de eficacia, seguridad y tolerancia en el tratamiento de fracturas pélvicas en la especie canina mediante fijación externa.
b) Demostrar la solidez de la fijación externa como sistema complementario de fijación junto a sistemas de fijación interna en el tratamiento de fracturas pélvicas en la especie canina.
c) Proponer una clasificación de los posibles sistemas de fijación externa aplicables en la pelvis de pequeños animales.

ESTUDIO 2: External Fixation for Fracture Stabilization of the Sacrum in 15 Dogs. *Front. Vet. Sci.* 2023, 10, 1222504. doi: 10.3389/fvets.2023.1222504

a) Mostrar resultados de eficacia, seguridad y tolerancia en el tratamiento de fracturas sacras en la especie canina mediante fijación externa.
b) Aportar una alternativa terapéutica en la resolución de fracturas tradicionalmente estabilizadas mediante fijación interna.

ESTUDIO 3: A Bilateral Acetabular Physeal Fracture Treated with External Fixation in an Immature Cat.

a) Demostrar la fiabilidad del uso de la fijación externa en fracturas de la fisis acetabular en un paciente inmaduro.
b) Ofrecer una opción terapéutica fácil y barata en casos altamente desafiantes como lo es el de una fractura fisaria bilateral acetabular en un paciente de pequeño tamaño e inmaduro.

Material y métodos

5. Material y métodos

5.1. Material

5.1.1. Material biológico

a) *Estudio 1*

En este estudio se incluyeron 32 perros tratados entre los años 2006 y 2022. Los criterios de inclusión para este estudio fueron pacientes de la especie canina con una o más fracturas pélvicas. En algunos casos, estas fracturas coexistían con lesiones extrapélvicas de diversos tipos. La condición crítica de la mayoría de los perros, principalmente de naturaleza politraumática, se consideró como un criterio de inclusión debido a la mínima invasión de la fijación externa en comparación a la fijación interna, y al tiempo anestésico más corto requerido para su implantación. En otros casos, se empleó la fijación externa como un sistema complementario para aumentar la estabilidad del foco de fractura tratado principalmente con osteosíntesis interna.

Este material corresponde al empleado en el trabajo: **Retrospective Assessment of Thirty-Two Cases of Pelvic Fractures Stabilized by External Fixation in Dogs and Classification Proposal. Vet. Sci. 2023, 10, 656. doi: 10.3390/vetsci10110656**

b) *Estudio 2*

En este estudio retrospectivo se incluyeron 15 pacientes caninos atendidos entre 2006 y 2021, que sufrieron fractura de sacro y fueron tratados mediante FE.

Este material corresponde al siguiente estudio: **External Fixation for Fracture Stabilization of the Sacrum in 15 Dogs. Front. Vet. Sci. 2023, 10, 1222504. doi: 10.3389/fvets.2023.1222504**

c) *Estudio 3*

Este trabajo incluye un paciente inmaduro de la especie felina tratado en 2020 mediante FE tras sufrir una fractura de la fisis acetabular bilateral.

El estudio es el siguiente: **A Bilateral Acetabular Physeal Fracture Treated with External Fixation in an Immature Cat (en revisión).**

5.1.2. Material quirúrgico

Para la realización de las cirugías se emplearon diferentes materiales descritos a continuación.

5.1.2.1. Material de cirugía general

El material quirúrgico general no ortopédico utilizado fue el estándar para la cualquier procedimiento quirúrgico e incluyó:

- 1 mango de bisturí n.º4, con hoja del n.º 20.
- 1 mango de bisturí n.º3, con hoja del n.º 15.
- 1 portaagujas de Mayo-Hegar.
- 1 tijera Metzenbaum curva.
- 1 tijera Metzenbaum recta.
- 1 tijera Mayo.
- 2 pinzas hemostáticas de Rochester rectas.
- 2 pinzas de Kocher rectas.
- 2 pinzas de Adson con y sin dientes.
- 4 pinzas Halstead de 11 cm curvas (mosquitos).
- 6 pinzas atraumáticas de Allis de 150 mm.
- 8 pinzas Backhaus (cangrejos) (AESCULAP AG®, Am Aesculap-Platz, 78532 Tuttlingen, Alemania).

5.1.2.2. Material de ortopedia general

El instrumental de ortopedia general empleado fue:

- 2 periostotomos.
- 2 separadores de Hohmann.
- 2 separadores de Senn.

- 2 retractores de Gelpi.
- 1 alicate plano.
- 1 alicate de corte (AESCULAP AG®).

El material de osteosíntesis empleado incluyó:

- Sistema de motor eléctrico para cirugía veterinaria Colibri II (DePuy Synthes, Synthes GmbH, Suiza). Esta unidad consta de varios componentes, como son:
    - Pieza de mano (DePuy Synthes, referencia 523.101).
    - Estuche para pilas recargables (DePuy Synthes, referencia 532.132).
    - Pila recargable (DePuy Synthes, referencia 532.103).
    - Cubierta estéril (DePuy Synthes, referencia 532.104).
    - Cargador universal II (DePuy Synthes, referencia 05.001.204).
    - Adaptador de anclaje rápido AO/ASIF (DePuy Synthes, referencia 05.001.250).
    - Mandril de tres mordazas (DePuy Synthes, referencias 05.001.252 y 05.001.253).
    - Adaptador de anclaje rápido para agujas de Kirschner (DePuy Synthes, referencia 532.022).

5.1.2.3. Material específico de fijación externa

En los tres trabajos presentados se emplearon sistemas de FE de tipo Meynard (Insorvet, Barcelona, España) o Polilock (Ad Maiora, Cavriago, Italia), que permiten la conexión de las agujas transfixiantes con una barra conectora externa.

El sistema Meynard consta de rótulas de acero inoxidable quirúrgico. Éstas se interconectan mediante un sólido clampado, facilitando la conexión de las agujas o clavos transfixiantes y las barras conectoras en un amplio rango de direcciones. Las rótulas o coaptadores están constituidos de dos partes simétricas y un tornillo que las mantiene unidas (Figura 1).

Figura 1. Detalle de las rótulas Meynard.

Por otro lado, el sistema Polilock consta de componentes radiotransparentes y con una configuración básica pensada para pacientes que no superan los 5 kg. Sus rótulas o coaptadores están fabricados con un polímero plástico que conecta las agujas o clavos y las barras conectoras. Estas barras están fabricadas en fibra de carbono (Figura 2).

Figura 2. Detalle de las rótulas del sistema Polilock (Ad Maiora).

5.1.3. Material radiológico

5.1.3.1. Aparato de Rayos-X

- Generador RX Orosia 30HF: Tubo Toshiba 30kw 100kv 400mA foco 0.6mm – 1.3mm. (Toshiba®, Tokio, Japón).

5.1.3.2. Programa informático de visualización de imágenes:

- Programa visor de radiografías en formato Dicom (Horos™).

5.1.3.3. Fluoroscopia:

- Arco quirúrgico General Electric C OEC One® (General Electric®, Boston, EE.UU.).

5.1.3.4. Otros

- Sacos de arena y cuñas de espumas para posicionar correctamente al animal.
- Cintas de sujeción de nylon radiotransparente.

5.1.4. Material anestésico

Los equipos empleados para la monitorización anestésica de los animales fueron:

- Máquina de anestesia con vaporizador de isofluorano y respirador, marca Mindray Wato EX35 (Mindray, Shenzhen, China).
- Monitor multiparámetros para monitorización de constantes, con pulsioxímetro y capnógrafo incorporados marca MINDRAY modelo ePM 12M Vet (Mindray).

El plano anestésico balanceado se mantuvo en todo momento a través de la utilización de fármacos anestésicos mediante un protocolo normalizado de trabajo. Los fármacos empleados en las distintas anestesias fueron:

a) Premedicación anestésica:

- Midazolam 15mg/3ml (Midazolam Sala®, Laboratorio Reig Jofre S.A., Sant Joan Despí, Barcelona, España).
- Dexmedetomidina 0,5mg/ml (Dexmopet®, Vetpharma Animal Health S.L., Barcelona, España).
- Cefazolina 250mg/ml (Cefazolina Normon® EFG, Laboratorios Normon, S.A., Tres Cantos, Madrid, España).

b) Analgesia preoperatoria:

- Metadona 10mg/ml (Semfortan®, Dechra Veterinary Products S.L.U., Barcelona, España).

c) Analgesia intraoperatoria:

- Fentanilo 0,05mg/ml (Fentanest®, Kern Pharma S.L., Terrassa, Barcelona, España).

d) Inducción anestésica:

- Propofol 10mg/ml (Propofol-Lipuro®, B. Braun VetCare S.A., Barcelona, España).

e) Mantenimiento anestésico:

- Isofluorano 100% (Isovet®, B. Braun VetCare, S.A.).

f) Analgesia regional:

- Bupivacaina 5mg/ml (Bupivacaina B.Braun®, B. Braun VetCare S.A.)
- Lidocaína 20mg/ml (Lidocaína B. Braun®, B. Braun VetCare S.A.).

g) Analgesia postoperatoria:

- Buprenorfina 0,3mg (Buprex®, Indivior Europe Limited, Dublín, Irlanda).
- Metadona 10mg/ml (Semfortan®, Dechra Veterinary Products S.L.U.).
- Tramadol 50mg-100mg (Tramadol Normon EFG®, Laboratorios Normon, S.A.).
- Firocoxib 5 mg/Kg (Previcox® 57mg o 227mg, Merial, Lyon, Francia).

El circuito anestésico utilizado fue un circuito cerrado con respirador incorporado en la máquina anestésica Mindray modelo ePM 12M Vet.

El material general de anestesia empleado fue:

- Jeringuillas de 1 ml, de 2 ml, de 5 ml y de 10 ml (Henry Schein España S.A.U., Madrid, España).
- Catéteres Introcan de 18, 20, 22 y 24 G (B. Braun VetCare S.A.).
- Sistemas de infusión de sueros (Care Fusion, Shangai International Holding Corp. GMBH (Europe), Hamburgo, Alemania).
- Tubos endotraqueales de 4, 4,5, 5, 5,5, 6, 6,5, 7, 7,5, 8, 8,5, 9, 9,5, 10, 10,5 y 11 (Henry Schein España, S.A.U.).
- Laringoscopios de fibra óptica (Welch Allyn Iberia, Centro Empresarial Best Point, San Fernando de Henares, Madrid, España).
- Soluciones de Lactato de Ringer de 500 ml (B. Braun VetCare S.A.).

5.2. Métodos

5.2.1. Método preoperatorio

Antes de cada procedimiento, se realizaron estudios radiológicos preoperatorios de cada paciente en proyecciones ventrodorsal y laterolateral.

Se procedió a rasurar la región dorsal lumbosacra y glútea de todos los pacientes, extendiéndose por debajo de las rodillas en todos los pacientes. Los animales se posicionaron en decúbito esternal en la mesa quirúrgica con las extremidades pélvicas abducidas mediante el empleo de un soporte abdominal para mantener al paciente lo más horizontal posible.

5.2.2. Método anestésico

Se llevaron a cabo protocolos anestésicos adaptados a la condición de cada paciente, utilizando un enfoque multimodal. Se administró clorhidrato de medetomidina a una dosis de 20 µg/kg (Sedín, Vetpharma Animal Health) y metadona a una dosis de 0.5 mg/kg de HCl (Insistor, Richter Pharma AG, Wels, Austria) por vía intramuscular, seguido de la inducción con propofol a una dosis de 3 mg/kg (Propofol Lipuro 1%, BBraun Melsungen AG) por vía intravenosa. El mantenimiento anestésico inhalatorio se llevó a cabo con isoflurano (IsoVet, BBraun Melsungen AG).

5.2.3. Método quirúrgico

En todos los pacientes se aplicaron diferentes sistemas de FE de manera individual o combinados con otras técnicas de osteosíntesis interna para la estabilización de las fracturas pélvicas y sacras incluidas en los diferentes trabajos.

a) Corredores seguros

Para el emplazamiento de los clavos transfixiantes se emplearon diferentes corredores seguros. En los estudios referentes a fracturas pélvicas (estudios nº 1 y nº 3), se describieron los siguientes corredores:

- Corredor de la cresta ilíaca.
- Corredor del cuerpo ilíaco.
- Corredor de la tuberosidad isquiática.

En el trabajo que aborda la resolución de fracturas sacras (estudio nº 2), se describieron los siguientes corredores:

- Corredor de la cresta ilíaca.
- Corredor del sacro.
- Corredor de la tuberosidad isquiática.

b) Abordajes

Los fijadores externos se aplicaron a foco cerrado, aunque en la estabilización de algunas fracturas pélvicas y sacras se combinó la fijación externa e interna, requiriendo la realización de un abordaje abierto. Aunque estos abordajes no han sido descritos en los trabajos pertinentes, se llevaron a cabo siguiendo las directrices marcadas en la bibliografía (Jonhson, 2004). El cierre de los abordajes se realizó por planos utilizando material de sutura absorbible de gliconato (Monosyn®, Braun VetCare S.A.) para planos muscular, subcutáneo e intradérmica, y de poliamida (Dafilon®, Braun VetCare S.A.) para piel, en los casos en los que se aplicó.

5.2.4. Método postoperatorio inmediato

a) *Control radiológico postoperatorio*

Al finalizar la cirugía, se realizaron radiografías inmediatamente postoperatorias en proyecciones dorsoventral y laterolateral para evaluar la reducción de las fracturas y tener un control de los implantes aplicados. La proyección dorsoventral con el paciente en decúbito esternal fue obligatoria debido a la presencia del sistema de fijación en la porción dorsal del paciente.

b) *Postoperatorio clínico inmediato*

La duración de la hospitalización dependió de las necesidades individuales de cada paciente, lo que incluía terapia de fluidos y antibióticos, medicamentos antiinflamatorios no esteroides y analgésicos. El cuidado fue el mismo que se aplica para los fijadores externos estándar, y se proporcionan instrucciones precisas al propietario sobre cómo realizarlo adecuadamente. Se recomendó reposo y confinamiento durante las primeras cuatro semanas postoperatorias. En los pacientes caninos, se aconsejó dar paseos con correa y controlar la actividad hasta la retirada del fijador. Para el paciente felino, se recomendó mantenerlo confinado en un transportín durante las primeras dos semanas.

Todos los pacientes fueron tratados con meloxicam (0,1 mg/kg/24 h por vía oral, Metacam, Boehringer Ingelheim, Ingelheim am Rhein, Alemania) durante 14 días y gabapentina (15 mg/kg/8 h por vía oral, Kern Pharma) durante 30 días.

5.2.5. Método postoperatorio a medio y largo plazo

a) *Controles radiológicos*

Durante el período postoperatorio la mayoría de los controles radiológicos se realizaron en proyección laterolateral y dorsoventral, obteniendo proyecciones oblicuas cuando la estructura del sistema impedía una correcta visualización del foco de fractura. Una vez alcanzada la consolidación ósea radiográfica de las fracturas, se procedío a la retirada del sistema bajo sedación. Generalmente, los controles radiográficos se realizaron a las 3, 6 y 12 semanas después de la cirugía, aunque este protocolo se modificó según la evolución específica de cada paciente. En algunos casos específicos se llevó a cabo una tomografía computarizada (TC) para una mejor evaluación del estado final de cicatrización.

b) Controles clínicos

Se realizaron controles semanales para la valoración de ciertos aspectos clínicos, utilizando escalas de valoración visual o VAS ("*Visual Assessment Score*").

En el estudio nº 1, el resultado del tratamiento a nivel clínico se evaluó mediante una escala de 4 niveles numéricos que consideraba el resultado funcional final y el dolor residual. La escala VAS utilizada fue la siguiente:

- Excelente: Sin dificultades para caminar, ni dolor aparente.
- Bueno: Buen resultado funcional con cojera residual o signos leves de dolor.
- Regular: Cojera evidente y constante o signos de dolor leve a moderado, pero no incapacitante.
- Malo: Cojera severa o dolor constante.

[Retrospective Assessment of Thirty-Two Cases of Pelvic Fractures Stabilized by External Fixation in Dogs and Classification Proposal. Vet. Sci. 2023, 10, 656. doi: 10.3390/vetsci10110656]

En el estudio nº 2 se emplearon dos escalas VAS. La primera realizaba una evaluación neurofuncional sobre las funciones neurológicas y ortopédicas básicas en el momento de la presentación del caso, durante las revisiones semanales y al final del tratamiento. Cada uno de los cinco aspectos a analizar se puntuaban según una escala de 3 niveles numéricos. Los aspectos evaluados se muestran en la Tabla nº 1.

EVALUACIÓN NEUROFUNCIONAL	
Capacidad para ponerse de pie	• No = 0 • Una extremidad = 1 • Dos extremidades = 2
Capacidad para caminar	• No = 0 • Con asistencia = 1 • Sí = 2
Capacidad para orinar espontáneamente	• No = 0 • Ocasionalmente = 1 • Sí = 2
Presencia de dolor	• Severo = 0 • Moderado = 1 • No = 2
Dolor profundo en los miembros pélvicos	• No = 0 • Dudoso = 1 • Sí = 2

Tabla 1. Tabla resumen de la primera escala de valoración visual empleada en el estudio nº 1.

La segunda VAS constaba de 5 niveles de evaluación basados en la estabilidad de la fijación externa y el desplazamiento del foco de fractura. A cada nivel de la escala se le asignó un valor numérico. Los diferentes niveles de esta escala fueron:

- Excelente (5): Sistema de fijación estable con reducción de fractura inalterada durante todo el proceso de curación.
- Muy bueno (4): Señales mínimas de inestabilidad en el sistema de fijación o ligero desplazamiento de la fractura. Solo se requirieron ajustes menores en la estructura externa sin anestesia general.
- Bueno (3): Señales moderadas de inestabilidad en el sistema de fijación o desplazamiento moderado de la fractura que no requirieron revisión quirúrgica pero sí ajustes de la estructura externa bajo anestesia general.
- Regular (2): Inestabilidad importante en el sistema de fijación o desplazamiento importante de la fractura que requiere revisión quirúrgica y ajustes o cambios importantes en la estructura del sistema.
- Malo (1): Cambios importantes en el sistema de fijación o desplazamiento importante de la fractura que requirió la retirada del fijador.

[External Fixation for Fracture Stabilization of the Sacrum in 15 Dogs. Front. Vet. Sci. 2023, 10, 1222504. doi: 10.3389/fvets.2023.1222504]

En el estudio nº 3 se emplearon dos VAS. El primero, que constaba de 6 niveles, hacía referencia al estado funcional del paciente a nivel neurológico y ortopédico:

- Nivel 0: Sin alteraciones funcionales o locomotoras. El paciente camina normalmente.
- Nivel 1: Alteraciones locomotoras leves, con cojera ocasional leve.
- Nivel 2: Alteraciones locomotoras leves a moderadas, con cojera leve y constante.
- Nivel 3: Alteraciones locomotoras moderadas, con cojera moderada y parcialmente constante.
- Nivel 4: Alteraciones locomotoras severas, con cojera pronunciada que provoca el uso intermitente del miembro.
- Nivel 5: Alteraciones funcionales muy severas con falta completa de uso del miembro.

