Use of hinged transarticular external fixation for adjunctive joint stabilization in dogs and cats: 14 cases (1999–2003)

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Objectives—To describe placement of hinged transarticular external fixation (HTEF) frames and evaluate their ability to protect the primary repair of unstable joints while allowing joint mobility in dogs and cats.

Design—Retrospective study.

Animals—8 cats and 6 dogs.

Procedure—HTEF frames were composed of metal or epoxy connecting rods and a hinge. Measurements of range of motion of affected and contralateral joints and radiographs were made after fixator application and removal.

Results—9 animals (4 cats and 5 dogs) had tarsal and 5 (4 cats and 1 dog) had stifle joint injuries. Treatment duration ranged from 45 to 100 days (median, 57 days). Ranges of motion in affected stifle and tarsal joints were 57% and 72% of control while HTEF was in place and 79% and 84% of control after frame removal. Complications were encountered in 3 cats and 2 dogs and included breakage of pins and connecting rods, hinge loosening, and failure at the hinge-epoxy interface.

Conclusions and Clinical Relevance—HTEF in animals with traumatic joint instability provided adjunctive joint stabilization during healing and protection of the primary repair and maintained joint motion during healing, resulting in early weight bearing of the affected limb. (*J Am Vet Med Assoc* 2005;227:586–591)

Trauma may lead to severe ligament sprains, juxta-articular fractures, and shearing injuries, resulting in joint instability. Severe ligament sprains include collateral and cruciate ligament ruptures. Juxta-articular fractures include malleolar fractures and fractures of the styloid processes and epicondyles. The treatment goals for these injuries are to limit further damage to the remaining supporting structures and articular surfaces, restore anatomic joint alignment, restore normal stability to affected joints, and maintain normal range of motion. Previously described repair methods include primary repair or replacement of the injured ligament with autogenous tissues or a prosthetic ligament.[1-5] Conventionally, these repairs are protected after surgery by use of external coaptation or rigid transarticular external fixation for 4 to 8 weeks.[5-7] Although joint immobilization has a protective effect in the short term (< 4 weeks),[8] it has a deleterious effect on physiologic features of the joint. Immobilization causes decreases in synovial fluid production, cartilage stiffness and thickness, and range of motion. It also leads to cartilage fibrillation, cleft formation, intra-articular adhesions, periarticular contractures, and the development of degenerative joint disease in normal and injured joints.[9-16] Joint immobilization also leads to loss of muscle mass and bone mineral content and density.[17,18] Remobilization of joints after periods of immobilization helps reverse the negative consequences of immobilization. Some of the changes present after joint immobilization, however, appear to be permanent. Rapid, sudden remobilization of joints after a period of immobilization (such as removing a splint or external fixator) is more detrimental to cartilage health than progressive, gradual remobilization with return to normal activity.[10,19-22] During the period of immobilization, there is a loss of the proteoglycan matrix that results in decreased resilience of the articular cartilage. Early aggressive remobilization may damage the structural integrity of the softened and thinned articular cartilage. Progressive remobilization permits increases in joint range of motion while maintaining stiffness of the articular cartilage. Clinically, early joint mobilization appears to have beneficial effects after distal radial, tibial, and fibular articular fractures in humans by decreasing the loss in muscle torque, grip strength, and range of motion.[23,24] Sustained joint motion also provides pain relief and improves limb function in the early postoperative period in dogs and humans.[25-27]

Hinged transarticular external fixation (HTEF) provides joint stabilization while maintaining relative freedom of movement in the joint's natural **plane of motion** (POM).[28] An appropriately placed hinge restricts motion to a single plane parallel to the joint's POM and rotates about the joint's natural **axis of rotation** (AOR).[29-31] This permits supported healing of the damaged structures while at the same time avoiding the deleterious effects of prolonged joint immobilization. Normal range of motion places physiologic loads on healing ligamentous structures and the joint capsule. This improves the microscopic and ultrastructural orientation of healed tissues while increasing the tensile strength of the tissues. Ligaments that heal without loading have a disorganized structure that is mechanically weak. Physiologically loaded ligaments have fibers that are oriented along lines of force, leading to a stronger and more functional ligament.[32,33] In humans,

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the results of HTEF for adjunctive treatment of interphalangeal and elbow luxations and phalangeal, distal radial, and distal tibial fractures appear promising.[27,28,34,35] To the authors' knowledge, HTEF has been briefly mentioned in veterinary medicine but no clinical reports have been published.[36,37]

The purposes of the study reported here were to describe the placement of an HTEF in clinical cases, evaluate its ability to protect the primary repair of unstable joints, and assess the range of motion maintained with the application of an HTEF, compared with the contralateral joint. We hypothesized that the addition of a hinge to transarticular stabilization would provide stabilization of the repaired joint, protect the primary repair during healing, and maintain range of motion of affected joints and good limb function. We also hypothesized that the HTEF would be easy to apply and would be well tolerated, without any detrimental effects on the patient or healing of the primary injury.

