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External skeletal fixation

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Abstract
External skelatal fixators have been used in veterinary medicine for many years. Fractures or joints stabilized using percutaneus fixation pins that penetrate the bone internally and connected externally. External fixators are useful for open and communited fractures that require prolonged fixation. It is especially useful in veterinary medicine because of the ease of application and wide spectrum indications.

Keywords: External skelatal fixation, dog, cat..

INTRODUCTION

The external fixation is a method of stabilization with percutaneous fixation pins that are attached internally to the bone and connected externally. The external fixator functions as an exoskeleton and with this method the motion system remains functional (Egger, 1998).

1. INDICATIONS

Minimally invasive osteosynthesis of external fixation is indicated, especially for the fixation of long bone fractures and osteotomies, but can also be very useful in the treatment of spinal and pelvic fractures (Wheeler et al., 2007; Fitzpatrick at al., 2008). The intraoperative adjustability of external fixations makes them very useful for the stabilization of fracture fragments. It is suitable for osteogenesis for limb lengthening as well as filling the remaining bone defects after bone resections (Yanoff et al., 1992; Markcellin-Little et al., 1998).

Ilizarov external fixator was designed by Gavriil Abramovich Ilizarov in Kurgan, Russia in the early 1950s. Ilizarov initially used this method by compression only for the purpose of osteosynthesis. However, after a patient accidentally performed distraction instead of compression in the system, new bone formation started between the fractured parts and he started to work on distraction osteogenesis (Girgin, 1983; Lette, 1997; Stallings et al., 1998).

External fixators are excellent for the treatment of bilateral complex, communited and open fractures. Because in open fracture wounds, necessary rigid stability can be achieved without implant in the region. It can also be easly used in fractures with bone loss and fractures with extensive soft tissue damage. The use of an external fixator allows the preservation of the length in the presence of bone defects and facilitates the process of bone graft application (Egger, 1998).

Advantages of external fixation

- Very useful for form a rigid construct.
- No implant at the fracture site.
- It does not cause any damage to soft tissues due to closed or minimally invasive approach.
- It is a useful structure for changing the fracture configuration (such as angular deformities.
- It can be combined with other fixation methods (Egger, 1998; Fossum, 2017)

2.PRINCIPLES OF EXTERNAL FIXATOR

Despite the numerous advantages of the external fixation system, there are some disadvantages that must be considered in order to achieve consistently positive results. The most prominent of these is the contact of the fixation pins to the skin and soft tissue. There is a risk of infection and pin tract inflammation of the incision sites. In addition, the connecting bars are away from the mechanically advantageous position within the central axis of the bone. As a result of these disadvantages, early pin loosening and pin tract inflammation are the most common complications of external fixation. Complications may be reduced by applying principles such as deciding external fixation, application technique, implant selection, and frame design (Guerin et al., 1998; Fitzpatrick et al., 2008).

3.TYPES OF EXTERNAL FIXATORS

3.1. Linear External Fixator

These systems are effective in compression, tension, bending, shear and neutralization of torsional forces (Palmer et al., 1992).

3.1.1. Indications and Biomechanical Principles

External skeletal fixators are a multipurpose treatment for long bone fractures, corrective osteotomies, joint arthrodesis and temporary joint immobilization. External fixators can be adjusted during and after operation to improve fracture alignment. They are not indicated for articular fractures (Egger, 1998; Fossum et al., 2017).

Factors influencing the strength and stiffness of the fixator and its ability to resist the axial loading, bending, and rotation associated with weight bearing include pins, connecting bars, frame configuration, and fracture configuration. Threaded pins are resistant to loosening as they are interlocking hold with bone. Increasing pin diameter increases pin stiffness, but the pin diameter should not exceed 25% of the bone diameter. Increasing the number of fixation pins in the main fracture pieces increases the stiffness of the fixator and the distribution of physiological loads between the pins. When more than four pins are used in the major proximal and distal fragment, the mechanical advantage is negligible. Shortening the distance between the bone and the fixation clamp increases the stiffness of the fixator. Increasing the number of bar and pin planes increases the strength and stiffness of the fixator. The connection bar material (stainless steel, aluminum, carbon fiber) affects the hardness of the fixator (Egger, 1998; Fossum et al., 2017).