Se empleó un segundo VAS de tres niveles que valoró el grado de confort del paciente con respecto al sistema de fijación implantado:

- Nivel A: No hay signos evidentes de dolor. El animal no muestra dolor al ser manipulado. Se considera un comportamiento normal.
- Nivel B: Signos leves a moderados de dolor. El animal muestra cierta incomodidad con quejidos espontáneos ocasionales. Puede haber dificultades moderadas en la micción y defecación. No hay otras alteraciones significativas en el comportamiento.
- Nivel C: Signos graves de dolor. Imposibilidad de manejar al paciente sin vocalizaciones. Dificultades severas en la micción y defecación. Apatía y depresión.

[A Bilateral Acetabular Physeal Fracture Treated with External Fixation in an Immature Cat (en revisión)]

5.2.6. Método estadístico

Los resultados clínicos fueron procesados estadísticamente con la ayuda del programa Microsoft® Excel 2016. Se realizó una estadística básica descriptiva. En el análisis de variables cualitativas se informaron las frecuencias absolutas y relativas (n y %, respectivamente). Para las variables cuantitativas, se reportaron la media y la desviación estándar (DE).

Resultados

6. Resultados

A continuación se adjunta una copia de los trabajos que componen la recopilación, con una carátula con el resumen y la referencia de la publicación, incluyendo el índice de impacto y la posición de la revista en el área del JCR en el año de su publicación.

6.1. Aplicación de los fijadores externos en pelvis para el tratamiento de las fracturas de pelvis en perros y propuesta de clasificación de los sistemas empleados

Tipo: Artículo científico

Estado: Publicado

Resumen: Los objetivos de este estudio fueron evaluar los resultados de la consolidación ósea, la comodidad del paciente durante el tratamiento, los resultados funcionales y las complicaciones en fracturas pélvicas tratadas con fijación externa, así como proponer un sistema de clasificación para los marcos externos aplicados. Se trató un total de treinta y dos pacientes caninos con fracturas pélvicas de diferentes orígenes. Se desarrolló un sistema de clasificación alfanumérico para ofrecer una mejor referencia de los marcos utilizados, detallando la estructura del marco, así como el número y la ubicación de los pines utilizados. En este estudio se trataron ochenta y seis fracturas en los 32 pacientes de este trabajo, con un tiempo promedio de fijación de 9.88 ± 4.15 semanas. No se detectaron complicaciones importantes en esta cohorte de casos, y los resultados se calificaron con un 9.46 en una escala de evaluación visual para la comodidad del paciente durante el tratamiento. Los resultados calificados como excelentes y buenos fueron del 96%. El uso de fijación externa para la estabilización de fracturas pélvicas debe considerarse como una opción técnica, especialmente para la estabilización mínimamente invasiva de fracturas complejas, ya sea como estabilización primaria o secundaria.

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Índice de impacto: El índice de impacto de *Veterinary Sciences* en el JCR del año 2022 fue de 2,4.

Posición: La revista *Veterinary Sciences* se posicionó en el JCR del año 2022 en el cuartil Q1 para la categoría de "Ciencias Veterinarias", ocupando la posición 29 de 144.

veterinary sciences

MDPI

Article

Retrospective Assessment of Thirty-Two Cases of Pelvic Fractures Stabilized by External Fixation in Dogs and Classification Proposal

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Simple Summary: This study was aimed to evaluate the use of external fixation to stabilize pelvic fractures. The technique was performed by minimally invasive procedures, substantially reducing the impact of open approaches on tissues and facilitating healing of tissues. External fixation applied to pelvic fractures proved to be a valuable complimentary fixation method as well, providing further stability to the primary one. Therefore, though it is a technique not usually used in pelvic fractures, in our case cohort, it proved to be an effective alternative to the sole use of plates, either as an exclusive stabilization method or as an adjuvant one. During the evaluation of the cases, the authors were prompted to establish a classification proposal for the frame configuration used, in order to better understand the differences among them.

Abstract: The goals of this study were to evaluate the outcomes of bone healing, patient comfort during the treatment, functional results, and complications in pelvic fractures treated with external fixation, as well as to propose a classification system for the applied external frames. A total of thirty-two canine patients with pelvic fractures of different origins were treated. To provide a better reference for the frames used, an alphanumeric classification system was developed, detailing the frame structure and the number and location of the pins used. In this study, eighty-six fractures were treated in the 32 patients of this work, with an average fixation time of 9.88 ± 4.15 weeks. No major complications were detected in this case cohort, and the outcomes were rated at 9.46 based on a visual assessment scale for the patient's comfort during treatment. Outcomes graded as excellent and good were 96%. The use of external fixation for stabilization of pelvic fractures should be considered as a technical option, especially for minimally invasive stabilization of complex fractures, either as a primary or secondary stabilization.

Keywords: external fixation; external fixation classification; fractures; pelvis; dog

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1. Introduction

Pelvic fractures in small animals account for 25% of those diagnosed in daily clinical practice [1,2]. Most fractures in dogs are caused by traffic accidents, falls, or blows. Pathological fractures are less frequent [3]. Conservative treatment is an option that, although some studies have reported successful outcomes [4], often leads to inadequate reduction and needs a long recovery time [5]. Surgical treatment is generally considered the standard choice in most cases, providing a shorter recovery time, faster healing, a reduced incidence of diseases related to the stenosis of the pelvic canal, and a better functional outcome [6].

In human medicine, the acute management of pelvic fractures by external fixation (EF) is commonly performed to avoid displacement of the fracture site, bleeding, neurovascular damage and/or post-traumatic pain [7]. Additionally, EF is a valuable technique for definitive stabilization due to its low rate of complications and ease of application [7–9].

In the veterinary literature, some studies have been published in which EF was used for the treatment of pelvic fractures. The main characteristics of this technique are safety, ease of application, and patient compliance, generally providing a good outcome with a low rate of complications [4,10,11]. The most frequent complications encountered were loosening of the frame and local infection at the pin sites [4,12].

The present study describes the surgical technique and evaluates the outcome of the treatment of pelvic fractures using EF, either as the primary or as a complementary technique, in 32 canine patients.

The hypothesis underlying this study was that external fixation could offer a significantly stronger lever arm compared to what could be achieved with internal fixation alone, due to its extension, and with a much less invasive surgical approach. These characteristics were expected to ensure better stability of the treated fracture and better comfort for the patient during the postoperative (PO) period, whether external fixation was used as a secondary support technique to internal fixation or used as a primary stabilization technique. Additionally, this study introduces a classification system for the frame constructs used, due to the absence of nomenclature and classification for this type of EF in the existing literature.

2. Materials and Methods

In the present study, 32 dogs treated at Hospital Veterinario IVCE Evidensia (Villaviciosa de Odón, Madrid, Spain) and Clinica Veterinaria Miller (Cavriago, Italy) between 2006 and 2022 were reviewed. The inclusion criteria for this study were dogs with one or more pelvic fractures. In some patients, these fractures coexisted with extrapelvic injuries of various kinds. The critical condition of most dogs, mainly of a polytraumatic nature, was considered as an inclusion criterion, because of the minimal invasivity and shorter anesthetic time required for EF compared with plating. In other cases, EF was chosen as a complementary system to increase the stability of the fracture site treated primarily with internal osteosynthesis. For each case, the collected information were signalment, the nature of the injury, a description and latency of the surgical procedure, and fixation time. During the PO period, the surgeon in charge evaluated the patient's comfort based on a visual assessment scale (VAS) ranging from 1 (indicating the worst comfort) to 10 (indicating the best comfort). Furthermore, the final functional outcome was evaluated based on follow-up (FU) evaluations.

Radiological studies were reviewed to confirm the quality of fracture reduction and the fixation systems used. Overall, data regarding age, level of activity, weight, breed or the grade of displacement in the fracture site were taken in account at the beginning of the surgical process. Additionally, it is worth mentioning that usually an open approach and a combined fixation was preferred in fractures highly displaced and heavier patients, while a closed approach and ESF as the unique method of stabilization was preferred for lighter animals and lightly displaced fractures. The external fixators were arranged in a linear configuration and used in different arrangements based on the evaluation of the surgeon in charge of the case. The pins were inserted at the iliac wing and the ischiatic tuberosity and, sometimes, the neck of the ilium, following the safe corridors described later. The pins used were threaded from 1.2 to 3.5 mm in diameter. Sometimes, K-wires were added to the frame construct for specific requirements. These pins were connected to a 3 mm stainless steel connecting bar using Meynard steel clamps (Insorvet, Barcelona, Spain) or to 5 mm carbon bars with plastic clamps (Polilock radiolucent EF system—Ad Maiora, Cavriago, Italy).

There was a considerable range of configurations employed, leading the authors to introduce a classification system for describing the frame designs used in this cohort. This classification utilizes an alphanumeric notation that conveys information about the number of pins placed in each of the recommended locations and the connection between the assemblies of both hemipelves. The information is listed from left to right, looking to the fixator frame from above. In the proposed classification, each hemipelvis is divided into three segments (Figure 1):

- Segment I: Iliac wing.
- Segment II: Body of the ilium and acetabulum.
- Segment III: Ischium.

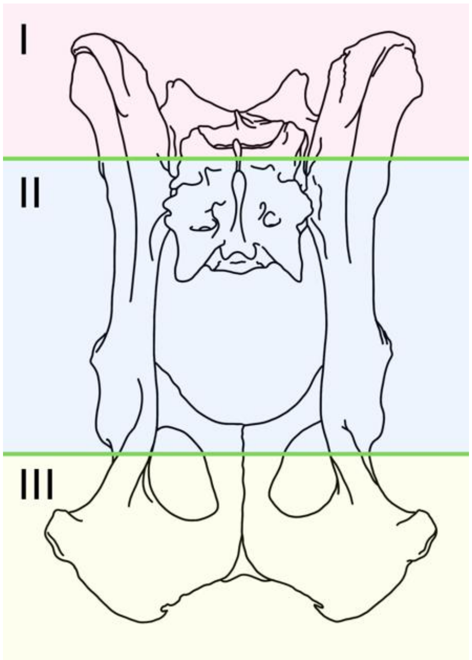

Figure 1. Segments into which the pelvis can be divided according to the proposed nomenclature for pelvic external fixation systems.

Each segment is followed by a number indicating the pins inserted at that location.

In the alphanumeric description of both the left and right hemipelves, there is a mention of how the pins are interconnected with the connecting bars within each hemipelvis. These interconnections were utilized in five distinct frame designs, each denoted by a capital letter (Figure 2):

- Type T: A single bar interconnects the pins located on both iliac wings.
- Type C: The bars connect the pins on the iliac wing and ischiatic tuberosity of one hemipelvis to each other, and with the pin located on the wing of the contralateral ilium.
- Type O: The bars interconnect the pins of each hemipelvis around the perimeter.
- Type L: The bars connect the pins of one hemipelvis to each other and with the pin located on the contralateral ischial tuberosity.
- Type X: The bars interconnect the pins around the perimeter and with a cross connection between the pins located at the vertices of the quadrilateral.

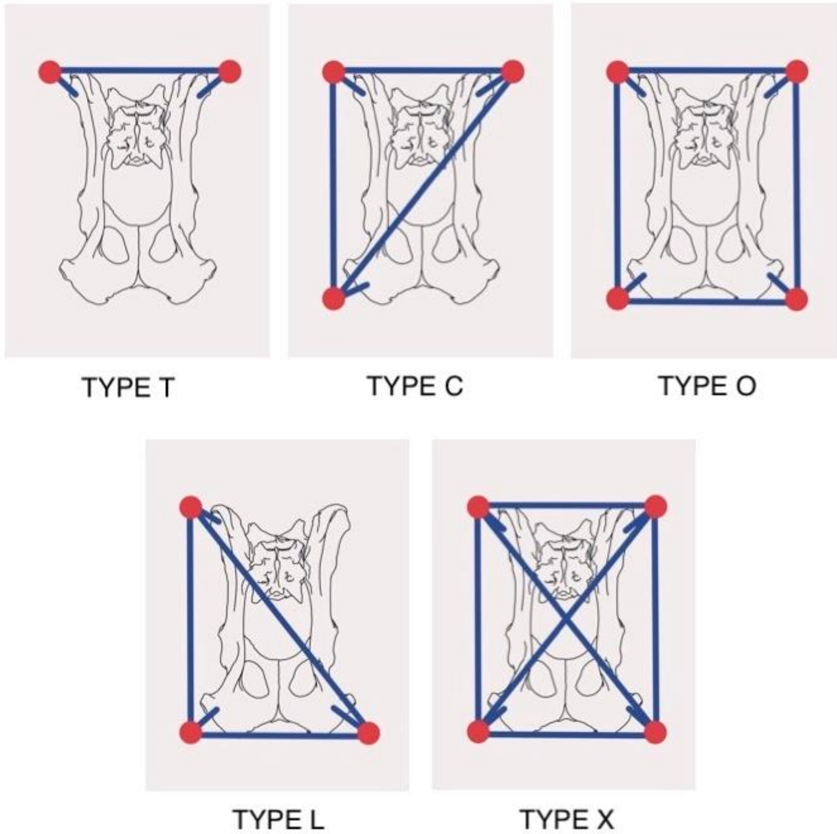

Figure 2. Different types of interconnections between hemipelves used as external fixation in the present study, as well as a classification proposal. Type T: a single bar interconnects the pins located on both iliac wings. Type C: the bars connect the pins on the iliac wing and ischiatic tuberosity of one hemipelvis to each other, and with the pin located on the wing of the contralateral ilium. Type O: the bars interconnect the pins of each hemipelvis around the perimeter. Type L: the bars connect the pins of one hemipelvis to each other and with the pin located on the contralateral ischial tuberosity. Type X: the bars interconnect the pins around the perimeter and with a cross-connection between the pins located at the vertices of the quadrilateral.

An illustrative example of the alphanumeric description utilized in this study is as follows. In the configuration:"I2.II1.III1.X.I1.II0.III1.", the alphanumeric code indicates the following:

On the left side (hemipelvis):

- Two pins have been inserted in the iliac wing.
- One pin has been placed in the body of the ilium.
- One pin has been inserted into the ischium.

On the right side (hemipelvis):

- One pin has been inserted into the iliac wing.
- There are no pins in the body of the right ilium.
- One pin has been placed in the right ischium.

All of these pins are interconnected using an X configuration, which represents a quadrilateral design with crossed bars between the contralateral ilium and ischium, as shown in Figure 3.

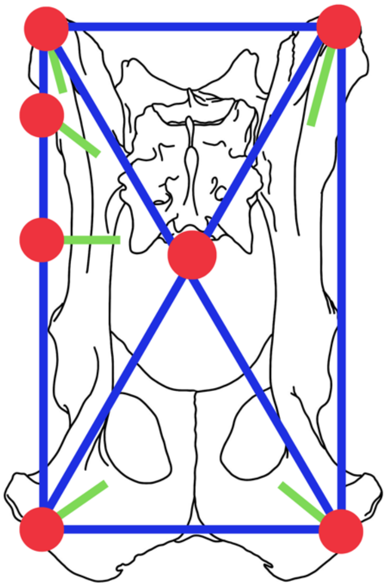

Figure 3. Descriptive illustration of the example for the proposed classification for pelvic external fixators with a configuration "I2.II1.III1.X.I1.II0.III1".

2.1. Preoperative Management

Each dog underwent preoperative X-rays examination. In some cases, when the correct evaluation of the fractures was difficult just based on standard radiographic examination, a CT scan was performed to provide a more comprehensive 3D assessment. Anesthetic protocols were planned regarding each patient's condition, using a multimodal approach based in the administration of medetomidine hydrochloride at a dose of 20 µg/kg (Sedín, Vetpharma Animal Health, Barcelona, Spain) and methadone at a dose of HCl 0.5 mg/kg (Insistor, Richter Pharma AG, Wels, Austria) by intramuscular route, followed by induction of propofol at a dose of 3 mg/kg (Propofol Lipuro 1%, BBraun Melsungen AG, Melsungen. Germany) by intravenous route. The anesthetic inhalational maintenance was carried out with isoflurane (IsoVet, BBraun Melsungen AG, Melsungen. Germany). As part of the preoperative protocol and during the anesthetic induction, cefazoline (at a dose of 22 mg/kg IV [Cefazolina Normon 1 g. Laboratorios Normon, Tres Cantos, Madrid. Spain]) was administered by intravenously.

2.2. Surgical Technique

The patients were shaved throughout their dorsal lumbosacral and gluteal region, extending below the stifle joints. They were positioned in sternal recumbency on the surgical table with the hind limbs abducted and with abdominal support to keep the pelvis as horizontal as possible on the surgical table. In the cases where internal osteosynthesis was performed, the external stabilization was performed after the internal procedure. For cases involving only external stabilization was used, a fluoroscopy-guided reduction in the fracture was attempted by manipulating the pelvis and the ipsilateral limb if it was not luxated. In some cases, especially in heavier patients or older fractures, this procedure was challenging, and the reduction achieved was not accurate, which represents a limit inherent to closed reduction procedures.

Safe corridors for pin placement were identified for the placement of the pins. Threaded self-tapping pins (Screwpin—Ad Maiora—Cavriago, Italy) were inserted using a pre-drilling technique at 300–500 rpm. The technique for pin insertion in the ilial wing was as follows. The ilial wing is easily palpated on the lateral aspect of the lumbo-sacral area. A stab wound was made at performed on the cranial part of its craniocaudal length, and the bone is contacted with a sleeve inserted through it to avoid wrapping soft tissues around the drill bit and the pin's threads. Depending on the patient's size and weight, a pin of an appropriate diameter was inserted at an angle of 10–15° from proximo-lateral to disto-medial with respect to the vertical plane. The corridor for pin insertion in the body of the ilium was located in its caudal aspect and along the origin of the deep gluteus muscle. The pin was inserted at an angle of 45–90° with respect to the horizontal plane. The third corridor was located on the ischiatic tuberosity. A stab incision is made over the palpable area of the ischiatic tuberosity, and the pin was inserted at an angle of 10–15° from the vertical plane in a proximo-lateral to medio-distal direction. After the first two pins were inserted, fragment distraction was performed whenever possible, achieving the best possible reduction in the fragments through a closed approach by manipulating the pins in a joystick way with fluoroscopic assistance. In other cases, the fracture reduction was achieved through minimally invasive approaches. Sometimes, a smooth small-diameter K-wire was used for temporary stabilization of the fracture fragments to facilitate the insertion of threaded pins, which could either be removed or left for ancillary stabilization. When internal fixation was performed, the external fixator is always implanted after the internal osteosynthesis. Finally, the pins were connected using the clamps and connecting bars selected for each patient. Cefazoline (at a dose of 22 mg/kg) was administered by intravenously and repeated every 2 h during the entire procedure.

2.3. Postoperative Care

The duration of hospitalization time varied depending on the specific needs of each patient, which included the administration of fluids, antibiotics, anti-inflammatories, and analgesics. All owners were informed of the rationale of the treatment performed, explaining pros, cons, and information on PO care instructions.

Frequent dressings of the pin entry points and strict rest and confinement were recommended for the first few weeks of the postoperative period. Most owners were able to perform daily fixator care correctly at home. Subsequently, and until the removal of the fixator, owners were advised to engage in leash walks and controlled activity. The patient's comfort during the time the fixator was in place was evaluated by the surgeon in charge weekly using a visual assessment scale (VAS). This scale ranged from 1 to 10, where a score of 1 indicated very poor comfort and 10 indicated excellent comfort for the patient.