Criteria for Selection of Cases

Medical records of dogs and cats evaluated at the North Carolina State University Veterinary Teaching Hospital and Miami Veterinary Specialists between December 1999 and June 2003 with traumatic fractures and ligamentous injuries resulting in joint instability of the tarsus and stifle were reviewed. Animals in which an adjunctive HTEF was applied to the affected joint for protection of the primary repair during healing were eligible for inclusion in the study.

Procedures

The signalment, cause of injury, location and severity of the injury, method of primary repair, concomitant injuries, fixator type and configuration, time to fracture healing and ligamentous stability, and duration of external fixation were recorded. Postoperative outcomes were determined by evaluating limb use and ranges of motion during and after fixation, compared with the contralateral joint.

The dislocated joints were explored to determine the presence of articular fractures and collateral ligament tears and, for stifle joints, potential cruciate ligament and meniscal tears. After exploration and primary repair of the joint, an HTEF frame was placed in accordance with recommendations for a linear external fixator, including pin size and number.[38-41] Positive profile end-threaded pins,[a] not exceeding 30% of the bone diameter, were placed in the long bones adjacent to the affected joint. The pins were placed on the lateral aspect of the femur and tibia to stabilize stifle joints and on the medial aspect of the tibia, talus, central tarsal bone, or metatarsal bones to stabilize tarsal joints. Factors influencing the number of pins included attempting to minimize soft tissue injury (stifle joints) while maintaining adequate stability of the joint, the degree of primary injury and fixation, and surgeon preference. The fundamental principles of conventional external fixation were followed as closely as the anatomic features of the injuries allowed. At least 2, preferably 3, pins were placed in each bone. Pins were placed in predrilled pilot holes so that the positive profile threads engaged both cortices, and most of the length of the long bone was spanned by use of the far-near-near-far principle.[36]

The connecting rods of the HTEF were made of metal (stainless steel or titanium; **Figure 1**), epoxy putty, or a combination of metal and epoxy[42] on the basis of patient size and availability of components. End-threaded titanium hybrid rods[a] were used with small SK clamps[a] and internally threaded female hinges[b] to form all-metal articulated frames. Externally threaded male hinges[a] (**Figure 2**) were embedded in epoxy putty[c] to form the free-form HTEF. Fully threaded stainless steel rods[b] were used with female hinges[b] to form a metal articulated frame, and epoxy was used to secure the pins to the connecting rods to form a composite frame (**Figure 3**). The hinge was placed over the joint so that its POM was parallel to that of the joint and its AOR was in the same axis as that of the joint. This was accomplished by slowly taking the joint through a range of motion while the clamps were tightened onto the connecting rods or while the epoxy hardened. For stabilization of the tarsal joint, the hinge was centered medially over the talar ridges, with the connecting bars along the axes of the metatarsals and tibia. For stabilization of the stifle joint, the hinge was placed over the AOR, which lies caudal to the longitudinal axes of the femur and tibia.[43-45]

Moderate activity recommended after surgery included leash walks and climbing or walking down stairs. Maintenance of the HTEF included daily cleansing of the pin tracts and application of a triple antimi-