3.1.2. Equipment and Supplies
External fixation devices comprise three basic units:

Fixation pins: Pins are classified as half pins or full pins depending on how they are applied. Half pins penetrate one skin surface and both bone cortices. Full pins penetrate one skin surface and both bone cortices, and they then exit through the opposing skin surface, transfixing the entire limb (Roe 1992; Toombs 1998). The fixation pins may be threaded. Threaded pins can be further described according to thread profile (negative or positive). Centrally threaded and end-threaded pins in which the core diameter of the threaded section is smaller than the diameter of the smooth section have a negative thread profile. If the core diameter is consistent between smooth and threaded regions, the thread profile is positive (Fossum et al., 2017).

Connecting bars: External connectors are made of stainless steel, titanium alloy, carbon fiber, aluminum, or acrylic (Fossum et al., 2017).

Pin-gripping clamps: The pin-gripping clamps connect the transfixation pins to the connecting bar. When using an acrylic system, the acrylic column serves as both the connecting bar and the pin-gripping device (Toombs, 1998).

3.1.3. Linear external fixator types
The fixation frames are classified according to the number of planes held by the frame and the number of sides to which the fixator protrudes from the limb (Egger, 1998).

3.1.3.a. Unilateral-uniplanar (type Ia) fixators
Type Ia fixators protrude only on one side of the extremity and are delimited by a plane, not perforating the opposite skin. Half pins are generally preferred. Type Ia fixators are usually placed laterally in the bones with long proximal level with medial chest and abdominal wall such as femur and humerus, and medially in distal long bones such as radius and tibia (Egger, 1998; Johnson, 2002).

3.1.3.b. Unilateral-biplanar (type Ib) fixators
It is formed by combining two Type Ia fixators. The purpose of this is that the two fixators combined have a higher hardness than one type Ia fixator. It is not the type of fixator used very often. Type Ib fixators are most commonly applied to the radius and tibia. In radius and tibia, one of the outer bars is placed on the craniomedial surface of the bone and the second on the craniolateral surface. In Tibia, one of the outer bars is placed on the craniomedial surface of the bone and the other on the craniolateral surface. Type Ia and Type Ib fixators are the least hardening types (Egger, 1998; Johnson, 2002; Fossum et al., 2017).

3.1.3.c. Bilateral-uniplanar (type II) fixators
Due to its position adjacent to the trunk, type II fixators cannot be placed on the femur or humerus. These are applied only to the radius and tibia and are usually applied in the frontal plane. Type II frames are formed by connecting one or more complete pins in each major fracture segment. The maximum type II frame consists of full pins. The minimal type II frame consists of one full pin proximal to the fracture segment and 1 full pin in the distal segment, and the remaining sites are filled with half pins. It is more durable than type I fixators (Egger, 1998; Fossum et al., 2017).

3.1.3.d. Bilateral-biplanar (type III) fixators
The frames protrude from two separate edges of the extremity. It consists of both type Ia and type II frames. It is not suitable for the femur and humerus due to their position on the body walls. Radius and tibia can be used. It is the most rigid linear fixator type. Unilateral frames consist of half pins that are located on the proximal surface of the skin and near and distal cortex of the bone. In bilateral frames, it is formed so that at least one full pin passes on both sides of the fracture. The full pin fits on both the near and distal skin and bone surfaces. The two-sided frame shown is the maximum type 2 because it consists of only full pins (Egger, 1983; Bronson et al., 2003).

3.1.3.e. External skeletal fixators with intramedullary pins (Tie-in fixators)
Humeral and femoral fractures are usually not fixed by external fixators alone because the most stable frames (type II and type III) cannot be applied to these bones. In order to provide the desired strength and stiffness for complex femoral or humoral fractures, it is often combined with an intramedullary pin type Ia or type Ib external fixators (Egger, 1998).

3.2. Circular External Fixators
The concept of distraction osteogenesis was first introduced in the 1950s by Prof.Dr. Gavriil Abramovich was developed by Ilizarov and has been successfully used in many orthopedic diseases that have not previously been treated. Ilizarov initially used this system for compression only for osteosynthesis. However, he began to study distraction osteogenesis by observing that a patient accidentally distraction instead of compression in the system and new bone formation started between the fractured ends (Girgin, 1983; Lette, 1997; Stallings et al., 1998).

There are many definitions of distraction osteogenesis. Distraction osteogenesis is the formation of new bone which is shaped by the gradual and controlled separation of the fragments. As defined by Ilizarov, it is the formation of new bone under the influence of low pressure. Regeneration during distraction is called the law of tension-stress (Peltonen et al., 1992; Lesser, 1994; Bilgili and Olcay, 1998; Stallings et al., 1998; Trostel and Radasch, 1998; Preston, 2000).