2.4. Follow-Up

During the PO period, clinical and radiological examinations were performed at the attending surgeon's judgment and based on the clinical progression of each case. Usually, the X-ray rechecks were scheduled at 3, 6, and 12 weeks after surgery, although this protocol was adjusted as needed based on individual patients. Differently from the usual radiographic standard, the sagittal projection was dorso-ventral because the patients cannot be placed in dorsal recumbency due to the presence of the fixator. In some cases, lateral oblique projections were used when overlapping existed. Concurrently, an overall evaluation of the fixator's condition and PO care were carried out. Once bone healing had progressed sufficiently, the external fixator (EF) was removed under sedation.

The outcome of the treatment was assessed based on the fracture healing, with an outcome scale that considered the final functional result and residual pain. The grading scale used was as follows.

1. Excellent: No walking difficulties nor apparent pain.
2. Good: Good functional result with residual lameness or mild signs of pain.
3. Fair: Obvious and constant but not disabling lameness or signs of mild to moderate pain.
4. Poor: Severe lameness or constant pain.

Complications related to the original trauma, for example of neurological origin, were included in this assessment, but not considered as complications related to the treatment.

3. Results

The stabilization of pelvic fractures was performed in thirty-two dogs. The mean age was 5.13 ± 4.27 years (median = 8.5 years; range = 0.15–14 years) and the mean weight was 14 ± 10.96 kg (median = 8.65 kg; range = 3–45 kg).

A total of 86 fractures were recorded in the 32 dogs of this study, and they were located as follows.

Ilium (*n* = 12; 14% [bilateral ilium: *n* = 4; 4%]); acetabulum (*n* = 10; 11% [bilateral acetabulum: *n* = 4; 4%]); pubis (*n* = 18; 21%); ischium (*n* = 20; 23%); sacroiliac dislocation (*n* = 26; 30% [bilateral sacroiliac dislocation: *n* = 16; 18%]). Car accidents (*n* = 25; 78%) were the most common cause, followed by falls or trauma of various origins (*n* = 6; 18%). In one case (3%), the cause was not determined. In this review, isolated ischial and pubic fractures were treated conservatively. Table 1 summarizes, in absolute numbers and percentages, the types of pelvic fractures treated and the EF configurations used in each case.

Table 1. Table showing, in absolute numbers and percentages, the type of pelvic fractures treated, and the external fixation configuration used. For ischiatic and pubic fractures the configuration used depended on another coexistent pelvic fracture. Isolated ischiatic and pubic fractures were treated conservatively.

	Ilium	Bilateral Ilium	Acetabulum	Bilateral Acetabulum	Sacroiliac Dislocation	Bilateral Sacroiliac Dislocation
Type O (*n* = 13)	2 (25%)	4 (100%)	2 (33%)	4 (100%)	3 (30%)	10 (62%)
Type C (*n* = 7)	2 (25%)	0 (0%)	1 (16%)	0 (0%)	4 (40%)	0 (0%)
Type T (*n* = 6)	2 (25%)	0 (0%)	0 (0%)	0 (0%)	1 (10%)	4 (25%)
Type X (*n* = 4)	1 (12%)	0 (0%)	3 (50%)	0 (0%)	0 (0%)	2 (12%)
Type L (*n* = 2)	1 (12%)	0 (0%)	0 (0%)	0 (0%)	2 (20%)	0 (0%)
TOTAL FRACTURES	8	4	6	4	10	16

In 21 (65%) cases, a total of 27 lesions located in other sites of their skeletal system were found. The injuries associated with pelvic fractures were sacral fractures (*n* = 14; 51%); coxofemoral dislocation (*n* = 4; 14%), femur fractures (*n* = 3; 11%), tibia fractures (*n* = 2; 7%), fracture of the proximal femoral physis (*n* = 3; 11% [bilateral: *n* = 1–3%]); and fracture of the vertebral body of the 5th lumbar vertebra (*n* = 1; 3%).

In the stabilization of pelvic fractures, an EF system was used as the sole stabilization technique in 23 patients (71%). In 20 (87%) out of the 23, the mean fixator time was 9.88 ± 4.15 weeks (median = 8 weeks; range = 1.3–20 weeks). In the remaining three cases (13%), the fixator removal was performed by the referring veterinarian, and the time could not be determined exactly. A combination of external and internal osteosynthesis was used in nine cases (28%). The external fixator was used as a secondary stabilization together with plating in five (55%) fractures of the ilium and four (44%) of the acetabulum. In these patients, the mean fixator time was 8.28 ± 5.82 weeks (median = 8 weeks; range = 2–20 weeks). In one case, the time could not be determined exactly because the procedure was performed by the referring veterinarian.

In most cases, the reduction with closed pinning was performed with a fluoroscopy-assisted technique, while internal fixation required open access.

The total number of each type of EF used in this work is as follows: 13 type O (Figures 4–7), 7 type C (Figure 8), 6 type T, 4 type X (Figure 9) and 2 type L.

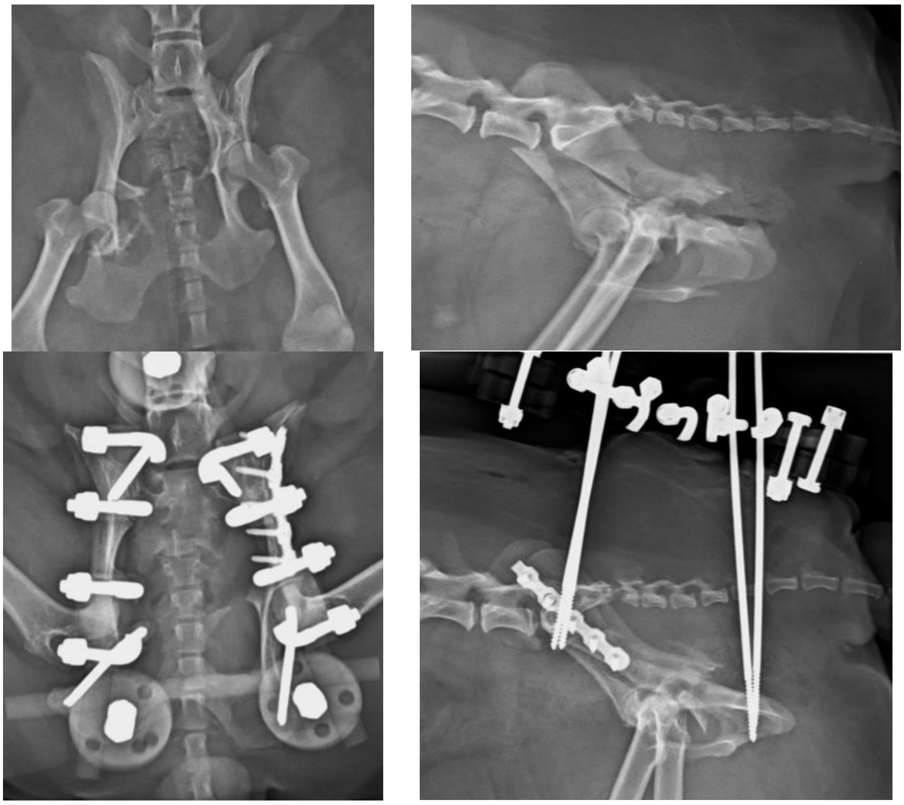

Figure 4. (**Top left**): Ventrodorsal (VD) projection of a patient with a fracture of the left ilium and a conminuted fracture of the contralateral acetabulum. (**Top right**): lateral projection of the same patient. (**Bottom left**): The fractures were reduced and stabilized by a type O radiolucent EF system. Note the plate used for the fracture of the ilium. (**Bottom right**): lateral projection of the same patient.

Figure 5. External appearance of the EF system used in the patient of Figure 4. A Polilock system composed of plastic and carbon fiber material was used.

Figure 6. (**Top left**): VD projection of a patient with left acetabulum, ischial and pubic fractures. Note the fracture of the left articular process of the sacrum. (**Top right**): Lateral projection of the same patient. (**Bottom left**): The fractures were stabilized by a type O radiolucent EF. The radiolucent components of the EF provide a better visualization of the bone. (**Bottom right**): PO lateral projection of the patient.

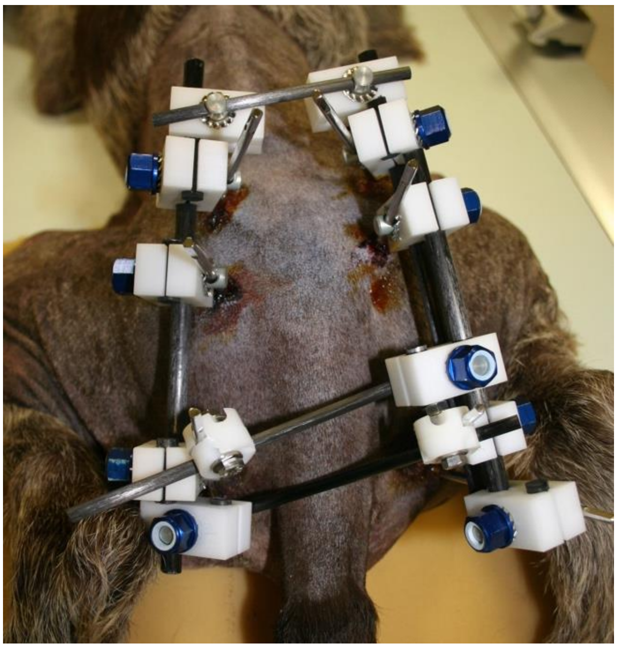

Figure 7. Picture of the type O EF used in the patient of Figure 6. Note the double connection bar between pins located in both ilial wings and ischia.

Figure 8. (**Top left**): VD view of a patient with fracture of the right ilium and of the right sacral articular process, and a left sacroiliac luxation. (**Top right**): Lateral projection of the same patient. (**Bottom left**): A combination of a type C EF and a plate have been used to stabilize the fractures. Note the lag screw for the left sacroiliac luxation. (**Bottom right**): Lateral projection of the same patient.

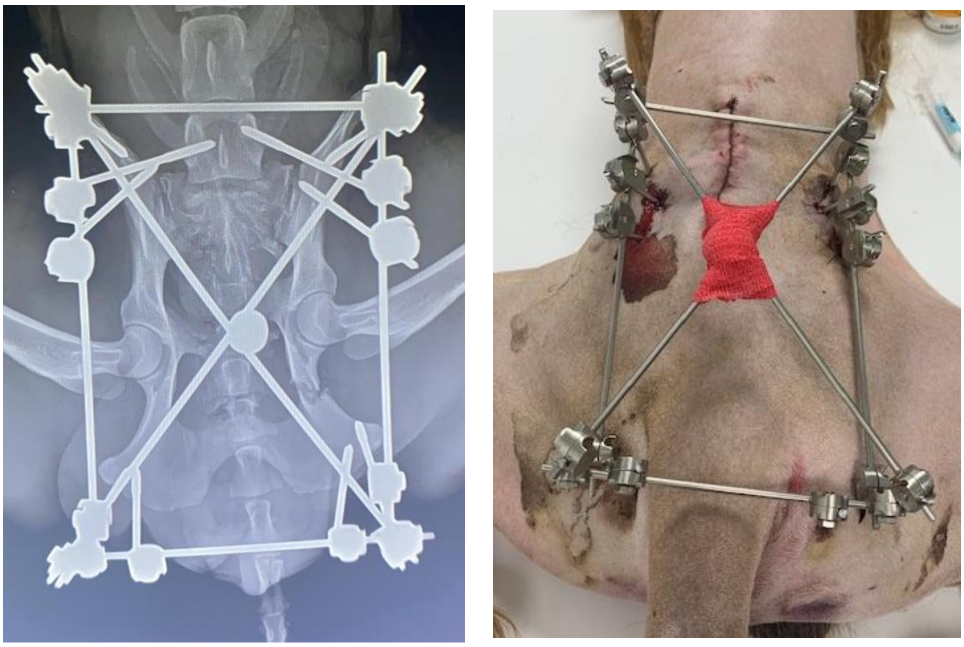

Figure 9. (**Left**): Radiograph of a patient treated with a type X EF. Note the fracture located on the ischial branch of both hemipelves and the pins inserted into the 7th lumbar vertebra to stabilize an additional fracture of the right sacral articular process. (**Right**): Picture of the external appearance of the EF.

Twelve fractures of the ilium were registered in 10 patients (31%). Four (40%) of these patients were treated exclusively with EF, and the healing period was 7.66 ± 0.57 weeks (median = 8 weeks; range = 1.3–8 weeks). In six (60%) patients, EF and plate were combined. In two of them, the time of bone consolidation could not be determined, because the removal of the implants was performed by the referring veterinarian. In the remaining four cases, the mean fixator time was 8 ± 3.65 weeks (median = 11.65 weeks; range = 4–12 weeks). The most common configuration in the 10 patients with iliac fractures was type O (*n* = 4), followed by type C and T (*n* = 2 each), and type X and L (one each).

The patient comfort graded by VAS was 8.75 ± 1.28 (median = 9; range = 7–10) in the 8 patients with unilateral fractures. In the bilateral cases, the comfort VAS was 10 in both with a type O configuration.

The outcome graded by VAS in the patients with unilateral fractures was excellent in five cases (62%), good in two (25%), and fair in one. Only mild neuropraxia of the pudendal nerve was detected in one case, and it resolved after the removal of the implant. Infection of the pin tracts was present in one case, and in another case the EF frame was too heavy and required changes to debulk it. The rest of the patients did not experience major complications due to the fixator. The outcome of the two dogs with bilateral iliac fracture was graded as excellent for both.

Eight patients (25%) with acetabular fractures were treated, and two of them were bilateral. Of the 10 acetabular fractures, 7 were treated exclusively with EF, and the healing period was 9.6 ± 5.44 weeks (median = 8 weeks; range = 5–20 weeks). Non-reducible acetabular fractures were treated with EF alone. The rationale of this choice was that if the procedure carried a too high risk of being unsuccessful, leaving implants that were not effective enough due to the fragmentation, it would not be helpful for the patient and could have prevented a hip prosthesis in a later phase. The types of configurations used in the resolution of unilateral acetabular fractures were O and X (*n* = 2 each). The other two patients (*n* = 2) were treated by combining the plate with EF, with a mean fixator time of 6.66 ± 2.30 weeks (median = 8 weeks; range = 4–8 weeks). In these cases, the types C and X (*n* = 1 each) were used. In the two cases with bilateral fractures, the O type was used, combining EF and plate in one of them. In our comfort VAS assessment, unilateral fracture patients were graded 9.33 ± 1.21 (median = 10; range = 7–10). In the two cases with bilateral fracture, the comfort VAS was graded 8 and 10. In one of these cases, femoral head and neck ostectomy had to be performed four months after fracture osteosynthesis due to femoral head necrosis. Histopathological analysis was not performed but a vascular damage due to the contusion was considered to be the most likely cause. The outcome was excellent for five (83%) patients with unilateral fracture. One of the six cases was valued as good because developed an L7-S1 discospondylitis. Bilateral fracture cases were graded as excellent and good. The latter one suffered a femoral and tibial fracture that required a long recovery time.

Ten cases (31%) of unilateral and eight (25%) of bilateral sacroiliac luxation were operated on. All bilateral injuries were stabilized with a sacroiliac screw and anti-rotational pin in addition to external fixation. The insertion of the anti-rotational pin was achieved once the dislocation was previously reduced and stabilized by the lag screw. The frame configurations were type O in five (62%), type T in two (25%), and type X in one. The mean fixator time was 8.5 ± 2.66 weeks (median = 8.5 weeks; range = 4–12 weeks). The stabilization for the 10 unilateral luxation was performed with EF in three cases with types C, L and T. Of the remaining cases, two were stabilized with crossed wires inserted between the iliac wings with type C external fixation. In the remaining five cases, the luxation was fixed using a screw and an anti-rotational K wire, with type O EF in three, type L and type C in one each. In patients with sacroiliac dislocation, type O was used in eight cases (44%), type C in four (22%), type T in three (16%), type L in two (11%), and type X in one. The overall mean fixator time was 8.37 ± 4.95 weeks (median = 8 weeks; range = 4–20 weeks). VAS for unilateral luxation was graded 9.6 ± 0.96 (median = 10; range = 7–10). In these cases, the outcome was excellent for eight patients (80%), good for one and fair for one. VAS for the eight patients with bilateral sacroiliac luxation was graded 9.6 ± 0.74 (median = 10; range = 8–10). The outcome was graded as excellent for six (75%), good and fair one case each. The overall result of comfort VAS for the 32 patients of this study was 9.46. Twenty-six (81%) patients had an excellent outcome, six (15%) were graded good and one fair.

The complications related to EF exclusively were as follows: loosening of the pins (n = 3–8%), occasional bleeding (n = 2–5%), and mild local infection processes at the pin insertion points (n = 15–39%). One patient suffered neuropraxia of the pudendal nerves due to the position of the fixator's pins. The rest of the neurological damages were pre-existing to the treatment and caused by the original trauma. Isolated ischiatic and pubic fractures were treated conservatively.

4. Discussion

There are few studies in the literature addressing EF applied to pelvic fractures in small animals [5], in opposition to human medicine, where its use is common in unstable pelvic fractures, especially in the early stages of treatment [13,14], due to its known biomechanical properties and its peculiar characteristics [15–19]. The modularity of the system and its simple application, either as a temporary or definitive method for fracture resolution, provides speed as a surgical technique, i.e., offering notable advantages in critical patients [20]. These fixators can be radiolucent, thus greatly facilitating the evaluation of healing [21]. Radiographic rechecks are easier, avoiding the need for oblique projections as usual with standard metallic EF frames (Figures 4 and 5). In addition, in patients treated with fluoroscopic-assisted techniques, the interference during the procedure is considerably reduced, allowing reduction maneuvers to be performed much more easily. However, a clear downside of the use of fluoroscopy is the radiation exposure, which may be considerable in long surgical procedures. Nevertheless, in our opinion, a highly experienced surgeon can reduce considerably the amount of radiation needed.

Another advantage for their use as a secondary technique, together with internal osteosynthesis as the primary technique [22–25], is represented by the added rigidity for the stabilization of unstable fractures [1–6,25–27]. This is mainly due to their lever arm, which can be comparable to the entire length of the pelvis, while the plate has usually a much shorter lever arm than the pelvis.

There is limited information available on the stiffness of the external fixation in comparison to internal in iliac fractures. Only one study concluded that the stiffness of both systems was similar, attributing notable biomechanical advantages to the external system due to its greater lever arm [5].

The outcome of unilateral ilium fractures was graded as excellent and good in 87% of the patients according to our assessment scale. The comfort VAS was 8.75 out of 10 for these eight cases, suggesting that EF was well tolerated by the patients. In most cases, the fixator time was almost the same of bone healing time. EF was used as the only stabilization technique in one of the two patients with bilateral fractures. In these two patients, the comfort VAS was graded 10 and the outcome was excellent for both. However, the progression of osteoarthritis is to be taken into account in the mid-long term when the fracture reduction is not anatomical, as is the case for most cases of EF. This can happen, though, also when anatomical reduction is not achieved by plating, and should be considered when planning an aggressive approach.

Most veterinary literature for the treatment of acetabular fractures in dogs reports the use of plates for stabilization [28,29]. Only Graville et al. (2018) described the use of EF for the stabilization of this type of fracture [11], suggesting that it was a viable option for the treatment of acetabulum fractures despite some limitations, such as challenging the reduction in the fracture site or pin loosening in some cases [5]. In our experience, the outcomes were good, with 67% of acetabular fractures having been treated exclusively with EF, achieving an acceptable time for bone consolidation. Seventy-five percent of the patients have graded a mean of 9.25 with comfort VAS. These results were considered satisfactory due to the specific features of the treated fractures and the reported critical management of acetabular fractures and their complications [28,30].