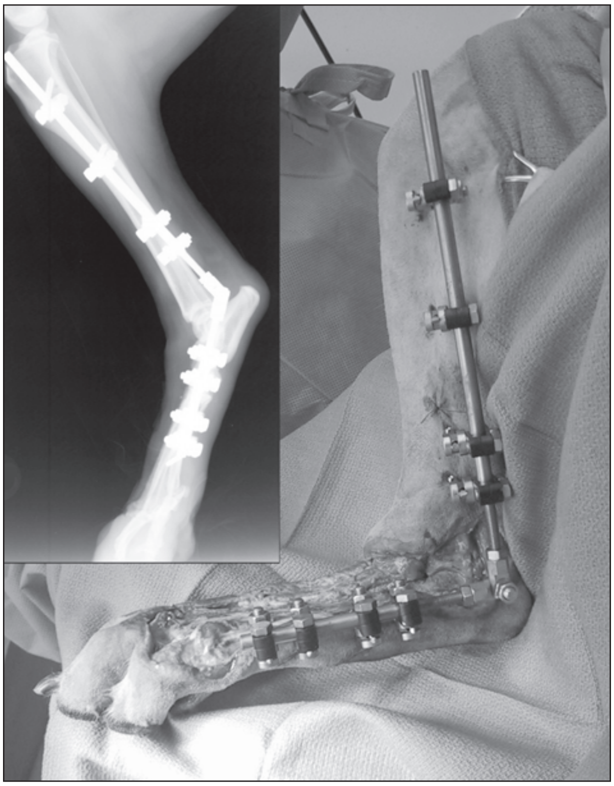

Figure 1—Photograph and lateral radiographic view of the hind limb of a 4-year-old Golden Retriever. A hinged transarticular external fixation frame has been placed medially across the tarsus to stabilize a shearing injury with tarsocrural luxation. Four pins are anchored in the tibia (inset), 1 in the central and fourth tarsal bones, and 3 in the second and third metatarsal bones. The frame consists of 2 titanium hybrid rods and a stainless steel hinge.

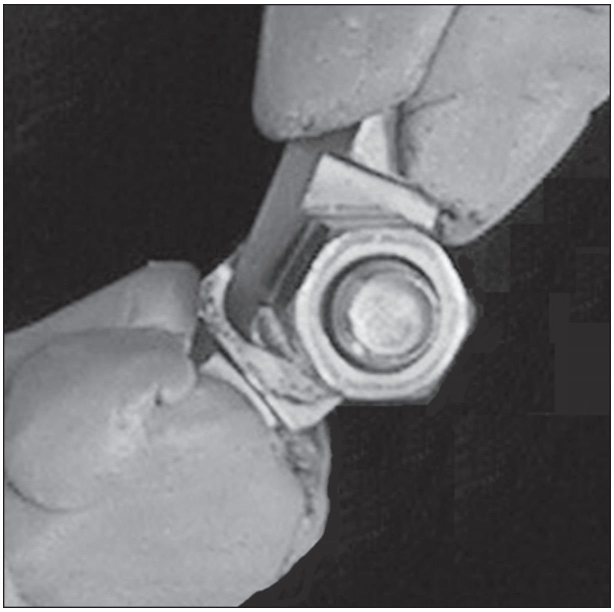

Figure 2—Magnified image of a stainless steel male hinge embedded in epoxy as part of a free-form hinged transarticular external fixation frame.

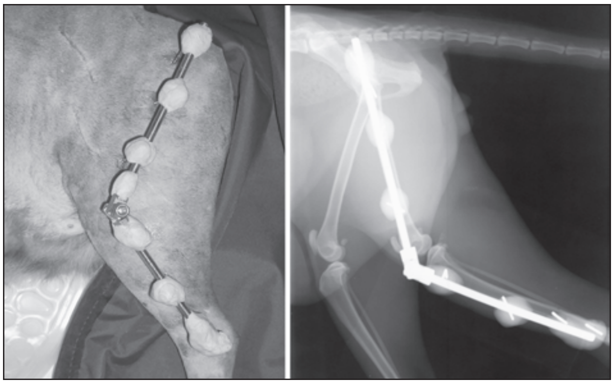

Figure 3—Photograph and lateral radiographic view of the hind limb of a 3-year-old domestic shorthair cat. A composite hinged transarticular external fixation frame has been placed laterally across the stifle joint to stabilize a traumatic luxation with tears of both menisci, both cruciate ligaments, and the medial collateral ligament. Three pins are anchored in the femur and 4 in the tibia. The frame consists of epoxy putty at the pin-connecting rod junction, 2 stainless steel threaded connecting rods, and a stainless steel hinge.

crobial ointment. The patients were sedated at the time of reevaluation, typically at 4 and 8 weeks after surgery. Affected joints were radiographed to assess frame integrity, possible mechanical complications, fracture healing, and potential osteomyelitis. The hinges were loosened to assess the varus-valgus stability of affected joints. The HTEF frames were removed if the fractures were healed and joints were considered to be stable on palpation and manipulation of the repaired joint. Measurements of the flexion and extension angles of affected and contralateral joints were made after frame application and upon frame removal, with the uninjured contralateral joint used for comparison, while the patients were sedated.[46] Complications were recorded. Outcomes were based on joint stability, range of motion, and limb use.