3.2.1. Indications and Biomechanical Principles
Circular external fixators are used for closed fractures of the limb (metaphyseal, diaphyseal, epiphyseal), treatment of congenital and traumatic pseudoarthrosis, nonunion, malunion, open fractures, correction of long bone and joint deformities, maxillofacial surgery fort he treatment mandibular hypoplasia, compress or distract fractures (Sisk, 1983; Bilgili and Olcay, 1998; Degna et al., 2000).

The circular external fixator is uniquely suited for controlled distraction of bone segments, resulting in new bone formation in the trailing pathways called distraction osteogenesis. Small-diameter tensioned wires provide adequate stability to bone segments but allow controlled axial micromotion at the fracture site without compromising the fixator’s stability (Lesser, 1998; Fossum et al., 2017).

For optimal mechanical stability, the frame comprises four rings securing four pairs of wires that are placed as close to perpendicular as the soft tissue anatomy allows. Ring diameter affects wire length and mechanical properties of the circular fixator. Increasing ring diameter decreases axial stiffness and to a lesser extent, torsional and bending stiffness. The smallest ring diameter, allowing a minimum of 2 cm between skin and ring, provides the optimal mechanical performance. The most proximal and most distal rings are placed at their respective metaphyseal locations, and the inner two rings are placed close to the fracture. This "far, near, near, far" construction provides optimal control and stabilization of the major bone segments (Lesser, 1998; Fossum et al., 2017).

3.2.2. Equipment and Supplies

Wires: Wires used for dogs and cats are generally 1, 1.2, or 1.5 mm in diameter. Wire strength and stiffness increase proportionately to the diameter of the wire. Wires with a bayonet point are preferred for drilling through cortical bone. Wires with a trocar point are reserved for drilling through cancellous bone (Fossum et al., 2017).

Rings: The unique feature and the central element of a circular external skeletal fixator is the ring. Rings are usually made of aluminium, stainless steel, or carbon fiber composite and have several holes around their circumference for placement of the other components. They are available in several diamaters and may be complete rings or partial rings (called arches) (Johnston and Tobias, 2018).

Wire fixation bolts: Cannulated wire fixation bolts allow wire passage through a concentrically placed hole at the base of the bolt head. The fixation bolt is then tightened to the ring surface with a nut, securely clamping the wire (Fossum et al., 2017).

Wire tensioner: The tensioner is an instrument used to tension the wires to an exact force. Wire tension affects the overall rigidity of the fixator construct. The exact amount of tensioning needed depends on the animal's weight, the local bone quality, the treatment plan, and the frame construction. Cats and small dogs do not require tensioning of the wires (Fossum et al., 2017).

Wrenches: At least two appropriately sized crescent wrenches are necessary for tightening bolts and nuts simultaneously (Fossum et al., 2017).

3.2.3. Treatment With Circular External Fixator

3.2.3.a. Arthrodesis

Circular external fixator can be used for carpal and tarsal arthrodesis. After the cartilage is removed, a pre-assembled frame with two rings proximal to the joint and two rings distal to the joint is placed and fixed (Marcellin-Little, 2003; Fossum et al., 2017).

3.2.3.b. Bone Lengthening

Bone lengthening is used to correct a shortened bone after premature physeal closure. Bone transport is used to fill a bone defect produced by traumatic bone loss or resection of a bone tumor. Successful application of this technique requires close attention to the details of appropriate osteotomy technique; preservation of marrow, periosteum, and extraosseous blood supply; application of a stable circular construct; and correct rate and rhythm of distraction (Fossum et al., 2017).

An optimum rate of 1 mm per day divided into a rhythm of four distractions per day (i.e., 0.25 mm per distraction) has been shown to favor regenerate bone formation without causing soft tissue discomfort and to be clinically achievable. Rate and rhythm of distraction can be varied slightly depending on the patient and on radiographic evidence of regenerate formation. An hourglass configuration of the regenerate bone indicates an overly rapid distraction rate. Inconsistent radiopacity, irregular bone columns, and focal failures of bone formation indicate instability or poor vascularity; the rate of distraction should be decreased until a normal regenerate is observed (Lesser, 1998).

3.2.3.c. Bone Transport

The principles and techniques described for bone lengthening are used when moving a segment of bone into a bone defect while stimulating new bone formation in the trailing pathway. The technique of bone transport is used to fill large bone column defects occurring after trauma, nonunion, osteomyelitis with sequestered bone, or bone tumor resection (Fossum et al., 2017).

3.2.3.d. Angular Limb Deformity Correction

Circular fixators are indicated for dogs that have severe limb length discrepancy, when additional extensive growth is anticipated, and in dogs that have significant craniocaudal deformity (Egger, 1998).