Among the registered complications, one dog underwent ostectomy of the femoral head and neck after undergoing fracture treatment with a plate and EF due to necrosis. Another patient developed an L7-S1 discospondylitis of unknown origin. The other complications registered were minor and had no significant impact on the expected outcome. The patients recovered a full clinical function of their affected pelvic limbs. Since it is not always possible to achieve an anatomical reduction with EF, and even though short-term functional recovery was excellent in most patients, osteoarthritis might develop in cases of non-anatomical reduction, particularly in patients with acetabular fragmentation. In those cases, though, the success of internal osteosynthesis was very debatable. The most used type of EF was O (62%), with pins inserted in both iliac wings and ischia.

In the present study, 26 sacroiliac luxations in 18 dogs were treated. The standard technique with screw and anti-rotational K wire to stabilize the sacroiliac joint [31–34] was applied in most cases. Only three fractures were exclusively treated with EF (11%), and they were unilateral. In the remaining 23 cases (88%), EF was employed as an additional technique to protect the internal osteosynthesis. In unilateral fractures, the support of the dislocated hemipelvis was provided by the external fixator anchored to the healthy hemipelvis. Type O was used in nine (50%) of the 18 patients, providing the necessary stability for an unstable type of injury, as reported in several studies [1–3]. The comfort VAS for all patients with sacroiliac luxation was graded 9.6, confirming the good acceptance of EF. Outcome was excellent for 14 (77%) out of 18 patients, which was considered satisfactory with a low rate of complications. Three patients with good outcome suffered mild miction and defecations disfunctions, which resolved after EF removal. Only in one patient was the outcome considered fair, primarily due to a multitude of complications related to other traumatic lesions. This large breed puppy suffered a vertebral L5 fracture with severe neurological deficit, in addition to a bilateral femoral capital physeal fracture, and for this reason it was not considered a primary complication of the EF application.

As previously mentioned, the fractures of the ischium and pubis were treated conservatively, avoiding the insertion of pins in the ischial tuberosities that were fractured.

One of the limits of the present study is its retrospective nature, because the philosophy and technical aspects of treatment changed over the course of this study, resulting in inconsistent treatment for all cases.

Another limitation is the difficult clinical assessment due to the pain and residual lameness encountered as part of the evaluation. We consider unavoidable to evaluate results under these conditions although a critical and objective analysis was performed at every moment. Additionally, making direct comparisons due to the highly varied conditions of patients at presentation may be challenging. This aspect, of course, was determined by the complexity of the fractures, and it is inherent to pelvic fractures, but also related to the concomitant injuries that are very common in dogs with severe trauma. For this reason, it is difficult to correctly evaluate the biomechanical behavior of coupling internal and external osteosynthesis techniques. A long-term analysis and biomechanical testing would be advisable for such evaluations.

5. Conclusions

In the study of 32 dogs presented here, EF has proven to be a viable option for the stabilization of pelvic fractures. The technique is safe provided that safe pin insertion corridors are followed, allowing fracture stabilization with minimal disturbance to the biological response. This characteristic minimizes the risks of iatrogenic damage [35,36] and infection while accelerating healing times [4,10,11]. In our experience, the outcome has been favorable when EF is used as a complementary fixation method, contributing to the holding power of internal osteosynthesis. When applied as the sole stabilization technique, EF has shown great efficacy in treating fractures of the ilium. EF alone was considered insufficient for the treatment of sacroiliac dislocations, due to the inherent instability of this type of injury [1–3], and internal fixation was considered necessary in most cases. Nonetheless, further biomechanical studies are required to provide a more comprehensive understanding of the stiffness and stability of various EF configurations in response to loads or specific applications. The evaluation of patient comfort with EF systems has shown a high level of acceptance among the dogs included in this study.

In conclusion, the proposed classification provides a useful method for better understanding the structure of the frames applied to pelvic fractures and facilitates the sharing information. However, and in the absence of a similar classification published in the bibliography, modifications or adjustments may be necessary in the future. So far, this classification has proven to be able to clearly describe the pelvic EF frames used in this study.

Overall, due to the ease of application of EF as a stabilization technique, the limited complications encountered, and the good tolerance of the system by the patients, EF should be considered among the techniques that can be used, whether as a primary or secondary approach, for stabilization of pelvic fractures in the dog.

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6.2. Aplicación de los fijadores externos en pelvis para el tratamiento de las fracturas de sacro en perros

Tipo: Artículo científico

Estado: Publicado

Resumen: Este estudio tuvo como objetivo evaluar la viabilidad, complicaciones y resultados de la fijación externa (FE) para el tratamiento de fracturas sacras en perros, ya sea como un sistema de fijación primario o como técnica complementaria. Un total de 15 perros con fracturas sacras fueron tratados quirúrgicamente utilizando diferentes configuraciones de FE, ya sea como estabilización primaria o secundaria. Se evaluaron los resultados en términos de reducción de la fractura, estabilidad durante el tratamiento, complicaciones y cicatrización ósea. En la mayoría de los casos, los resultados fueron excelentes en cuanto a la cicatrización ósea, las condiciones neurológicas y la evaluación del dolor. El tiempo promedio de cicatrización ósea fue de 9.45 ± 5.66 semanas. Un paciente (6.66%) presentó una complicación relacionada con la técnica. En conclusión, se debe considerar el uso de FE para la estabilización de fracturas sacras debido a su mínima invasividad, estabilidad y facilidad de aplicación.

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External Fixation for Fracture Stabilization of the Sacrum in 15 Dogs

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This study aimed to evaluate the feasibility, complications, and outcomes of external fixation (EF) for the treatment of sacral fractures in dogs, either as a primary fixation system or as a complementary technique. A total of 15 dogs with sacral fractures were surgically treated using different EF configurations, either as primary or secondary stabilization. The results were evaluated for the extent of fracture reduction, stability during treatment, complications, and bone healing. In most cases, the outcomes were excellent in terms of bone healing, neurological conditions, and pain assessment. The mean bone healing time was 9.45 ± 5.66 weeks. One (6.66%) patient presented a complication due to the technique. In conclusion, the use of EF should be considered for the stabilization of sacral fractures because of its minimal invasiveness, stability, and ease of application.

KEYWORDS
dog, external fixation, sacrum, fractures, stabilization

1. Introduction

Sacral fractures in dogs are commonly caused by vehicular trauma (1–7). The sacrum houses nerve roots that play a role in the pelvic, pudendal, and perineal nerves, in addition to the most tail-end segments of the sciatic nerve. The nerves extending to the tail's base are a further extension of the cauda equina (2). These fractures can lead to pain and varying degrees of neurological impingement, which may compromise urination and defecation (1–9). Moreover, they can result in an inability to support one or both pelvic limbs (8). Various types of sacral fractures have been described in the literature for both canine and feline species. These fractures are classified based on two different systems: one based on the longitudinal axis of the sacrum, with the foramina serving as the boundary between axial and abaxial fractures (1), and the other based on the type and location of fracture lines within the sacrum, resulting in five distinct types (2). Surgical intervention is the preferred approach for treating these fractures, particularly when they coincide with other pelvic fractures or cause severe pain (5, 6, 8, 9). Conservative treatment is considered for patients exhibiting mild neurological dysfunction and minor displacement at the fracture site (3, 7, 8).

While plates, screws, and pins in combination with polymethyl methacrylate (PMM) are commonly employed for the surgical treatment of spinal fractures (3, 10–15), the utilization of external fixation (EF) for sacral fractures is comparatively less frequent (7) than techniques such as compression screws (16), locking osteosynthesis plates (3, 8), transiliac wires (4), or pins for lumbosacral transarticular fixation (5). The EF system, initially described for vertebral fractures (17, 18), offers several advantages in terms of safety, simplicity, patient tolerance, and final outcomes (19).

The primary objective of surgical stabilization is to prevent movement at the fracture site, which can impede healing and lead to pain (18, 20). This retrospective study aimed to test the hypothesis that EF provides reliability for the surgical treatment of fractures of the sacrum, as well as to assess the surgical technique, complications, and outcomes of applying EF for the stabilization of sacral fractures in 15 client-owned dogs.

2. Methods

This retrospective study included 15 canine patients. The inclusion criteria consisted of dogs with a diagnosis of sacral fractures treated with external skeletal fixation (ESF). Medical records from Clinica Veterinaria M. E. Miller (Italy) and Hospital Veterinario IVC Evidensia Prïvet (Spain) between 2006 and 2021 were evaluated and included age, weight, etiology, sacral fracture type, presence of additional fractures, surgical treatment, complications, healing time, and clinical and radiographic outcomes. Radiographic controls were conducted by a veterinarian or a radiology technician and scheduled at 3, 6, and 12 weeks post-surgery to validate fracture alignment and the stability of the external fixator during the postoperative time. Additional assessments were conducted as deemed necessary by the surgeon in charge. The fractures were described based on the proposed classification by Anderson et al. (2) (Figure 1):

I. Alar: oblique fracture line on the ventrodorsal radiograph, originating at or immediately adjacent to the juxta-articular notch and terminating at the articular surface of the sacral wing.

II. Foraminal: longitudinal or oblique fracture line on the ventrodorsal radiograph through the first or first and second sacral foramina.

III. Transverse: transverse fracture.

IV. Avulsion: avulsion fracture of the origin of the sacrotuberous ligament.

V. Comminuted: comminuted fracture.

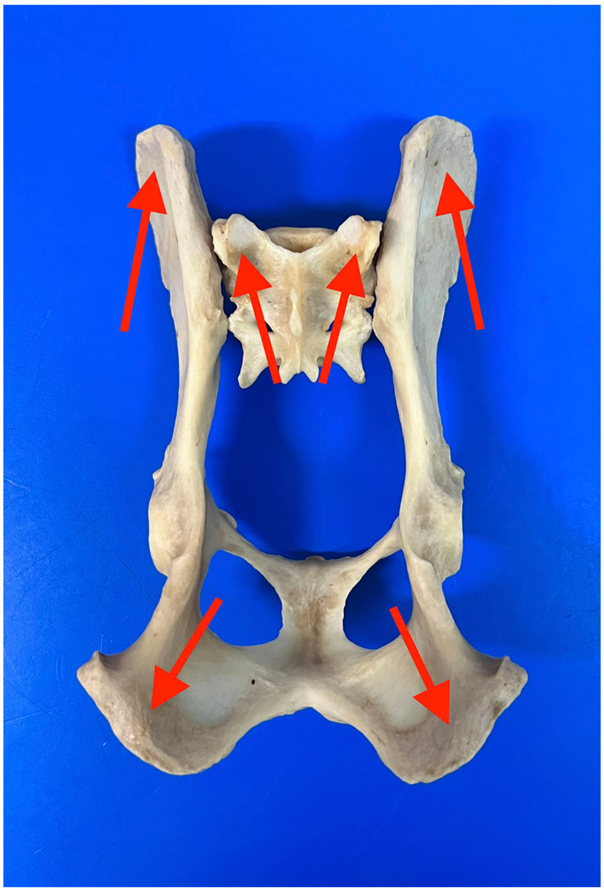

FIGURE 2
Image showing the locations of the areas for the placement of the pins. Blue arrows: iliac wing; red arrows: ischiatic tuberosity; green arrows: sacral wing.

2.1. Preoperative management

Preoperative radiographs were taken in latero-lateral and ventro-dorsal projections in sedated patients. The anesthetic protocols were based on medetomidine (100 µg/kg IM; Medetor 1 mg/ml, Virbac, Spain) and midazolam (0.1 mg/kg IM; Midazolam Normon, Laboratorios Normon SA, Spain). For pain management, methadone (0.4 mg/kg IM, Semfortan, Eurovet Animal Health, The Netherlands) was used.

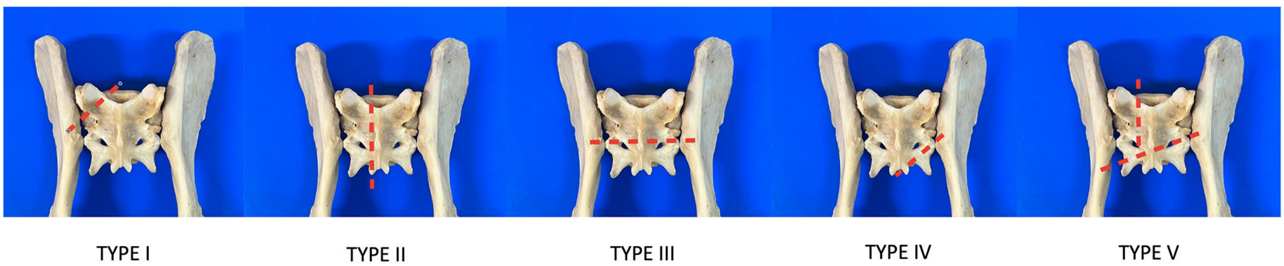

FIGURE 1
Drawings showing the sacral fractures following the classification described by Anderson et al. (2).

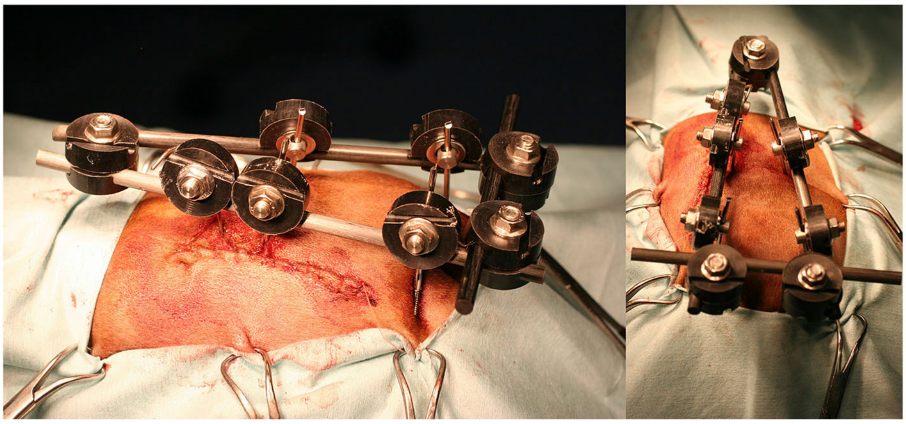

FIGURE 3
Lateral **(left)** and dorsal **(right)** clinical images of a radiolucent fixator with type O configuration.

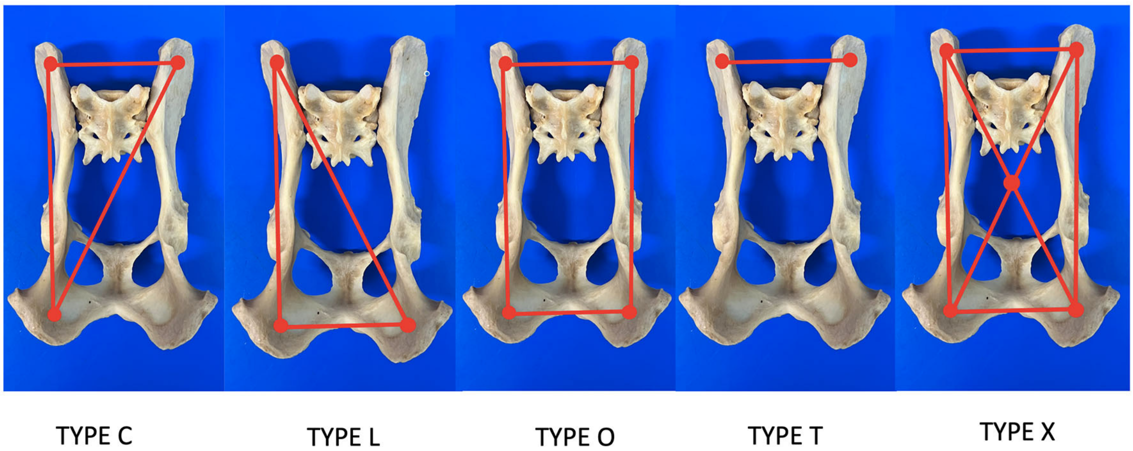

FIGURE 4
Drawings of the EF configurations used for the stabilization of fractures of the sacrum.

2.2. Surgical technique

The canine patients were induced with propofol (2 mg/kg IV, Propofol Lipuro 10 mg/ml; B. Braun Melsungen AG, Germany) and maintained with isofluorane (Isoflo; Ecuphar, Spain) in oxygen. The patients were shaved and disinfected from the proximal area of the tibiae of both pelvic limbs. The position of choice was sternal recumbency with the hind limbs flexed cranially and positioned close to the abdomen ("kneeling dog" position), facilitating lumbosacral joint flexion and fracture reduction. In those with a combination of osteosynthesis plate and ESF, a lateral recumbency was used first, and a sternal recumbency for ESF was adopted later. The surgical technique included two modes of fixation, depending on the patient and fracture characteristics. In general, patients with slight displacement or comminuted fractures were stabilized by EF alone, while those with displaced fractures were stabilized by internal osteosynthesis combined with EF.

The previous approach solely involved external, close stabilization, whereas the latter entailed internal fixation followed by external stabilization. This approach occasionally improved the precision of fracture reduction achievable through the open approach. A stab incision as small as possible was performed, and a sleeve was used as a guide for predrilling and pin insertion. EF frames used 1–3-mm-diameter self-tapping threaded pins, according to the size and weight of the patient, inserted at 300–500 rpm.

The fracture was reduced using a fluoroscopy-assisted technique, previously locating safe corridors for good placement of the pins (Figure 2). Corridor 1 was located in the sacral tuberosity of the ilium, close to the origin of the gluteus medius. The skin was incised by a stab wound, and the bone is located underlying the fascia. Once the thick dorsal border of the iliac wing was identified, a sleeve was inserted into the wound, the predrilling was performed using an appropriate drill bit, and the pins were inserted through the same sleeve to prevent soft tissue wrapping, at an angle of

TABLE 1 Neurofunctional assessment results regarding the functional and basic neurological status of each patient at presentation, as well as the type of fracture registered in each case.

Patient no.	Fracture type	Preoperative ability to stand 0 = no 1 = one limb 2 = two limbs	Preoperative ability to walk 0 = no 1 = with help 2 = yes	Preoperative ability to urinate spontaneously 0 = no 1 = occasionally 2 = yes	Preoperative pain 0 = severe 1 = moderate 2 = no	Preoperative perception of deep pain pelvic limbs on neurological exam 0 = no 1 = doubtful 2 = yes	Average
1	I	1	1	1	0	2	1
2	I	0	0	0	0	2	0.4
3	III	0	0	0	0	0	0
4	I	0	0	0	0	1	0.2
5	I	1	0	2	0	2	1
6	I	1	0	0	0	1	0.4
7	III	1	1	0	0	1	0.6
8	I	1	1	1	0	2	1
9	I	0	0	0	0	0	0
10	III	1	1	1	0	2	1
11	I	2	1	1	0	2	1.2
12	V	0	1	1	0	1	0.6
13	III	1	0	0	0	2	0.6
14	IV	1	1	1	0	2	1
15	I	0	0	1	1	2	0.8
AVERAGE	0.66	0.46	0.6	0.06	1.46		

TABLE 2 Neurofunctional assessment score according to the type of fracture at presentation.