Statistical analyses—The measurements obtained from the affected and contralateral stifles and tarsi were compared. One-tailed *t* tests were used to compare measurements between affected joints with the fixator applied and control joints, affected joints with the fixator applied and after its removal, and affected joints after the fixator was removed and control joints.

Comparisons of measurements were made individually between joint flexion, extension, and overall range of motion for stifles and tarsi. For all comparisons, differences were considered significant at values of $P < 0.05$.

Results

Eight cats and six dogs were included in the study. The cats were 2 to 15 years old (median, 3 years old), and the dogs were 4 months to 12 years old (median, 3 years old). Five dogs and 4 cats had tarsal injuries, including 7 medial and 2 lateral collateral ligament injuries. Three of these injuries were shearing injuries with varied loss of articular cartilage. One dog and 1 cat with tarsal injuries had concurrent contralateral coxofemoral luxations. Five patients (4 cats and 1 dog) had traumatic luxations of the stifle joint with multiple ligament sprains. One cat with a stifle luxation had an ipsilateral coxofemoral luxation and a contralateral acetabular fracture. One dog had a concurrent radius and ulna fracture and bilateral pelvic fractures. The witnessed injuries were caused by motor vehicle accidents (3/14) or being caught in a trap (1/14) or an electric garage door (1/14). Nine injuries occurred while the animals were roaming outdoors unsupervised.

Primary repair of injured ligaments was performed in 4 patients (1 stifle and 3 tarsi) with 2-0 polypropylene. Prosthetic ligaments were placed in 9 patients. Four stifle joints were stabilized with lateral extracapsular sutures (monofilament nylon). One of these had an additional medial extracapsular suture, and another had an additional prosthetic suture of polydioaxanone and bone screws. Of the 4 tarsal injuries, 2 were stabilized with a nonabsorbable suture (1 polypropylene and 1 nylon) and 2 with stainless steel wire figure-of-8 sutures placed around bone screws. Tibial and fibular malleolar fractures were repaired by use of Kirschner wires, bone screws, or tension band wires. Two tarsal shearing injuries underwent daily wet-to-dry bandage changes of the medial wound until a healthy granulation bed was achieved, then were covered with nonadherent bandages until epithelialization was complete. The third shearing injury was closed primarily. Stifle joint stabilization was achieved with free-form epoxy putty in 1 dog that weighed 16 kg (35.2 lb) and 3 cats, and a modified metal-acrylic frame was used in 1 cat (Figure 3). Tarsal stabilization was achieved with free-form epoxy putty frames in 4 cats and 1 dog that weighed 13 kg (28.6 lb) and with threaded metal connecting bars in 4 dogs (Figure 1). Two to 4 pins were used proximal and distal to the joint. The pin shaft diameters ranged from 0.9 mm (0.035 inches) to 3.2 mm (0.125 inches).

Flexion of normal stifle joints ranged from 15° to 40° (mean, 30°), and extension ranged from 165° to 180° (mean, 172°). Flexion of affected stifle joints after frame placement ranged from 55° to 65° (mean, 58°), and extension ranged from 125° to 160° (mean, 140°). The range of motion ranged from 127° to 160° (mean, 142°) for normal stifle joints, from 60° to 105° (mean, 82°; 57% of control) for affected stifle joints after frame placement, and from 83° to 130° (mean, 113°; 79% of control) at frame removal. Mean loss of flexion of stifle joints was 27° after frame placement and 19° after frame removal. Mean loss of extension of stifle joints was 29° after frame placement and 11° after frame removal.

Stifle joint range of motion and flexion were significantly different between affected joints with fixators and control joints (range of motion, $P = 0.005$; flexion, $P = 0.032$), affected joints with fixators and after fixator removal (range of motion, $P = 0.019$; flexion, $P = 0.008$), and affected joints after fixator removal and control joints (range of motion, $P = 0.021$; flexion, $P = 0.021$). Stifle joint extension was significantly different between affected joints with fixators and control joints ($P = 0.029$) and between affected joints with fixators and after fixator removal ($P = 0.029$), but no difference was detected between affected joints after fixator removal and control joints ($P = 0.085$).