3.3. Hybrid External Fixators

3.3.1. Indications and Biomechanical Principles

Hybrid external fixators are a combination of ring fixator and linear fixator. Hybrid fixators are indicated for fractures near the joint. Hybrid fixators can be applied to the radius, tibia, femur and humerus. Typically, type Ia and Ib hybrid fixators are applied to the radius and tibia. Modified frames using fixation pins passing through the loop and connected to an intramedullary pin are applied to the humerus and femur. Hybrid fixators are also used for the treatment of some angular limb deformities (Fossum et al., 2017).

3.4. Acrylic External Fixation System

Advantages:

- Easy to use.
- No restrictions such as pin size.
- No complex planning or pre-assembly of fixator frames required before assembly
- There is little risk of loosening of pins or connecting bars.
- The surgeon can insert the pins freely into the bone (Kraus et al., 2003).

Disadvantages:

- Reduction is difficult to maintain if used for primary fixation.
- Heat (curing) occurs during polymerization.
- The fumes produced during the preparation are harmful, toxic and teratogenic (Kraus et al., 2003).

5. POSTOPERATIVE MANAGEMENT OF EXTERNAL FIXATORS

After surgery, the fixator and limb should be cleaned from blood and debris. Protective plastic caps should be applied to the cut end of each pin (Choate et al., 2011).

First, topical antibiotic (eg Bacitracin, neomycin and polymyxin B) ointment should be applied to the fixation element and skin interfaces to reduce microbial contamination and transition from the skin surface to the fixation element (Aron and Dewey, 1992; Rovesti et al., 2007). Sterile gauze is then placed between each fixing element and the skin to prevent the bandage layers from sticking. (Choate et al., 2011). Then the limb is wrapped with cotton. This bandage absorbs the exudate that may occur and reduces postoperative swelling that has the potential to cause soft tissue necrosis (Harari et al., 1996).

The pressure also reduces the movement of soft tissues around the fixation elements. The frequency of bandage changes is determined by the drainage intensity of open wounds (if present) (Choate et al., 2011).

In cases where pressure bandage is no longer required, a protective bandage technique is used. This bandage is intended to protect the animal and its owners from accidental damage or injury. The protective bandage should allow the maintenance of interfaces between the skin and fixation elements (Choate et al., 2011).

The time between routine check-ups depends on the complications and the fixator care of the patient owner (Lewis ve Bloomberg, 1994; Anderson et al., 2002). At each check-up, the fixator should be inspected and tightened. Radiographs should be obtained at intervals of four to six weeks during the recovery period. The fixator can be removed when bone healing is clinically and radiographically shaped (Choate et al., 2011).

External skeletal fixation is a multimodal and effective treatment model, but requires careful care throughout the healing period. Before deciding to use an external fixator, the possibility of patient owners and pets to follow postoperative care instructions should be considered. Fixators usually need to be maintained for a long period of time, and if the owner's suitability or pet's tolerance to the structure is low, external fixation will not be appropriate for that patient (Choate et al., 2011).

6. COMPLICATIONS

6.1. Pin tract drainage

Soft tissue movement around a fixation element causes exudation (Aron and Dewey 1992; Piermattei et al. 2006). Excessive or prolonged drainage causes loosening of the fixation component and infection (Aron and Dewey, 1992; Lewis and Bloomberg, 1994; Piermattei et al., 2006).

6.2. Implant loosening

The place where the fixation element enters the bone is the weakest link of the structure (Lewis and Bloomberg, 1994). Bone resorption and subsequent implant relaxation may occur if necrosis of the bone surrounding the fixation element occurs during placement. Insertion of pins or wires that are too close to the fracture site is caused by insufficient frame rigidity, excessive soft tissue movement around the fixation elements, or infection of a fixation element pathway (Choate et al., 2011).

6.3. Infection

Drainage is purulent, the fixation components are loosened by excessive drainage, bone lysis around the fixation element is visible by radiography and the use of the extremity by the patient is reduced (Aron and Dewey, 1992; Harari et al., 1996). In the treatment of infection of the fixation component pathway, it is necessary to remove the fixation component, clean the pathway of the fixation pathway and the surrounding soft tissues and apply systemic antibiotics (Choate et al., 2011).

6.4.Iatrogenic Fractures

Fracture of the pin channels is typically a result of inappropriate surgical technique. Using fixation component exceeding one third of the diameter of the bone; other fixation pins, and inadequate post-operative exercise restriction are considered to be the causes of fractures (Piermattei et al., 2006).

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