Fracture type	No. of patients	Neurofunctional assessment score
I	9 (60%)	0.66
III	4 (26.66%)	0.55
IV	1 (6.66%)	1
V	1 (6.66%)	0.66

TABLE 3 Summary of total fractures classified according to type and surgical technique performed in each case.

Fracture type	No. of patients	ESF exclusively	ESF and internal osteosynthesis
I	9 (60%)	8 (88.88%)	1 (11.12%)
III	4 (26.66%)	3 (75%)	1 (25%)
IV	1 (6.66%)	1 (100%)	-
V	1 (6.66%)	1 (100%)	-

10–15 degrees to the vertical, running from proximo-medial to disto-lateral through the same sleeve to avoid soft tissue wrapping. Corridor 2 was located on the ischial tuberosity. A small stab incision was made over the palpable area of the ischial tuberosity. This area is generally located directly lateral to the root of the tail. The wound was enlarged by a small mosquito down to the bone. The technique for predrilling and pin insertion was the same as for iliac pins. The pins were inserted at an entry angle of 10–15° from proximo-lateral to disto-medial. Corridor 3 was located on the sacrum. The reference was located over the median sacrocaudal musculature and the underlying medial crest of the sacrum. A safe site for pin insertion was identified between the median and intermediate ridges, avoiding the dorsal sacral foramina and their paths to the medullary canal. Two other points of insertion were on the sacral wings, in a divergent direction toward the articular processes that articulate the sacrum with the seventh lumbar vertebra. The distraction of the fragments was performed whenever possible after the first pins were inserted, achieving a closed reduction of the fragments by manipulating these pins with a fluoroscopy-assisted technique. The connection of the pins to the connecting bar was performed using Meynard clamps (Insorvet, Barcelona, Spain) and Polilock radiolucent clamps (Ad Maiora, Cavriago, Italy) with 1.2–3-mm steel connecting rods for the Meynard clamps and 5-mm carbon rods for the Polilock clamps (Figure 3). The EF system design was based on individual fracture characteristics, obtaining various configurations based on the involvement of one or both hemipelvises and the type of interconnection between the pins. A review of the types of frame configurations used made it possible to define five types.

TABLE 4 Summary of the data regarding ESF configurations applied to each type of fracture and values of the assessment scale for each ESF type configuration.

ESF configuration type	ESF assessment scale	No. of patients	Sacral type fracture				
			I	II	III	IV	V
X	1.5 ± 1	4 (26.66%)	4 (100%)	–	–	–	–
T	1.25 ± 0.5	4 (26.66%)	2 (50%)	–	1 (25%)	–	1 (25%)
O	1.5 ± 0.57	4 (26.66%)	2 (50%)	–	1 (25%)	1 (25%)	–
C	1.66 ± 1.15	3 (20%)	1 (33.33%)	–	2 (66.67%)	–	–

This classification refers to the manner in which the pins of each hemipelvis are interconnected during the treatment of pelvic fractures with an external fixator (Figure 4). The configurations are the following:

- Type O: The bars interconnect the pins around the perimeter.
- Type X: The bars interconnect the pins on the perimeter with a cross-connection between the clamps located at the vertices of the quadrilateral.
- Type C: The bars connect the pins of one hemipelvis with a pin located on the contralateral ilium or articular sacral process.
- Type T: A single bar interconnects the pins located on both iliac crests and sacral wings.
- Type L: The bars connect the pins of one hemipelvis to the pin located on the contralateral ischial tuberosity.

2.3. Postoperative care

The hospitalization period depended on individual patient needs, including postoperative radiographs, fluid and antibiotic therapy, non-steroidal anti-inflammatory drugs, and analgesics. The care of the pin entry holes was performed by cleaning and dressing with antiseptic-impregnated sponges on a daily basis for the first few days and then as required. The care was the same as for standard external fixators, and the owner received instructions on how to perform it to avoid unnecessary patient movement. Strict rest and confinement were recommended during the first four postoperative weeks. Walking on a leash and activity control were recommended until the removal of the fixator. All patients were treated with meloxicam (0.1 mg/kg/24 h PO, Metacam, Boehringer Ingelheim, Germany) for 14 days and gabapentin (15 mg/kg/8 h, Kern Pharma, Spain) for 30 days.

2.4. Follow-up

Physical examinations were conducted weekly during the postoperative period, and radiographic bone consolidation of the fractures was assessed if this was the case. In the postoperative period, most controls were performed in lateral projection, and if sagittal projection was needed, ventral recumbency was mandatory due to the presence of the ESF frame.

A functional outcome scale and an EF stability and fracture site displacement scale were used for evaluation. Once radiographic bone consolidation of the fractures was achieved, the external fixator was removed under sedation. Usually, the x-ray controls were 3, 6, and 12 weeks after surgery, although this protocol was changed according to the specific evolution of each patient. The disappearance of the radiographic fracture line was considered complete bone healing, although in some specific cases, a CT scan was performed for better evaluation. Unfortunately, it was not always available, and some owners could not afford it. In those cases, only a radiographic assessment was performed.

A neurofunctional assessment scale regarding the condition of the basic neurological and orthopedic functions at presentation is included. In most of those patients, a standard neurological and orthopedic examination was not possible due to pain, inability to move or stand, and aggressive responses due to manipulations. For these reasons, a simplified evaluation scale was used, which is given as follows:

Ability to stand

- No = 0
- One limb = 1
- Two limbs = 2

Ability to walk

- No = 0
- With assistance = 1
- Yes = 2

Ability to urinate spontaneously

- No = 0
- Occasionally = 1
- Yes = 2

Presence of pain

- Severe = 0
- Moderate = 1
- No = 2

Deep pain in pelvic limbs

- No = 0
- Doubtful = 1
- Yes = 2

The same assessment scale was applied at the end of the treatment and when further rechecks were scheduled. The score at presentation and the one at outcome were compared.

A third assessment scale was added based on ESF stability and fracture site displacement. Each scale level was assigned a numerical value, which is given as follows:

- Excellent (5): Stable fixator frame with unaltered fracture reduction throughout the healing process.
- Very good (4): Minor signs of instability in the fixator frame or slight fracture displacement. Only minor adjustments to the frame were required without general anesthesia.
- Good (3): Moderate signs of instability in the fixator frame or moderate fracture displacement that did not require surgical revision but required adjustments of the frame under general anesthesia.
- Fair (2): Major instability in the fixator frame or major fracture displacement that requires surgical revision and major adjustments or changes in the fixator frame.
- Poor (1): Major changes in the fixator frame or major fracture displacement that required fixator removal.

3. Results

Fifteen dogs with sacral fractures were included in this study. Information related to the breed, age, weight of each patient, date, cause of the trauma, type of sacral fracture, presence of other concomitant fractures, description of the EF configuration used, complications registered, healing time, and final functional results were obtained.

The mean age of the patients included in the study was 4.44 ± 3.76 years (median, 3.5 years; range, 0.3–11 years), and the mean weight was 19.37 ± 12.76 kg (median, 12.5 kg; range, 3–45 kg). The identified causes of the fractures were as follows: run-over (n = 11, 73.33%), fall from a height (n = 1, 6.66%), and unknown causes (n = 3, 20.00%).

In 14 (93.33%) patients, fractures at other locations other than the sacrum were present. The data obtained from the 32 fractures in these 14 patients were as follows: ilium (n = 4, 12.5%); acetabulum (n = 3, 9.37%); pubis (n = 9, 28.12%); ischium (n = 9, 28.12%); unilateral sacroiliac dislocation (n = 6, 18.75%); and bilateral sacroiliac dislocation (n = 1, 3.12%). Extrapelvic lesions were found in one case (6.66%), with bilateral fractures of the femoral head physis, body of the fifth lumbar vertebra (L5), and spinous process of the sixth lumbar vertebra (L6).

According to the classification provided by Anderson et al. (2), the following types of sacral fractures were found: 9 (60%) type I, 4 (26.66%) type III, 1 (6.66%) type IV, and 1 (6.66%) type V.

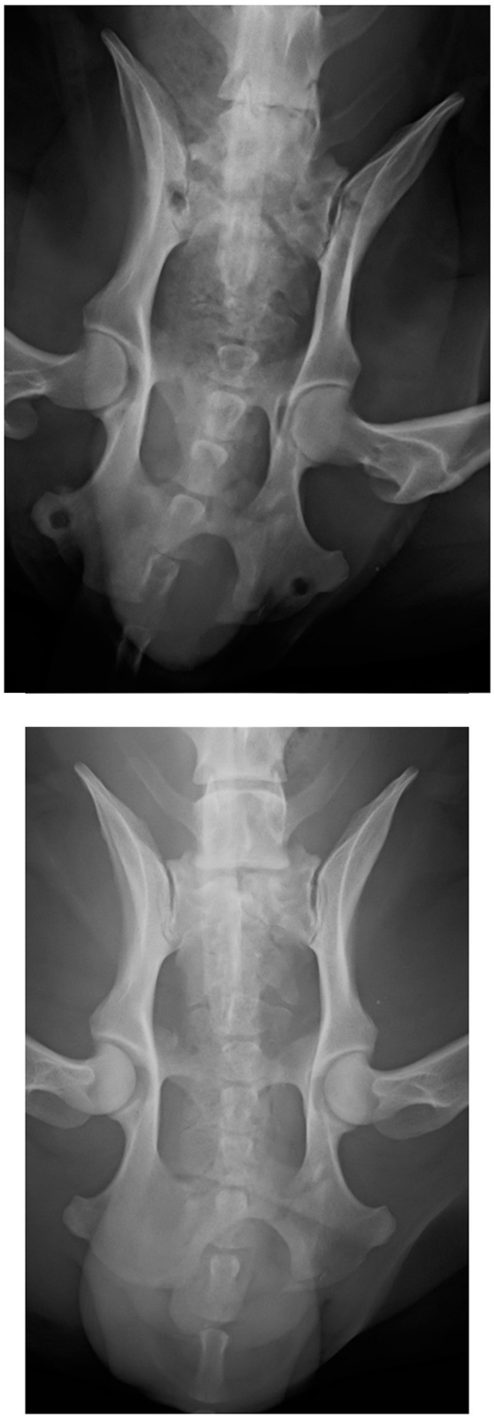

FIGURE 5
Dorsoventral projection of a type IV fracture at presentation **(top)**. Dorsoventral projection of the same patient 8 weeks postoperatively after ESF removal **(bottom)**.

According to the assessment scale regarding functional and basic neurological conditions at presentation, 14 (93.33%) patients were registered with an inability to walk with their pelvic limbs, and the set of all 15 canine patients in this study obtained an average score of 0.46 ± 0.51 regarding the ability to stand. Severe pain was

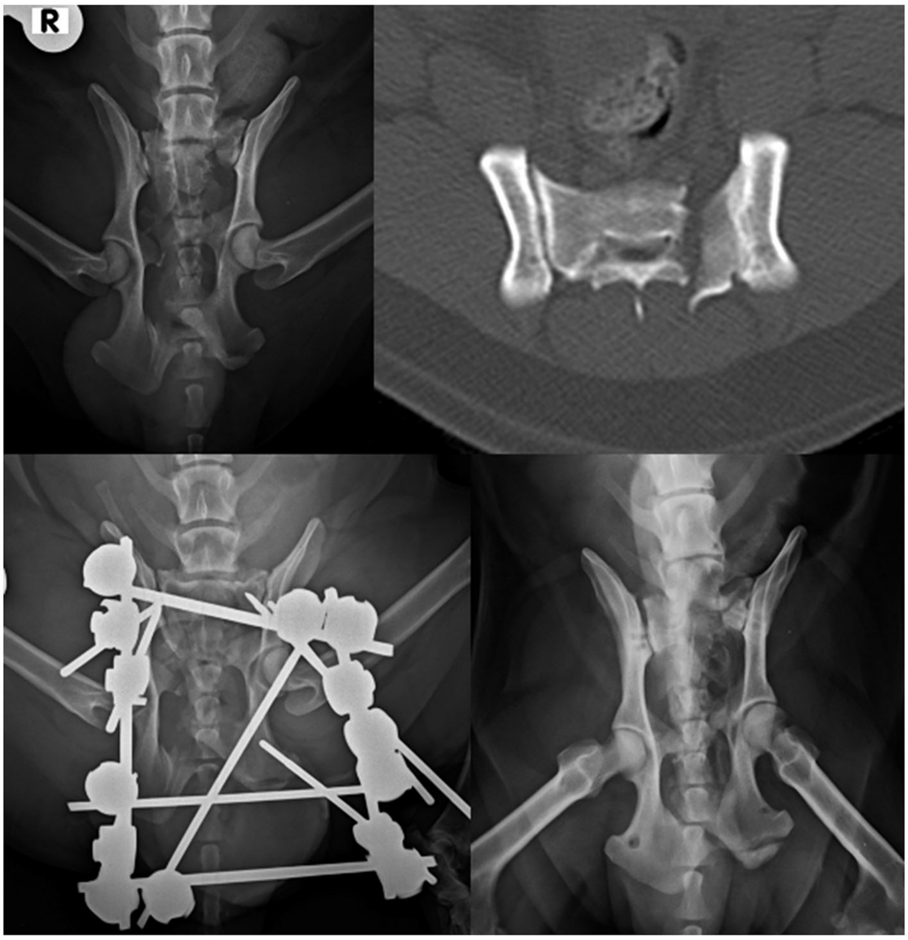

FIGURE 6
Dorsoventral projection of a type I fracture of the sacrum **(top left)**. CT scan of the fracture **(top right)**. Ventrodorsal projection of the same patient after surgery **(bottom left)**. Follow-up radiograph after ESF removal at 12 weeks **(bottom right)**.

FIGURE 7
Dorsoventral projections **(left and middle)** of Type III sacral fracture that was treated primarily with internal osteosynthesis by two plates and EF as ancillary stabilization. Note the radiolucent elements of the EF that allowed a better radiographic follow-up. This patient also suffered a left sacroiliac luxation and a fracture of the right ilium. Radiograph after 4 weeks of follow-up when ESF was removed **(right)**.

TABLE 5 Healing time in weeks related to the type of fracture.

Fracture type	No. of patients	Healing time (weeks)	
		ESF exclusively	ESF and internal osteosynthesis
I	8	10.5 ± 6.45	3 ± 1.41
III	2	6 ± 2.82	10.3 ± 5.39
IV	1	5	–
V	1	8	–

detected in 14 (93.33%) patients, and an average score of 0.06 ± 0.25 was recorded for this neurological assessment. As for the evaluation of deep pain sensitivity, its presence could not be detected in 2 (6.66%) dogs, and the 15 patients obtained an average score of 1.4 ± 0.38 in this aspect of the scale. The overall mean value for all patients regarding their functionality and neurological records was 0.65 ± 0.38 (median, 0.6; range, 0–1.2). The type of fracture was related to the functional condition, and the data are summarized in Table 1.

The functional condition of each patient was related to the type of fracture experienced. Patients suffering a type I fracture of the sacrum scored 0.66. Patients with type III scored 0.55, and types IV and V scored 1 and 0.66, respectively (Table 2).

Out of the 15 cases treated, EF was used as the sole fixation system in 13 (86.66%). In 2 (13.34%) patients, the EF applied to stabilize the sacrum was combined with two osteosynthesis plates. Of the 13 patients treated with EF exclusively, 8 (61.53%) suffered type I, 3 (20%) type III, 1 (7.69%) type IV, and 1 (7.69%) type V fracture. Of the two patients in whom EF was combined with an internal fixation system, one suffered type I and one type III fracture (Table 3).

Regarding the type of frame configuration of the EF, out of the 15 patients treated, 4 (26.66%) were treated with type X, 4 (26.66%) with type T, 4 (26.66%) with type O, and 3 (20.00%) with type C. When reviewing the type of configuration according to the type of fracture, nine type I fractures were treated as follows: four (44.44%) with type X, two (22.22%) with type O, two (22.22%) with type T, and one (11.11%) with type C. Out of the four cases registered with type III sacral fracture, one (25.00%) was treated with type O, one (25.00%) with type T, and two (50.00%) with type C. The patient with a type IV fracture was treated with type O, and the patient with a type V fracture was treated with type T (Table 4).

According to the assessment scale regarding ESF stability and fracture site displacement, the average value for all the cases evaluated is 1.46 ± 0.74 (median, 1; range, 1–3). The assessment based on the configuration used is the following: type X mean value 1.5 ± 1 (median, 1; range, 1–3), type T 1.25 ± 0.5 (median, 1; range, 1–2), type O 1.5 ± 0.57 (median, 1.5; range, 1–2), and type C 1.66 ± 1.15 (median, 1; range, 1–3). This information is summarized in Table 4.

The global healing time was 9.45 ± 5.66 weeks (median, 8 weeks; range, 2–20 weeks) (Figure 5). According to fracture type, the results are as follows: in eight dogs with type I fracture, the healing time is 10.5 ± 6.45 weeks (median, 8 weeks; range, 2–20 weeks) (Figure 6). In two dogs with type III, it is 6 ± 2.82 weeks (median, 6 weeks; range, 4–8 weeks). In the dogs with types IV and V, it is 5 and 8 weeks, respectively. In the dogs treated with EF in combination with internal osteosynthesis, it is 3 ± 1.41 weeks (median, 3 weeks; range, 2–4 weeks) and 10.3 ± 5.39 weeks (median, 8 weeks; range, 3–20 weeks) (Figure 7). These data are summarized in Table 5.

According to the assessment scale regarding functional and basic neurological status at the end of the treatment, once bone healing was achieved and ESF was removed, lameness in one limb persisted in one patient (6.66%). The average rating for this parameter is 1.86 ± 0.55. Another patient (6.66%) presented ambulatory problems that were only possible with assistance. This patient had multiple orthopedic problems as well. Ambulatory capacity had an average score of 1.86 ± 0.35. Out of the 15 patients, 8 (53.33%) had no presence of pain, 7 (46.66%) experienced moderate pain, and 1 (6.66%) had severe pain. The mean pain score was 1.4 ± 0.63. The overall final outcome score was 1.74 ± 0.26. The data are summarized in Table 6.

The complications encountered were mostly of neurological origin due to sacral fractures and their accompanying ones. Some patients experienced more than one kind of complication. Complications were encountered in seven (46.66%) patients and summarized in Table 7.

Of the seven cases with complications, four (57.14%) showed alterations in sphincter function (urination and defecation), which were treated pharmacologically. One (14.28%) had problems moving his tail. In another patient (14.28%), discospondylitis developed at L7-S1, which resulted in chronic pain. In the last patient (14.28%), a large puppy, most complications were due to the simultaneous presence of bilateral pelvic and vertebral fractures.

Of the seven patients that presented complications, four (57.14%) had type I sacral fractures, two (28.57%) type III, and one (14.28%) type IV. Two (28.57%) were treated with EF type C, three (42.85%) with type O, one with type T (14.28%), and one (14.28%) with type X (Figure 8).

4. Discussion

To the best of our knowledge, no studies have reported on the use of EF as a stabilization method for sacral fractures in veterinary medicine, unlike in human medicine, where its application has been described as a complementary technique (20, 21). In our research, most sacral fractures resulted from collisions by cars (73.33%), with falls from a height being a less frequent cause (6.66%), which coincides with previous studies (1, 7). These injuries mainly produced type I fractures (60.00%), in contrast to the publication by Anderson et al. (2), in which type III fractures were the most common (50.00%). Falls from a height usually cause transverse sacral fractures, whereas blows from vehicles usually produce longitudinal fractures (2). No type II fractures were present in this case cohort, in accordance with previous studies (1, 2).