Flexion of normal tarsi ranged from 20° to 47° (mean, 33°), and extension ranged from 154° to 180° (mean, 169°). Flexion of affected tarsi after frame placement ranged from 36° to 75° (mean, 59°), and extension ranged from 127° to 175° (mean, 157°). The range of motion ranged from 107° to 160° (mean, 135°) for normal tarsi, from 65° to 138° (mean, 98°; 72% of control) for affected tarsi after frame placement, and from 86° to 145° (mean, 114°; 84% of control) at frame removal. The mean loss of flexion of the tarsi was 25° after frame placement and 20° after frame removal. The mean loss of extension of the tarsi was 14° after frame placement and 9° after frame removal.

Tarsal joint range of motion and flexion were significantly different between affected joints with fixators and control joints (range of motion, $P = 0.036$; flexion, $P = 0.036$) and between affected joints after fixator removal and control joints (range of motion, $P = 0.018$; flexion, $P = 0.021$) but not between affected joints with fixators and after fixator removal (range of motion, $P = 0.087$; flexion, $P = 0.084$). No differences were observed in measurements of tarsal joint extension between affected joints with fixators and control joints ($P = 0.089$), affected joints with fixators and after fixator removal ($P = 0.088$), or affected joints after fixator removal and control joints ($P = 0.094$).

Restoration of normal joint stability was achieved in all patients, and all fractures healed. Treatment duration ranged from 45 to 100 days (median, 57 days). All patients were bearing weight on their affected limbs at the time of hospital discharge. Complications included loosening of the metatarsal pins (n = 2), broken distal metatarsal pins (1), broken connecting rod (1), loose hinge (1), and failure of the epoxy-hinge interface (1). All complications were treated under sedation by modifying (n = 5) or removing the frames (1). Osteomyelitis was not apparent radiographically in any animal, and excessive drainage of the pin tracts was not observed.

Discussion

The principles of fracture treatment formulated by the Arbeitsgemeinschaft für Osteosynthesefragen are anatomic reduction; stable fixation; preservation of blood supply; and early, active mobilization of muscles and joints.[47] Hinged transarticular external fixation is the only described technique that satisfies the principle of early, active mobilization in the treatment of traumatized joints. The frames described in this report were intended to protect primary-repaired unstable joints in the postoperative period while allowing protected range of motion, thus facilitating early weight bearing.

The range of motion of affected stifle and tarsal joints was decreased during treatment but allowed motion within the range of motion used at a walk.[48] It was subjectively felt that allowing protected range of motion throughout the postoperative period led to a surprisingly rapid return to function. Overall, HTEF appeared to be successful because the fractures healed, the joints were stable at frame removal, the frames were well tolerated by the patients, no patient needed a second surgery, and limb function at the end of treatment was good in all joints treated. Although HTEF and other forms of early protected joint motion appear to be beneficial in the short term in humans with fractures and dislocations,[23,24,49,50] its long-term benefits are not fully known.[51] Physical therapy, including joint range of motion exercises, results in earlier and more complete return to limb function and reduces the potential of secondary degenerative changes in dogs.[15] The specific benefits of HTEF in dogs should further be evaluated by conducting a long-term, prospective, randomized study, comparing various postoperative restrictions of joint motion in patients with severe sprains. The benefits of a specific physical rehabilitation program involving passive range of motion manipulation and therapeutic exercises could also be evaluated in dogs and cats.

We used similar goniometric measurement methods for dogs and cats in this study and reported the combined results for dogs and cats. Although goniometry has been validated in dogs,[46] it has not been validated in cats. We assumed that goniometry would be as reliable for cats as for dogs. Each patient was used as its own control by comparing motion in affected and contralateral joints. While the frames were in place, loss of range of motion appeared higher for stifle joints (43% loss) than for tarsal joints (28% loss). This may be attributable to the fact that an HTEF frame is more likely to follow the hinge motion of the tarsal joint than the sliding-gliding motion of the stifle joint. At frame removal, the mean losses in the range of motion of stifle and tarsal joints were low (21% and 16% of control) and loss of flexion (19° and 20°) appeared higher than loss of extension (11° and 9°). Our data indicated that the frame did mechanically limit the extremes of range of motion and seemed to limit flexion more than extension. The frames were originally placed with the limb in a standing angle, and this may explain the preferential preservation of extension versus flexion. The limitation of flexion persisted after frame removal and may have been attributable more to the original injury than mechanical limitation of the frame. Although these ranges of motion were judged to be compatible with good limb function, the short- and long-term functional consequences of HTEF are not fully known. In a study[11] comparing rigid fixation versus mobilization of the talocrural joint in sheep with an articulated transarticular external fixator, rigid fixation and intermittent passive range of motion resulted in a significant decrease in immediate joint range of motion, compared with maintained voluntary joint motion. Over time, animals in that study with rigid external fixation had improvement of joint range of motion. In a group of dogs with traumatic stifle joint luxations treated by use of rigid transarticular external fixation and evaluated over a period of 1 to 5 years postoperatively, stifle joints lost < 5° of extension and 10° to 40° of flexion, compared with contralateral joints.[3] Because joint motion increases months after frame removal in patients treated with distraction osteogenesis and circular external fixators, the joint motion in joints treated with HTEF is likely to be maintained or increase over time.[52,53] Hypothetically, the difference in overall maintained joint range of motion and overall prognosis for the stifle and tarsal injuries in the present study may be a result of the primary injury. Although stifle joint injuries were limited to ligament disruptions, tarsal injuries were more likely to include damage to articular cartilage by fracture or shearing. The combination of articular damage and joint instability may worsen the long-term prognosis, compared with joint instability alone.