Surgical treatment of this type of fracture has been suggested to control the pain and neurological deficits due to the sacrum displacement and impingement on the nerve roots (7). They can

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TABLE 6 Neurofunctional assessment results regarding the functional and basic neurological conditions of each patient at the end of the treatment, once bone healing was achieved and ESF was removed.

Patient no.	Fracture type	Frame configuration	Postoperative ability to stand 0 = no 1 = one limb 2 = two limbs	Postoperative ability to walk 0 = no 1 = with help 2 = yes	Postoperative ability to urinate spontaneously 0 = no 1 = occasionally 2 = yes	Postoperative pain 0 = severe 1 = moderate 2 = no	Postoperative perception of deep pain pelvic limbs on neurological exam 0 = no 1 = doubtful 2 = yes	Average
1	I	X	2	2	2	2	2	**2**
2	I	**T**	2	2	1	1	2	**1.6**
3	III	O	2	2	1	1	2	**1.6**
4	I	X	2	2	2	0	2	**1.6**
5	I	O	2	2	2	2	2	**2**
6	I	O	2	2	1	1	2	**1.6**
7	III	F	2	2	2	1	2	**1.8**
8	I	X	2	2	2	2	2	**2**
9	I	F	0	1	1	1	2	**1**
10	III	T	2	2	2	1	2	**1.8**
11	I	T	2	2	2	2	2	**2**
12	V	T	2	2	2	2	2	**2**
13	III	F	2	2	1	1	2	**1.6**
14	IV	O	2	2	1	2	2	**1.8**
15	I	X	2	1	2	2	2	**1.8**
Average			**1.86**	**1.86**	**1.6**	**1.4**	**2**	

The type of fracture and configuration of the frame are included as well.

TABLE 7 Summary of the complications found in the seven affected patients according to the type of fracture and the type of EF system configuration used in each case.

Patient	Type of fracture	Type of EF configuration	Complication
2	I	T	Alteration in urination and defecation
3	III	O	Alteration in urination and defecation
4	I	X	Discospondylitis L7-S1
6	I	O	Alteration in urination and defecation
9	I	C	Several complications due to other fractures
13	III	C	Defecation and tail movement
14	IV	O	Alteration in urination and defecation

be stabilized using plates (8) or pins and screws with PMM (7). The drawbacks of treating fractures of the sacrum are notable due to their anatomical complexity. More data on this subject are available for human medicine, where the difficulty of using fixation systems without causing iatrogenic neurological damage (22) in addition to the instability of most sacral fractures is highlighted (23). In this cohort, 13 (86%) patients were treated with EF only; thus, owing to the minimal invasiveness of the fluoroscopy-assisted technique and closed reduction of the fracture site, the open approach and aggressive manipulation of the fragments were avoided. EF also has characteristics that make its application relatively simple and fast and reduce surgical time, which can be an important issue to consider for the treatment of complex fractures in seriously ill patients (24, 25). In four (26.66%) patients, radiolucent fixators were used which allowed better intraoperative visualization of the bone fragments under fluoroscopic guidance and radiological follow-up. Furthermore, carbon fiber or plastic polymers are lighter than metallic fixators, and this feature can be particularly useful for small dogs.

Regarding ESF stability and fracture site displacement, the T configuration achieved the best grading, with a mean value of 1.25, even though it was applied to complex fractures, such as type III ($n = 1$) and type V ($n = 1$) fractures. In these cases, the complications or delays in bone healing were minimal. The mean removal time for EF was 9.45 weeks, which is considered quite short for this type of fracture.

In two cases, EF was applied as an ancillary stabilization technique together with an internal osteosynthesis technique. In these two patients, EF removal was performed after 3 weeks, whereas for patients treated exclusively with EF, it was 10.3 weeks. In these patients, EF showed a good protective capacity for internal stabilization, preventing its failure and providing a good level of comfort.

Comparing the neurofunctional assessment scale at presentation and at the outcome, a significant improvement was observed after treatment for patients with difficulty in standing up, and only one out of the initial six patients was ultimately unable to stand up spontaneously. The entire group of 15 patients went from an initial score of 0.66 to 1.86 after completing the treatment. This result is similar to previously published studies [Paré et al. (5), Wilson et al. (7)]. Paré et al. highlighted that one (12.50%) patient experienced deficits in a pelvic limb while walking. In our study, two patients scored 1 on our assessment scale, indicating that they needed assistance to walk at the time of discharge (13.32%). The overall score for the 15 cases increased from 0.46 to 1.86, which can be considered a good outcome due to the neurological impact of sacral fractures (5, 7, 8). For the same reasons, it is considered promising that only 1 (6.66%) patient showed residual pain at discharge, compared to the initial 14 patients with severe pain. Similarly to the mentioned references (5, 7), sphincter functionality returned to completely normal levels at the end of the treatment.

These data coincide with bibliographical references that attribute worse results to longitudinal sacral fractures (2), due to their characteristics and greater involvement of the nerve roots.

Mild complications were encountered in seven patients. However, the overall result was considered very good, owing to the frequent iatrogenic damage described and the numerous complications typical of this type of fracture (7).

The retrospective nature of this study is among its limitations due to some technical aspects that changed during the time it

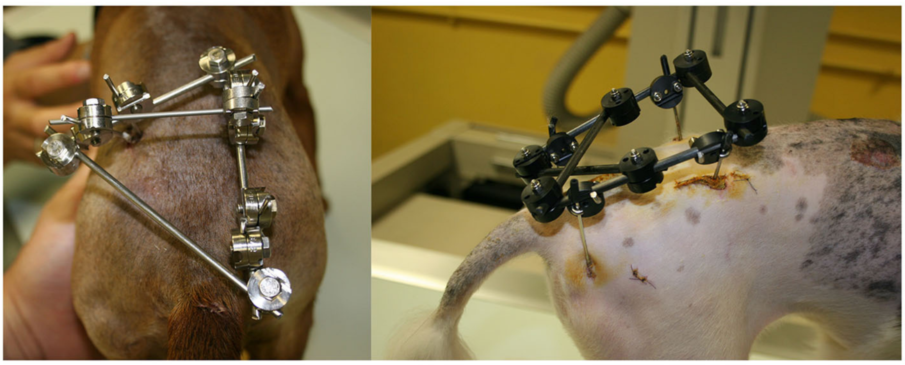

FIGURE 8
Images of C type **(left)** and X type **(right)** frame configuration.

was developed, resulting in inconsistent treatment for all cases. Another limitation is due to the complexity of the fractures and the differing circumstances of each patient, which prevented the comparisons between the same conditions. Patients with pelvic and vertebral fractures presented bigger challenges than those with relatively minor trauma. Furthermore, evaluating the biomechanical behavior of the pairing of internal and external systems is difficult. Therefore, specific biomechanical tests should be performed to better clarify the performance of this combination.

5. Conclusion

EF is an osteosynthesis technique characterized by its minimal invasivity, relative simplicity of application, and lower cost compared to internal osteosynthesis implants (26, 27). To the best of our knowledge, no previous studies have described the use of EF for sacral fractures in the veterinary literature.

The results obtained in this case-cohort study showed that EF is a good stabilization system for sacral fractures and, owing to its aforementioned characteristics, should be evaluated for the treatment of patients with this kind of lesion. The improvements observed in various aspects of patient wellbeing underscore the potential clinical utility of the technique in addressing the challenges presented by such injuries.

In conclusion, EF showed excellent outcomes in the stabilization of sacral fractures in dogs, with minimal invasiveness and a low complication rate. The combination of internal and external systems provided good protection and comfort to the patients. EF should be considered a primary or complementary technique for internal osteosynthesis, although more studies are needed to gather data on its clinical application.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not required for the studies involving animals in accordance with the local legislation and institutional requirements. It doesn't need ethical approval by an Ethical Committee because all our patients were pets treated with the informed and signed consent of each owner, without testing in any case, since they were not neither experimental nor commercially available animals. Our patients were experimented with at any time. This work is based on the description of surgical techniques already described but modified. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

JF, GR, and JR-Q: conceptualization, validation, resources, visualization, and writing—review and editing. GR and JR-Q: methodology and formal analysis, data curation, supervision, and investigation. JF: software and writing—original draft preparation and funding acquisition. JR-Q: project administration. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

GR owns shares of the Ad Maiora company.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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6.3. Aplicación de los fijadores externos en pelvis para el tratamiento de una fractura acetabular bilateral en un gato inmaduro

Tipo: Artículo científico

Estado: En revisión

Resumen: Este estudio tuvo como objetivo evaluar el resultado del tratamiento con fijación externa en un gato inmaduro con una fractura fisaria bilateral no traumática de acetábulo, una técnica quirúrgica que no suele emplearse en pacientes inmaduros. El tiempo de fijación fue de 40 días y se retiró una vez que se logró la cicatrización ósea radiográfica. No se identificaron complicaciones significativas relacionadas con la técnica y el resultado se clasificó como bueno, basado en las escalas de evaluación funcional y de dolor utilizadas. El uso de fijación externa para estabilizar fracturas de acetábulo en gatos inmaduros debería considerarse como una opción técnica viable, especialmente para estabilización mínimamente invasiva.

animals

MDPI

Case report

A BILATERAL ACETABULAR PHYSEAL FRACTURE TREATED WITH EXTERNAL FIXATION IN AN IMMATURE CAT

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Simple Summary: This study was intended to show the use of external fixation to resolve fractures of bilateral acetabular physeal fractures in an immature cat, obtaining a good outcome with a low rate of complications. A great part of this success was because external fixation allows fractures to be stabilised through a minimally invasive procedure. In addition to its relevance as fixation method, it was possible to show that external fixation provided comfort and a high level of tolerance for the patient during the whole healing period.

Abstract: This study aimed to assess the outcome of a bilateral not-traumatic acetabular physeal fracture treated with external fixation in an immature cat, a surgical technique not usually employed in immature patients. The fixator time was 40 days, and it was removed after radiographic bone healing was achieved. No significant complications related to the technique were identified, and the outcome was classified as good, based to the functional assessment and pain scales employed. The use of external fixation to stabilize acetabular fractures in immature cats should be considered a viable technical option, especially for minimally invasive stabilization.

Keywords: dog; cat; joints; osteoarthritis; osteoarthrosis; orthopedic disease; lameness; acetabular; external fixation; fracture

1. Introduction

Pelvic fractures in cats account for 22-32% of all skeletal system fractures [1,2] Among these, acetabular fractures constitute 14-43% of the total [3,4]. Despite this, there are few bibliographic references related to not-traumatic fractures, particularly regarding "acetabular physeal fractures" (APF) [1][5]. The acetabular physis closes within 20-24 weeks of age [1], and it is unknown whether APFs share an origin with the "Feline Epiphyseal Dysplasia Syndrome," where spontaneous fractures of the femoral head are described [6-9], in male patients, typically early-neutered, young, obese [9] and/or hypothyroid [10]. There is no data in the literature supporting the same theory for the origin of APF.

Conservative treatment of acetabular fractures has traditionally been considered a therapeutic option in immature patients [11]. Non-surgical options, though, are not the best choice for the treatment of this type of fracture [1-5][11], as the most common complication is the development of osteoarthritis [12]. Piana et al. suggest that displacements of more than 3 mm in fracture reduction are associated with a higher risk of osteoarthritis in the affected joint [13]. However, other authors argue that this decision is more of a biomechanical matter, where factors such as the patient's level of activity and body weight are important factors for deciding on conservative or surgical treatment

[14]. Other complications observed in displaced, non-reduced acetabular fractures include narrowing of the pelvic canal with subsequent constipation, neurological deficit, and pain [4].

Different techniques are described for the treatment of acetabular fractures, with the most commonly used being small fragment plates or locking plates [4][13-17], and the combination of screws with polymethyl methacrylate or cerclage wire [1][4][18-20]. If surgical repair is not possible, salvage procedures, such as femoral head and neck ostectomy, can provide pain relief and maintain good limb function [21]. The use of external fixation (EF) as a sole stabilization method in the treatment of APFs in immature cats has not been described in the literature to our knowledge. This technique has been described in only one case in the dog as a complementary method [5], in contrast to human medicine, where it is a very useful technique in pediatric patients with traumatic acetabular fractures [22,23].

The potential benefits of EF are a minimally invasive approach, reducing the damage to the vascular supply of tissues, avoiding a delay in bone healing [24,25], and providing less postoperative pain [26]. The technique requires a good understanding of the principles of application [24] to avoid complications. The most frequent complications are implant loosening and delayed bone healing [27,28].

This paper describes the surgical technique and the outcome of a case of a bilateral not-traumatic APF in a 5-month-old cat.

2. Materials and Methods

This study involves a 20-week-old cat admitted to Prïvet Veterinary Hospital (Villaviciosa de Odón, Madrid, Spain). The cause of the fracture, the details of the surgical procedure, the radiographic images, and the evaluation of lameness before and after the intervention are included. Information on postoperative (PO) progress was collected during follow-up consultations at the hospital, as well as through two phone calls conducted 4 and 6 months after the intervention to assess the presence of lameness and ambulatory function.

Preoperative Management

To facilitate the radiographic study, the patient was sedated with an intramuscular injection of medetomidine (Medetor 1mg/ml, Virbac España SA, Spain) at a dose of 100 mcg/kg, methadone (Semfortan, Eurovet Animal Health BV, Netherlands) at a dose of 0.4 mg/kg, and midazolam (Midazolam Normon, Laboratorios Normon SA, Spain) at a dose of 0.1mg/kg. Lateral and ventrodorsal pelvic projections were taken, revealing a bilateral APF with a displacement of 6 mm between the fragments in both fracture sites.

After 24 hours, the patient was operated to address both fractures. The premedication protocol was the same as that used for sedation during the previous radiographic study. The patient was induced with propofol (Propofol Lipuro 10mg/ml; B.Braun Melsungen AG, Germany) at a dose of 2 mg/kg intravenously and maintained with inhalation anesthesia using isoflurane (Isoflo; Zoetis Spain SL, Spain).

Surgical Technique

The surgical site was prepared by shaving and disinfecting the lumbosacral and gluteal dorsal region, extending from the midportion of the lumbar spine to below the two stifle joints. The patient was positioned in sternal recumbency, with a ventral support that maintained the hind limbs abducted and the pelvis as horizontally as possible on the surgical table. During the procedure, the main anatomical references of the pelvis were identified: iliac crests, iliac wings, and ischial tuberosities. Safe corridors for the placement of the external fixator (EF) transfixing nails were determined as follows.

- Sacral tuberosity corridor of the ilium, near the origin of the gluteus medius muscle. The pins were inserted at an angle of 10-15º from proximo-medial to disto-lateral to the vertical.
- Corridor of the body of the ilium, in the caudal aspect, along the origin of the gluteus profundus muscle, inserting the pins at an angle of 10-15º to the vertical of the iliac crest.
- Ischial tuberosity corridor, with pins inserted at an entry angle of 10-15º to the vertical.

In total, eight threaded self-tapping 1.2-mm diameter pins were inserted: one pin in each iliac crest, another pin in each body of the ilium, and a third and fourth pin in each body of the ischium and ischial tuberosity. Once properly placed by a fluoroscopy-assisted procedure, the pins were used to reduce both BPAs, and they were interconnected with a 1.5 mm bar and Meynard clamps (Insorvet, Barcelona, Spain).

Postoperative Care

Lateral and ventrodorsal projections were taken to confirm the fracture reduction. After 24 hours, the patient was discharged, with a prescription for cephalexin (Cefaseptin 75 mg; Vetoquinol Especialidades Veterinarias S.A., Spain) at a dose of 15 mg/kg every 12 hours orally and meloxicam (Inflacam 0.5 mg/ml; Virbac España SA, Spain) at a dose of 0.1 mg/kg every 24 hours orally.

Follow-up

Owners were instructed for daily care of the pin entry sites. Strict confinement of the cat was advised for the first 2 weeks. From the third week until the removal of the fixator, it was recommended to gradually increase the available space for movement, avoiding access to areas where the patient could run or jump. Follow-up radiographs were taken at 21 and 40 days post-surgery in both lateral and dorsoventral projections. For the dorsoventral projections, the hips were flexed to facilitate better positioning of the patient with the EF. In the last check-up at 40 days, bone healing was confirmed, and the implants were removed. Subsequently, ventrodorsal and lateral projections of both pelvises were obtained.

In addition to monitoring bone healing, weekly physical examinations were conducted to assess functional and pain assessment and to check the adjustment of the Meynard clamps and pin stability. Two additional rechecks for functionality and pain were performed at 16 and 24 weeks PO.

For functional assessment, a 6-level scale was established to help determine progress and the final outcome.

- Level 0: No functional or locomotor alterations. The patient walks normally.
- Level 1: Mild locomotor alterations, with occasional mild lameness.
- Level 2: Mild to moderate locomotor alterations, with mild and consistent lameness.
- Level 3: Moderate locomotor alterations, with moderate and partially constant lameness.
- Level 4: Severe locomotor alterations, with pronounced lameness involving intermittent non-use of the limb.
- Level 5: Very severe functional alterations with complete limb disuse.

The pain experienced by the patient during the healing period was assessed using a modified Visual Assessment Scale (VAS) based on the scale described by Flores et al (accepted for publication). This modified scale ranged from A to C, with A indicating very good comfort and C indicating poor comfort for the patient.

- Level A: No apparent signs of pain. The animal exhibits no complaints upon manipulation. Considered normal behavior.
- Level B: Mild to moderate signs of pain. The animal shows some discomfort with occasional spontaneous moans. There may be moderate difficulties in urination and defecation. No other significant behavioral alterations.
- Level C: Severe signs of pain. Inability to handle the patient without accompanying vocalizations. Severe difficulties in urination and defecation. Apathy and depression.

Once radiographic confirmation of bone consolidation of the fractures was achieved, the removal of the EF was performed. This removal procedure involved sedation and the same protocol described in the preoperative management.

3. Results

The case of a 5-month-old, 950 g European domestic cat was recorded, presented with difficulty standing and walking, along with clear signs of pain during physical examination. The cause of the fracture could not be determined, as the owners did not observe any prior trauma. No other traumatological injuries were detected in the patient. Radiographic images revealed the presence of FPAs in both hips (Figure 1).

Figure 1. Left: Lateral projection of the pelvis showing the double APF. Right: Ventrodorsal projection of the same patient.

To stabilize the fractures, a fixator consisting of 8 positive-threaded 1.2 mm threaded pins and a connecting bar of 1.5 mm diameter was used (Figures 2 and 3).

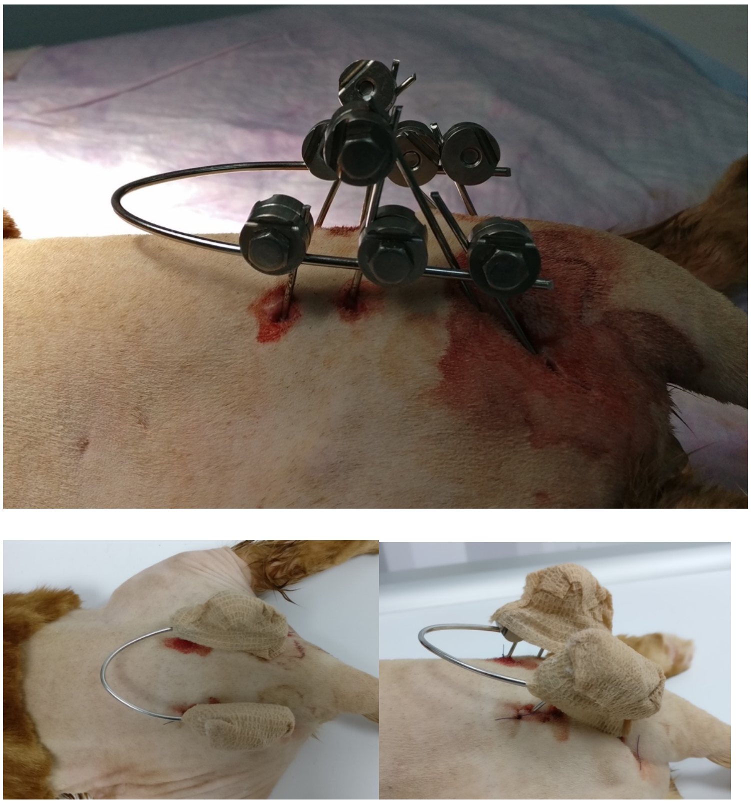

Figure 2. Top: Detail of the external appearance of the EF. Bottom left: Dorsal view of the EF. Bottom right: Lateral view of the EF.

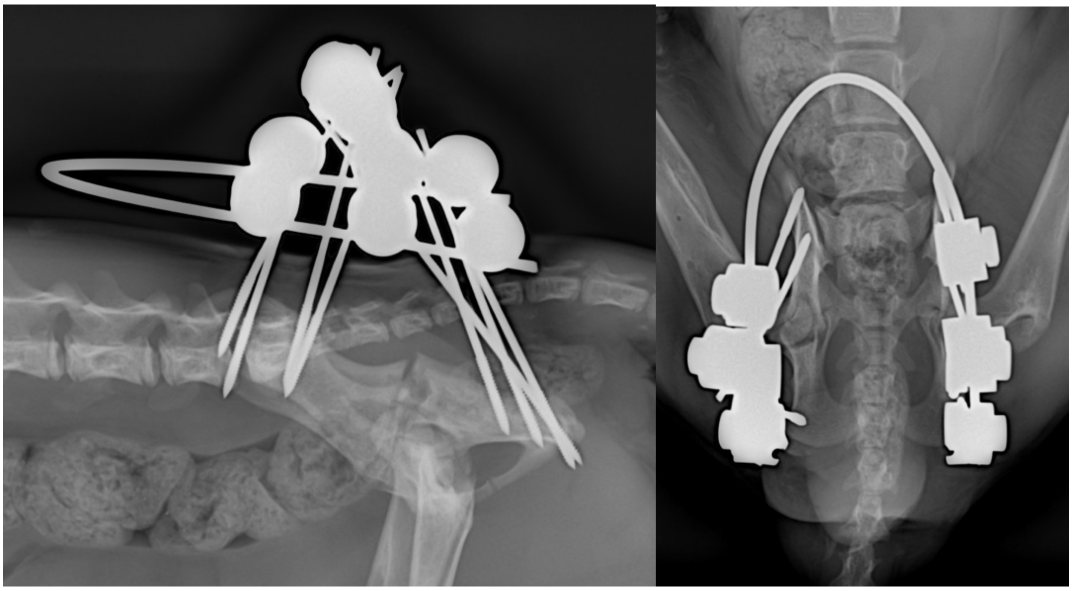

Figure 3. Left: PO lateral projection. Note the evident reduction of the gap at the fracture site. Right: PO dorsoventral picture. In the dorsoventral FU radiographs, the hips are flexed for better and more comfortable patient positioning.

The treatment time with the EF had a total duration of 40 days, with an intermediate radiological check at 21 days (Figure 4) showing initial signs of healing. In the second and final radiological examination at 40 days (Figure 5), complete bone healing was confirmed, allowing the removal of the system under patient sedation. This was carried out following the aforementioned anesthetic protocols, and after removal, a new radiological control was performed (Figure 6).

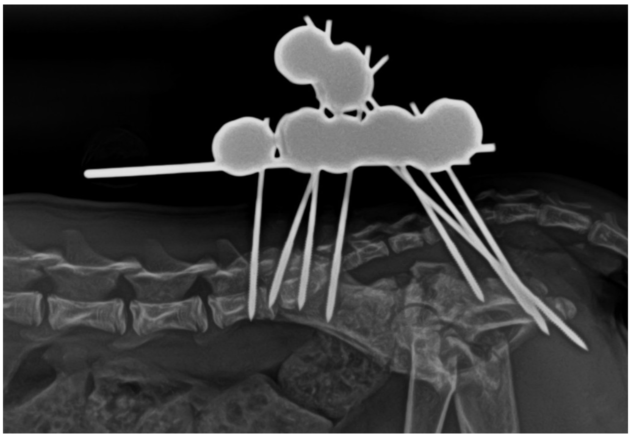

Figure 4. Lateral radiography of the pelvis obtained 21 days after the surgical intervention. Initial radiological signs of healing are observed.

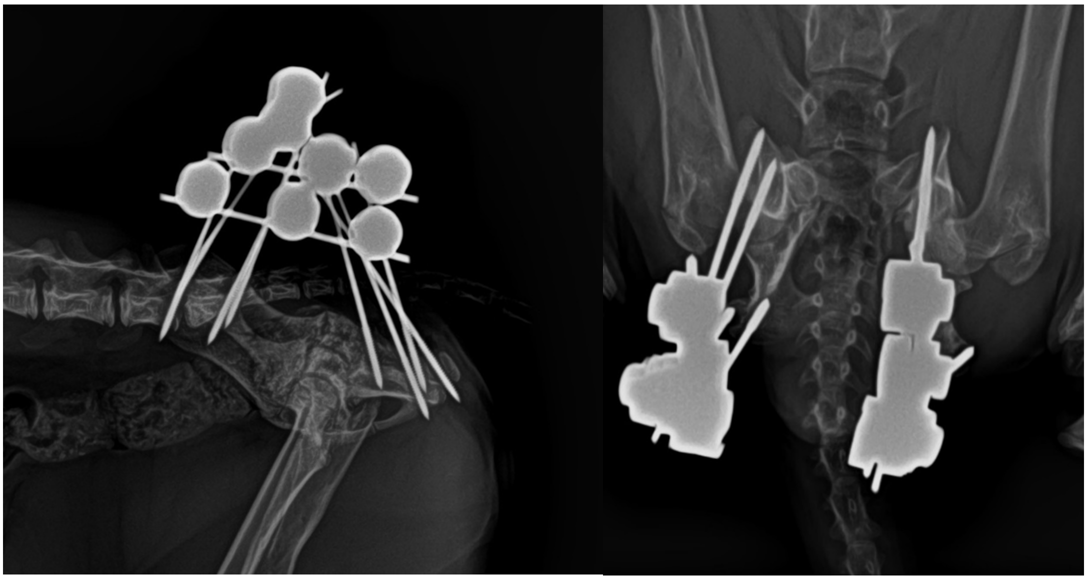

Figure 5. Left: Lateral projection at 40-day PO. Right: Dorsoventral projection.

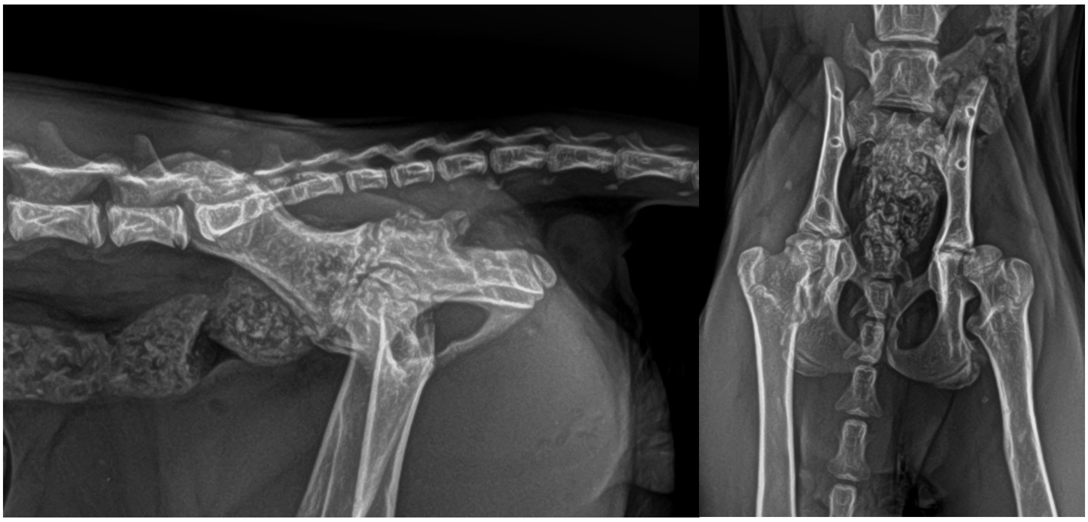

Figure 6. Left: Lateral projection after the removal of the external fixator. Acceptable healing and proper congruence of both fragments are observed. Right: Dorsoventral projection. No stenosis of the pelvic canal is evident.

In the initial clinical assessment, the patient had difficulty in walking and supporting its own weight with the pelvic limbs, rated at levels 5 and C on both scales. At this point, a neurological examination did not reveal any abnormalities of this nature, although the patient experienced difficulties in urination and defecation, with stranguria and constipation, respectively.

After the surgical intervention, the patient still exhibited a level 5 in functionality and C in the pain scale. The use of both pelvic limbs was appropriate, with levels 3 and B during the first 2 weeks of treatment. Some difficulty in extending the spine was observed due to the forward position of the connecting bar between both half-fixators, although this did not prevent the patient from leading a completely normal life with the system. For this reason, it was decided to remove the connecting bar 21 days after its placement. At the 3- and 4-week controls, the patient showed levels 2 and B on the assessment scales. In weeks 5 and 6, the patient was evaluated with levels 1 and A. After the removal of the system, the patient remained at levels 2 and A for 24 hours. Subsequently, the patient returned to complete normality, showing no pain or any alteration in gait, maintaining levels 0 and A in the scheduled follow-ups at 16 and 24 weeks. Information regarding functional and pain evolution during the treatment period has been summarized in the following table (Table 1).

	PrO	PO	W1	W2	W3	W4	W5	W6	WXP	W16	W24
Functional Scale	5	5	3	3	2	2	1	1	2	0	0
Pain Scale	C	C	B	B	B	B	A	A	A	A	A

Table 1. Data obtained in different follow-up controls assessing the patient's functional status and pain according to the described assessment scales. (PrO): Preoperative; (PO): Postoperative; (W): Week; (EXP): Implant removal.

Regarding the resistance of the employed system, no loosening of the pins and/or the clamps was recorded due to fatigue in the 40 days of fixation.

Throughout the entire healing period, no major complications were experienced, except for the modification of the system at 21 postoperative days and mild, intermittent, and episodic serosanguinous discharge from the pin entry holes during the first two weeks of treatment.

4. Discussion

In the literature, there are few references on the treatment of spontaneous acetabular physeal fractures in cats. This is due to the low frequency of this type of fractures [1][5] and the predominant use of internal fixation for the resolution of any type of acetabular fracture [4][13-16]. In human medicine, the use of EF in pelvic fractures at certain stages of treatment has been described [29-33] due to its structural advantages [30-37], including acetabular fractures in particular [32-34]. EF allows for minimal invasion, resulting in minimal damage of surrounding tissues, with the consequent lower risk of infection, a shorter healing time, and a good level of patient tolerance [24-27].

In the presented case, conservative treatment was ruled out due to possible neurological consequences and sustained pain during the consolidation period [1-5][11]. Another factor taken into account was the possible onset of osteoarthritis associated with incomplete reductions of the fracture site [12,13]. Due to the small size of the patient, internal osteosynthesis techniques were excluded due to the extensive approach required and the small size of the anatomical structures involved. The possibility of performing a double femoral head and neck excision was considered, but this option was discarded after considering its possible drawbacks, such as limb shortening, reduced range of motion, muscle atrophy, patellar luxation, and constant pain and lameness [38].

In this patient, EF was used to reduce both fractures without the need for an open approach, using fluoroscopy for precise manipulation of the bone fragments and achieving good anatomical alignment of the reduction. The use of EF to treat acetabular fractures in cats is uncommon, and only Graville et al (2018) and Flores et al (accepted for publication) have described this system applied to acetabular fractures in canines successfully for this type of fractures [5][27]. In other types of pelvic injuries, such as sacroiliac luxations, closed reduction has been shown to be effective and provides good results [39], allowing for a faster recovery in the postoperative period. The patient's size also influenced the choice of the EF system over internal osteosynthesis, as finding suitable implants for a bilateral fracture in a very small cat would have been a challenge [1]. All the described aspects were decisive in choosing EF for the treatment of acetabular physeal fractures.

This patient showed good locomotor function from the early weeks, being able to walk with moderate restrictions during the first two weeks and with minimal alterations until the end of treatment. Severe signs of pain were only detected at the time of presentation and during the first 24 hours after surgery. Once the fractures were stabilized with the external fixation and the inflammation decreased, the pain began to gradually reduce, and signs of stranguria and constipation induced by it disappeared. From the first postoperative week, the patient showed significant improvements, moving from levels 5 and C in the assessment scales to levels 3 and B, which is considered a relatively short time for this type of joint fracture. Anti-inflammatory drug treatment was only administered during the first postoperative week, demonstrating the patient's good tolerance to the fixation system. The only incident worth noting was related to the positioning of the connecting bar between both sides of the fixator, which was removed at 21 days of treatment. The bar was positioned too far cranially, preventing proper extension of the lumbosacral spine. In the chosen configuration, this bar consisted of a single piece connecting the two parts of the system, so it was decided to cut it, so that both sides, from that time and with 50% of bone healing achieved, behaved as independent fixator. The patient showed a very good degree of tolerance compared to open approaches, especially the one described for the acetabular region, which often involves greater trochanter osteotomy or gluteal tenotomy [1][39,40].

Bone healing was recorded at 40 days, and this timeframe is considered acceptable compared to figures obtained in similar cases treated with internal fixation, which often required up to 60 days [1]. In this case, the closed approach allowed for faster recovery, as described in the literature [41]. The use of an EF allowed for easy, quick, and non-invasive implant removal, which is crucial in growing patients. This contrasts with cases where internal fixation is used, which often require a reintervention with an open approach to remove the implants, as mentioned in a study by Langley-Hobbs et al. Additionally, it is highlighted that the diameter of the pelvic canal did not experience any collapse after treatment, which is a common complication, and sometimes unavoidable when treating acetabular fractures [1][3][4,5].

During the healing period, no serious complications related to the implant were identified. Only, as mentioned earlier, a modification in the system design had to be made after two weeks of treatment. The system remained intact until the end of the treatment, unaffected by the usual complications of such systems, such as serous discharge from the entry points of the transfixing pins, loosening of the system components, and/or poor bone healing [42].

5. Conclusions

This work highlights the advantages of EF, demonstrating that its minimally invasive approach and specific characteristics allowed for the successful resolution of a challenging double fracture in a very small and immature patient. Complications encountered were very minor, and the patient showed a good quality of life from the early stages of treatment. Additionally, this type of implant is very cheap, and this is useful for acceptance by the owners.

In summary, pending further research to support these findings, this study supports the consideration that EF should be regarded as a viable technique for stabilizing acetabular fractures in immature cats.

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Discusión integradora

7. Discusión integradora

En esta tesis, a través de los tres trabajos que la conforman, se busca demostrar la eficacia, seguridad y tolerancia de la fijación externa como tratamiento de fracturas pélvicas y sacras en pequeños animales. Además, se presenta una propuesta de clasificación destinada a definir los diversos montajes de fijadores externos utilizados en el tratamiento de las afecciones ortopédicas y traumatológicas en esta área quirúrgica.

En el artículo "**Retrospective Assessment of Thirty-Two Cases of Pelvic Fractures Stabilized by External Fixation in Dogs and Classification Proposal. *Vet. Sci.* 2023, 10, 656. doi: 10.3390/vetsci10110656"** se ha desarrollado una clasificación alfanumérica que proporciona información sobre el número de clavos transfixiantes ubicados en áreas específicas y la interconexión entre las estructuras de ambas hemipelvis. La secuencia numérica se enumera de izquierda a derecha al observar dorsalmente el sistema del fijador aplicado sobre el paciente. En la clasificación propuesta, cada hemipelvis se divide en tres segmentos:

- Segmento I: Ala ilíaca.
- Segmento II: Cuerpo del ilion y acetábulo.
- Segmento III: Isquion.

A cada segmento le sigue un número que indica los clavos insertados en esa ubicación. En la descripción alfanumérica, tanto de la hemipelvis izquierda como la derecha, se menciona cómo los clavos están interconectados mediante las barras de conexión dentro de cada hemipelvis. Se describen 5 tipos distintos de interconexión:

- Tipo T: Una barra única conecta los clavos ubicados en ambas alas ilíacas.
- Tipo C: Las barras conectan los clavos en la ala ilíaca y la tuberosidad isquiática de una hemipelvis, tanto entre sí, como con el clavo ubicado en el ala contralateral del ilion.
- Tipo O: Las barras interconectan los clavos de cada hemipelvis alrededor del perímetro.
- Tipo L: Las barras conectan los clavos de una hemipelvis entre sí y con el clavo ubicado en la tuberosidad isquiática contralateral.

- Tipo X: Las barras interconectan los clavos alrededor del perímetro y establecen una conexión en cruz entre los clavos ubicados en los vértices del cuadrilátero.

La propuesta de esta clasificación, como precedente en medicina veterinaria, surge de la complejidad anatómica de la pelvis, que requiere el empleo de diseños y configuraciones de FE que no pueden ser clasificados mediante las nomenclaturas existentes en la literatura.

En medicina humana, los sistemas de FE pélvica se componen de fijadores lineales que se subdividen en diversas categorías, como uniplanares, multiplanares, unilaterales, bilaterales o circulares en algunos casos (Hadeed et al., 2023). Los puntos de inserción de los clavos, descritos como corredores seguros, son los elementos distintivos entre un sistema y otro, como son los ilíacos o los supracetabulares (Rieger et al., 1996; Calafi y Routt, 2013; Lee y Sciadini, 2018). Hasta la fecha, no existe una nomenclatura específica basada en el diseño del sistema, tal y como se propone en el ámbito de la medicina veterinaria a través de este trabajo.

Esta clasificación propuesta busca ofrecer una herramienta visual y práctica para el diseño sistemas específicos en el tratamiento de fracturas pélvicas y sacras, proporcionando precisión sobre la configuración empleada, lo que facilitará la estructuración de los resultados obtenidos, mejora la comprensión de cada diseño y proporciona un desglose detallado de los datos. Además, sirve como punto de partida para futuros estudios biomecánicos, los cuales necesitarán establecer distinciones nominales para cada configuración analizada.

Aunque la literatura existente sobre el uso de la FE aplicada a fracturas pélvicas es limitada en medicina veterinaria (Fitzptrick y Hamilton, 2012; Graville et al., 2018), su aplicación en medicina humana, donde la FE es común en fracturas inestables, especialmente al inicio del tratamiento (Mears y Fu, 1980; Hu et al., 2012). La FE destaca por sus propiedades biomecánicas y sus características particulares reconocidas en múltiples estudios (Gardner y Nork, 2007; Scaglioni et al., 2010; Vècsai et al., 2010; Tiziani et al., 2014; McDonald et al., 2015), aunque se consideran necesarios más trabajos que profundicen en este aspecto para comprender mejor la rigidez y la estabilidad de las distintas configuraciones de FE.