Long-term radiographic assessment of the affected joints was not performed in the present study. Because of the variety of injuries and intra-articular damage from the initial injury, degenerative joint disease sequential to hinge placement would not be discernable from the effects of the primary injury and repair. Evaluation of the long-term effects of transient application of a hinged transarticular external fixator would necessitate the placement of the fixator on uninjured joints with long-term radiographic, histologic, and goniometric analysis. This type of study may also assist in determining whether inappropriate hinge placement (hinge out of the AOR or POM of the joint) affects the long-term outcome of joint health and motion.

The surgical placement of an HTEF may be challenging because of variation in location of the AOR and POM due to differences in joint anatomy, limb size, and limb shape. Tarsal joint motion is almost a pure hinge, but its AOR is directed 25° laterally off the sagittal plane.[29,54,55] The motion of other joints, however, is even more complex. The POM of the elbow joint is more sagittal in extension and becomes more transverse as the joint flexes, describing a curved plane.[54] The AOR of the stifle joint is caudal to the joint, and the AOR of the carpus is cranial to the joint.[46] The stifle joint is a sliding-gliding joint with a limited amount of axial rotation. The stifle joint has an AOR that moves within a caudally directed loop as the joint flexes and a POM that changes as the joint is extended (the screw-home phenomenon).[30] The screw-home phenomenon is an external torsion of the tibia at the extreme of extension. Our hinged frames did not allow this torsion but limited the stifle-to-sagittal motion in the middle part of the joint's natural range of motion. A previous report[37] recommended identifying the AOR and POM via visual cues and driving a Steinmann pin through it for localization of the AOR. That method has the disadvantage of being traumatic to the joint and potentially inaccurate. Inaccurate placement of a transarticular hinge may place abnormal stresses on the healing support structures and the articular cartilage.[53] The motion of the joint follows the misplaced hinge, resulting in potential disruption of the fixation and altered stresses and strains to the articular surfaces. In the stifle joint, however, which is a sliding-gliding joint with a distinct screw-home torsional component, the apparent limitation of the fixator may not be as detrimental as it appears. Having the hinge motion limited to a pure plane, thereby preventing the torsion present in a normal joint, may actually be beneficial by restricting uncontrolled joint motion that could be detrimental to healing.

For the patients in this study, the AOR and POM were located by placing the connecting rods along the axes of the long bones adjacent to the affected joints, slowly flexing and extending the affected joints, and then placing the hinge over the center of the joint's rotation. The use of free-form epoxy frames facilitated the placement of that hinge because the shape of the frame may be modified while the epoxy is hardening. This is particularly advantageous when the AOR is not aligned with the anatomic axes of the bones, for example, with the stifle joint. Free-form epoxy frames have additional benefits, including low cost, easy availability, ease of use, and lighter weight for small patients. Most of the implant failures that occurred in the patients in this study were considered to result from excessive activity. However, breakage of the thread of a titanium hybrid rod was suspected to have occurred because of a malpositioned hinge.

In this case series, the application of HTEF effectively sustained joint motion and allowed early weight-bearing activity in patients with severe joint instability. The functional outcome of a joint stabilized with HTEF appears promising, although additional studies are necessary. Further analysis of HTEF is required to objectively assess the long-term outcome on joint health and mobility and evaluate whether long-term function is superior to traditional techniques that use rigid immobilization to protect the repair.

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[a] IMEX Inc, Longview, Tex.
[b] Small bone fixator, Hofmann srl, Monza, Italy.
[c] Oatey, Cleveland, Ohio.

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