Su modularidad y facilidad de aplicación, ya sea como método temporal o definitivo para tratar fracturas, ofrece ventajas significativas en pacientes críticos (Bible y Look, 2015). Además, la FE radiolúcida simplifica la evaluación de la curación (Bonardi et al., 2022), facilitando los controles radiográficos y evitando la necesidad de realizar proyecciones oblicuas en algunas ocasiones. Es destacable el papel importante de la fluoroscopia en estos procedimientos, pues contribuye considerablemente en el proceso de reducción de la fractura, a pesar de la exposición a la radiación, la cual puede ser controlada por cirujanos experimentados (Bonardi et al., 2022).

La FE también se puede emplear como técnica complementaria, junto con la osteosíntesis interna (McLaughlin y Tillson, 1999; Ben-Amotz et al., 2009; Panta et al., 2013), proporcionando rigidez para la estabilización de fracturas inestables (Innes y Butterworth, 1996; Harasen et al., 2007; Fitzpatrick et al., 2008; Lee et al., 2012; Panta et al., 2013; Kenzig et al., 2017; Fathy et al., 2018; Blakely et al., 2019). Aunque los estudios comparativos de la rigidez de la FE con la osteosíntesis interna en fracturas ilíacas son limitados, el trabajo de Fitzpatrick y colaboradores (2008) sugiere una rigidez similar, resaltando las notables ventajas biomecánicas de la FE debido a su mayor brazo de palanca.

En pacientes con fracturas unilaterales de ilion la configuración más empleada fue el tipo O (40%), demostrando un alto nivel de rigidez para la estabilización de este tipo de fracturas, observándose además que el 87% mostró resultados muy buenos según nuestra escala de evaluación, con una puntuación de confort de 8,75 sobre 10, lo que indica una buena tolerancia al sistema empleado. Es importante destacar que la FE a través de la configuración O se utilizó como única técnica de estabilización, con un nivel máximo en la escala de tolerancia, en pacientes con fracturas bilaterales, respaldando de nuevo la idea de la eficacia y confort de este diseño para fracturas ilíacas. Sin embargo, se advierte sobre la posible progresión de la osteoartritis a medio-largo plazo en aquellos casos en los que la reducción no es anatómica, una situación también aplicable a la osteosíntesis interna.

En el tratamiento de fracturas acetabulares en perros, la tendencia actual se inclina hacia el uso de placas de osteosíntesis (Forterre et al., 2007; Piana et al., 2020; Roberts et al., 2021). A pesar de ello, Graville y colaboradores (2018) sugieren la viabilidad de la FE para este tipo de fracturas. En nuestro trabajo, obtuvimos resultados satisfactorios en el 67% de los casos tratados exclusivamente con FE, con una puntuación de comodidad media de 9,25 sobre 10. Aunque se presentaron ciertas limitaciones, como una difícil reducción anatómica del foco de fractura o el riesgo de aflojamiento de los clavos (Fitzpatrick y Hamilton, 2012), los resultados obtenidos se consideran aceptables dadas las características de este tipo de fracturas y sus posibles complicaciones asociadas a este tipo de fracturas (Walker et al., 2002; Burton, 2011). Las configuraciones O y X fueron las más empleadas, considerando su rigidez la más apropiada para la estabilización de fracturas inestables como las acetabulares. Además, se destaca la variabilidad en el enfoque terapéutico para dos pacientes tratados mediante la combinación de placa y FE. En estos casos se utilizó una combinación de tipos C y X. Este enfoque mixto sugiere la necesidad de adaptar la estrategia de tratamiento según la naturaleza de cada fractura acetabular unilateral. En los dos casos de fracturas bilaterales, la configuración empleada fue el tipo O, y en uno de ellos se combinó con FE y placa. Este hallazgo destaca la polivalencia de la configuración tipo O en fracturas complejas y sugiere que la combinación de técnicas puede ser beneficiosa en ciertos contextos clínicos. Entre las complicaciones registradas, fue necesaria una ostectomía de la cabeza femoral debido a un proceso de necrosis posterior, y otro paciente desarrolló discospondilitis L7-S1 de origen desconocido. Sin embargo, la mayoría de las complicaciones fueron menores y no afectaron significativamente al resultado final.

En 18 pacientes, se trataron 26 luxaciones sacroilíacas empleando la técnica estándar de combinación de un tornillo de compresión y una aguja antirrotacional, la cual ha sido muy referenciada en la literatura (Bernasconi et al., 2001; Dèjardin et al., 2016; Bird y De Vicente, 2020; Tomlinson, 2020). Únicamente se utilizó la FE en tres fracturas (11%), todas ellas unilaterales, mientras que en los 23 casos restantes (88%), la FE se empleó como técnica adicional para proteger la osteosíntesis interna. En lesiones bilaterales, el tipo O fue el más frecuente, seguido por tipo T y tipo X, lo cual confirma de nuevo la gran utilidad de las configuraciones más completas (O y X) en lesiones bilaterales debido a su mayor inestabilidad. Sin embargo, para las luxaciones unilaterales la estabilización se realizó con configuraciones C, L y T, debido al aporte de estabilidad proporcionado por la hemipelvis sana.

La valoración del nivel de comodidad fue evaluada para todos los pacientes con luxación sacroilíaca y arrojó un promedio de 9,6, confirmando la buena tolerancia de la FE. Se obtuvieron resultados excelentes en el 77% de los pacientes, considerados satisfactorios con una baja tasa de complicaciones. Tres pacientes con buenos resultados experimentaron disfunciones leves en la micción y defecación, las cuales fueron resueltas tras la retirada de la FE. Sólo un paciente tuvo un resultado discreto debido a complicaciones relacionadas con otras lesiones traumáticas. Este paciente sufrió una fractura vertebral L5 con grave déficit neurológico, además de una fractura bilateral de la cabeza femoral, que no fue considerada una complicación resultante de la aplicación de FE.

En cuanto a la aplicación de la FE como método de estabilización en fracturas sacras, destaca la escasa bibliografía existente al respecto (Schuetze et al., 2022; Wu et al., 2013). En nuestro estudio (**"*External Fixation for Fracture Stabilization of the Sacrum in 15 Dogs". Front. Vet. Sci.* 2023, 10:1222504. doi: 10.3389/fvets.2023.1222504**), la causa principal de este tipo de fracturas fue el atropello por vehículos (73,33%), en contraste con las caídas desde altura (6,66%), coincidiendo con estudios previos (Kuntz et al., 1995; Wilson, 2015). En cuanto a la tipología de fracturas, las fracturas tipo I predominaron (60%), a diferencia de otros estudios donde las tipo III fueron las más comunes (50%) (Anderson y Coughlan., 1997). La cirugía es fundamental para tratar el dolor y las deficiencias neurológicas causadas por el desplazamiento del sacro y su impacto en las raíces nerviosas (Wilson, 2015). En la literatura, se han empleado placas de osteosíntesis (Mills, 2009) o agujas y tornillos con polimetilmetacrilato (PMM) para estabilizar estas fracturas (Mills, 2009). En nuestro estudio, el 86% de los pacientes fueron tratados exclusivamente con FE, aprovechando su mínima invasión mediante una reducción cerrada, y sus características que simplifican la aplicación, reduciendo el tiempo quirúrgico (Bible y Look, 2015; Kim et al., 2020). Además, la utilización de fijadores radiolúcidos permitió una mejor visualización intraoperatoria. En términos de estabilidad, la configuración en T arrojó los mejores resultados con un desplazamiento mínimo del foco de fractura, incluso en fracturas complejas.

La comparación de la escala neurofuncional al inicio y al final del tratamiento reveló una mejora significativa en pacientes con dificultades para ponerse de pie, con una puntuación global que aumentó de 0,46 a 1,86. A pesar de que dos pacientes requirieron asistencia para caminar al alta, el resultado se considera positivo dada la complejidad neurológica de las fracturas sacras (Pare et al., 2001; Mills, 2009; Wilson, 2015). La recuperación completa de la funcionalidad de los esfínteres respalda estos resultados, lo cual concuerda con otros trabajos (Pare et al., 2001; Wilson, 2015). Aunque se registraron complicaciones leves en siete pacientes, en general los resultados fueron muy satisfactorios, a pesar de los frecuentes daños iatrogénicos y las complicaciones habituales asociadas en el manejo de estas fracturas (Wilson, 2015).

En la literatura, existen escasas referencias sobre el manejo de fracturas espontáneas de la fisis acetabular (FFA) en gatos debido a su baja frecuencia de aparición (Langley-Hobbs et al., 2007; Graville et al., 2018). En general, las fracturas acetabulares se estabilizan principalmente mediante el uso de fijación interna (Amato et al., 2008; Haine et al., 2019; Piana et al., 2020; Roberts et al., 2021; Murugarren et al., 2023). En medicina humana, se ha descrito el uso de la FE en fracturas pélvicas, incluidas las acetabulares, debido a sus ventajas estructurales (Mears y Fu, 1980; Gardner y Nork, 2007; Scaglioni et al., 2010; Vècsei et al., 2010; Frydrysec et al., 2012; Hu et al., 2012; Tiziani et al., 2014; McDonald et al., 2015), incluso específicamente en fracturas acetabulares (Vècsei et al., 2010; Frydrysec et al., 2013; Tiziani et al., 2014; McDonald et al., 2015). La FE permite una invasión mínima, reduciendo el daño a los tejidos circundantes, lo que conlleva un menor riesgo de infección, un tiempo de curación más corto y un buen nivel de tolerancia por parte del paciente (Dudley et al., 1997; Johnson et al., 1999; Palmer et al., 2012; Hudson et al., 2020).

En el caso presentado en el trabajo **"A Bilateral Acetabular Physeal Fracture Treated with External Fixation in an Immature Cat (En revisión)"**, se descartó el tratamiento conservador debido a las posibles consecuencias neurológicas y al dolor constante durante el período de consolidación, como se describe en varias referencias (Boswell et al., 2001; Langley-Hobbs et al., 2007; Krebs et al., 2014; Meeson et al., 2017; Graville et al., 2018; Haine et al; 2019). Además, se consideró la alta probabilidad de desarrollar osteoartritis asociada con reducciones incompletas de la fractura, como señalan algunos estudios previos (Orrenius, 2019; Piana et al., 2020). Debido el pequeño tamaño del paciente, se excluyeron las técnicas de osteosíntesis interna, las cuales exigen un abordaje extenso en proporción al tamaño del gato, además de la dificultad para encontrar implantes adecuados para una fractura bilateral de este tipo, tal y como describe la bibliografía (Langley-Hobbs et al., 2007). Se consideró la escisión de ambas cabezas y cuellos femorales, pero esto se descartó debido a posibles inconvenientes de este procedimiento, como el acortamiento de la extremidad, la reducción del rango de movimiento, atrofia muscular, luxación rotuliana, dolor y la presencia de cojera constantes (Harper et al., 2017). En este paciente, se utilizó la FE en configuración O para reducir ambas fracturas, evitando un abordaje abierto. Se empleó la fluoroscopia para manipular los fragmentos óseos y lograr un buen alineamiento anatómico de la reducción. En otros tipos de lesiones pélvicas, como luxaciones sacroilíacas, se ha demostrado que la reducción cerrada es efectiva y proporciona buenos resultados, lo que permite una recuperación más rápida en el período postoperatorio (Tonks et al., 2008).

El uso de FE para tratar fracturas acetabulares en gatos es infrecuente, y solo Graville y colaborades (2018) han descrito este sistema aplicado con éxito en fracturas acetabulares en la especie canina. El paciente felino presentado en este estudio mostró una buena función locomotora desde las primeras semanas, caminando con mínimas alteraciones hasta el final del tratamiento. Los signos severos de dolor solo se detectaron en el momento de la presentación clínica y durante las primeras 24 horas después de la cirugía. Una vez estabilizadas las fracturas con la FE, la inflamación disminuyó y el dolor comenzó a reducirse gradualmente. Desde la primera semana postoperatoria, el paciente mostró mejoras significativas, pasando de niveles 5 y C en las escalas de evaluación a niveles 3 y B, lo que se considera un tiempo relativamente corto para este tipo de fractura articular. El tratamiento con antiinflamatorios solo fue necesario durante la primera semana postoperatoria, lo que sugiere una buena tolerancia del paciente al sistema de fijación. El único incidente destacable estuvo relacionado con la posición de la barra de conexión entre ambos lados del fijador, que se retiró a los 21 días de iniciado el tratamiento. El paciente mostró un grado muy bueno de confort después de la cirugía en comparación con los abordajes abiertos necesarios para realizar una estabilización interna, especialmente los descritos para la región acetabular, que a menudo implican la osteotomía del trocánter mayor o la tenotomía glútea (Tonks et al., 2008; DeCamp et al., 2016; Harper et al., 2017).

La cicatrización ósea se registró a los 40 días, lo cual se considera un plazo aceptable en comparación con otros casos similares tratados con fijación interna, que a menudo requieren hasta 60 días (Langley-Hobbs et al., 2007). En este caso específico, el abordaje cerrado permitió una recuperación más rápida, como ya se ha mencionado anteriormente. La retirada del implante fue fácil, rápida y no invasiva gracias al uso de la FE, y en contraste con los casos en que se utiliza la fijación interna, los cuales suelen requerir reintervenciones con un enfoque más invasivo, como se menciona en un estudio de Langley-Hobbs y colaboradores (2007). Es importante destacar que el diámetro del canal pélvico no experimentó ningún colapso después del tratamiento, lo cual es una complicación común y a veces inevitable en el tratamiento de las fracturas acetabulares (Boswell et al., 2001; Langley-Hobbs et al., 2007; Graville et al., 2018; Haine et al., 2019).

A lo largo del período de curación, no se registraron complicaciones graves asociadas con el implante. Además de la modificación mencionada previamente en el diseño del sistema después de dos semanas de tratamiento, no se observaron eventos que afectaran significativamente al sistema durante el resto del tratamiento. El implante se mantuvo intacto hasta el final del tratamiento, sin verse afectado por las complicaciones habituales de este tipo de sistemas, como la secreción serosa de los puntos de entrada de los clavos transfixiantes, el aflojamiento de los componentes del sistema y/o problemas de consolidación ósea (Yeh et al., 2021).

Conclusiones

8. Conclusiones

Las conclusiones obtenidas en esta Tesis Doctoral son las siguientes:

1. La fijación externa ha demostrado un alto nivel de eficacia cuando se utiliza como única técnica de estabilización quirúrgica en fracturas de ilion, acetábulo y sacro. Además, muestra un alto nivel de adaptabilidad, pudiendo ser empleada para tratar fracturas pélvicas de distinta índole, así como fracturas de sacro y fracturas fisarias acetabulares en animales muy jóvenes y de pequeño tamaño.

2. La seguridad de la fijación externa ha sido evidente, siempre y cuando se tenga un profundo conocimiento anatómico de la pelvis y se comprendan los fundamentos básicos de la técnica. En esta Tesis Doctoral se han detallado los corredores anatómicos para una aplicación segura de los implantes en la estabilización de fracturas pélvicas y sacras en pequeños animales. Además, se ha desarrollado una propuesta de clasificación de las diversas configuraciones de FE aplicables, lo que facilita la comprensión de los sistemas y sienta las bases para futuros estudios biomecánicos basados en los diseños propuestos.

3. El estudio respalda el empleo de la fijación externa como opción viable para estabilizar fracturas pélvicas y sacras en perros, mediante procedimientos rápidos, mínimamente invasivos y seguros. Sin embargo, esta opción requiere el conocimiento de los corredores seguros pélvicos y sacros, el dominio del uso de la técnica y la supervisión constante de la estructura del sistema durante todo el período de tratamiento. Se ha podido concluir que la configuración tipo O fue la más empleada en fracturas pélvicas, seguido de la X, tanto en fracturas de ilion como acetabulares, donde el diseño de estas configuraciones las hace polivalentes y estables.

4. Los resultados obtenidos en términos de curación, seguridad y bajo nivel de complicaciones para la estabilización de fracturas sacras en perros son destacables, permitiendo procedimientos mínimamente invasivos y precisos. La necesidad de fluoroscopio, el conocimiento de los corredores seguros, el

dominio de la FE y un cuidadoso mantenimiento del sistema durante todo el periodo de curación son los inconvenientes más notables. La configuración tipo T fue la más empleada, a pesar de su sencillez, debido a los buenos niveles de estabilidad aportados para este tipo de fracturas.

5. La fijación externa ha demostrado ser un tratamiento competente y seguro en el manejo de fracturas fisarias acetabulares en paciente felinos muy jóvenes y de pequeño tamaño, donde otras opciones quirúrgicas entran en conflicto por el gran tamaño de los implantes disponibles y su mayor invasión y daño tisular. Las desventajas más reseñables son la necesidad del uso de fluoroscopio para su aplicación y el mantenimiento diario del sistema externo.

6. En el desarrollo de los tres estudios, se han descrito diferentes escalas de valoración visual, para la evaluación del confort y la tolerancia de la FE por parte de los pacientes estudiados. Los buenos resultados, convirtiendo este dato en un fuerte argumento a favor de la FE para el tratamiento de fracturas pélvicas y sacras.

Conclusions

9. Conclusions

The conclusions obtained in this Doctoral Thesis are as follows:

1. External fixation has demonstrated a high level of effectiveness as the primary technique for surgically stabilizing fractures of the ilium, acetabulum, and sacrum. Additionally, it shows a high level of adaptability, allowing its application in different pelvic fractures, as well as sacral and acetabular physeal fractures in very young and small animals.

2. The safety of external fixation has been demonstrated, provided there is a deep anatomical knowledge of the pelvis and a comprehension of the basic technique principles. This Doctoral Thesis has described anatomical corridors for the safe application of implants in stabilizing pelvic and sacral fractures in small animals. Furthermore, a proposed classification of various external fixation configurations has been developed, facilitating the understanding of these systems, and establishing the basis for future biomechanical studies based on the proposed designs.

3. The study supports the use of external fixation as a viable option to stabilize pelvic and sacral fractures in dogs, employing rapid, minimally invasive, and safe procedures. However, this method requires knowledge of safe pelvic and sacral corridors, proficiency in the technique and continuous monitoring of the system structure during the treatment duration. The study concluded that the O-type configuration was the most frequently utilized in pelvic fractures, followed by the X-type, particularly in ilial and acetabular fractures, where the versatility and stability of these configurations were noted.

4. The achieved outcomes in terms of healing, safety and a low level of complications while stabilizing sacral fractures in dogs are noteworthy, enabling precise and minimally invasive procedures. The essential requirements of fluoroscopy, understanding safe corridors, expertise in external fixation and careful maintenance of the system throughout the healing process are significant

considerations. The T-type configuration, despite its simplicity, was the most used due to the good stability levels provided for this type of fractures.

5. External fixation has demonstrated competent and safety in managing acetabular physeal fractures in very young and small feline patients. This technique stands out when other surgical options are limited due to the unavailability of larger implants and their increased invasiveness, resulting in increased tissue damage. However, notable drawbacks include the necessity of fluoroscopy for application and daily maintenance of the external system.

6. The three studies developed various visual assessment scales to evaluate patient comfort and tolerance regarding external fixation. The positive outcomes from these assessments provide strong argument for the use of external fixation in the treatment of pelvic and sacral fractures.

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10. Bibliografía

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