THE TREATMENT OF FRACTURES WITH A DYNAMIC AXIAL FIXATOR

GIOVANNI DE BASTIANI, ROBERTO ALDEGHERI, LODOVICO RENZI BRIVIO

From the Institute of Clinical Orthopaedics and Traumatology, University of Verona, Verona

The results obtained with a lightweight dynamic axial fixator in the treatment of fractures are reported. The apparatus comprises a single bar with articulating ends which clamp self-tapping screws and can be locked at an angle appropriate for axial alignment. A telescopic facility allows ready conversion from rigid to dynamic fixation once periosteal callus formation has commenced. Reduction and controlled distraction or compression are achieved by means of a detachable compressor unit.

We treated 288 patients with fresh fractures and 50 with ununited fractures. The success rate for fresh fractures was 94%, with average healing times ranging from 3.4 to 6.5 months. In ununited fractures also, the success rate was 94% with average healing times ranging from 4.7 to 6.5 months. Complications were minimal. The device is versatile and can be applied in an average of 15 minutes. It permits ambulatory fracture care without sacrificing a sound anatomical result.

External skeletal fixation has become increasingly popular over the past decade as a result of the improvements to the original Hoffmann system made by Vidal and his group (Vidal *et al.* 1976). During that time, two schools of practice have emerged. One, which has been widely accepted, conceives of the method as a primary treatment for complicated fractures with extensive soft-tissue injury. Its proponents have cited the rigidity of the multibar Vidal system as an important advantage; results have been reported from many sources, including Olerud (1973), Brooker (1979), Edwards (1979) and Mears (1979). The second approach has been championed by Burny and his group (Burny 1972). This conceives of external skeletal fixation as a valid alternative to most other forms of fracture stabilisation and, as such, its wide use in simple, closed fractures, as well as in more complicated injuries. Burny's method departs from the Vidal approach by using a single unilateral bar to connect the pins, thereby introducing a degree of elasticity to trigger a bulkier callus than can be achieved with the more rigid frame technique.

After seven years' experience with the Hoffmann type of external fixation device in Verona (where 174 patients have been treated with the Vidal frame and 48 with the Burny frame), a variety of technical and clinical problems stimulated a re-examination of the biomechanical and biological principles underlying external skeletal fixation. Several goals were established which, hypothetically, would result in a simpler, more reliable system. These include an apparatus which could accomplish the following points.

1. Maximal versatility with a minimal number of parts, to facilitate application of the apparatus and reduction of the fracture.
2. A single external bar and pin system which controls lateral bending and torque forces while permitting controlled distraction, compression or dynamic axial loading once callus formation begins.
3. Maximal rigidity which can be easily achieved after reduction and maintained during the first phases of fracture healing.
4. A pin design which maximises stability, minimises potential trauma to soft tissues during application, and decreases the incidence of long-term pin complications.
5. Lightness of weight and freedom from cumbersome features which might prevent the patient from functioning normally.
6. Ease of removal of the frame and pins as an outpatient procedure.

After extensive testing in the biomechanics laboratories of the Universities of Montpellier and Padua, the major goals outlined above were achieved in 1977 (De Bastiani, Aldegheri and Renzi Brivio 1979a). The resulting device* (Fig. 1) comprises a single bar with two articulating ends which clamp the screws and are capable of being locked at an appropriate angle for axial alignment by means of a cam system. A telescopic facility within the body of the bar allows conversion from rigid to dynamic fixation by turning a single screw. This system

G. De Bastiani, MD, Professor and Director
R. Aldegheri, MD, First Assistant
L. Renzi Brivio, MD, Assistant
Institute of Clinical Orthopaedics and Traumatology, University of Verona, Policlinico di Borgo Roma, 37134 Verona, Italy.
Requests for reprints should be sent to Professor G. De Bastiani.

*Orthofix (registered trademark).

does not allow rotation, but does permit axial movement which, applied at the appropriate time, stimulates callus formation; hence the term dynamic axial fixator (DAF).

Reduction of the fracture and controlled distraction or compression are achieved by means of a separate compressor unit which attaches to the body of the fixator and can be removed at will.
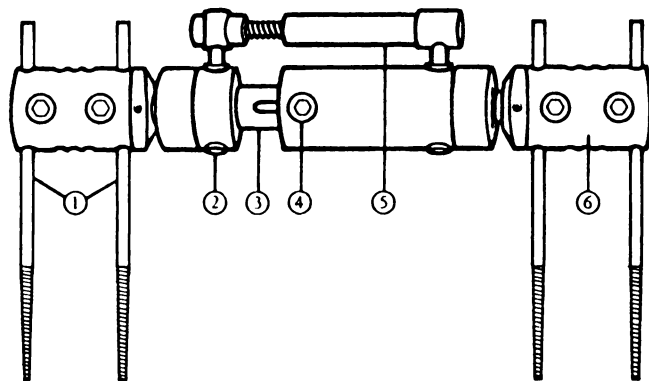

Fig. 1

Basic features of the dynamic axial fixator: *1*, self-tapping screw with diameter of 6 mm tapering to 5 mm; *2*, locking cam; *3*, telescopic body which permits conversion from rigid to dynamic system, and assures linear (axial) compression without torque or bending after initial healing in rigid state; *4*, stop-screw which prevents rotational displacement and allows telescopic adjustment; *5*, compressor/distractor which is removed to minimise weight once the fracture is reduced, distracted or compressed; *6*, articulating heads which are locked using a cam system.

The point of maximal stress is the screw–cortex interface nearest to the body of the fixator. Studies demonstrated that to ensure optimal stability at this point, with minimal bending of the screws and respect for bone integrity both at insertion and after removal of the screws, the screw-thread diameter should taper from 6 mm to 5 mm (De Bastiani *et al.* 1979b).

This report summarises the clinical results, since 1978, of using the dynamic axial fixator in simple and complex fractures, as well as in ununited fractures. It demonstrates the validity of the design in relation to the stated goals and highlights the fact that the average time required to apply the apparatus ranges from 10 to 20 minutes.

PATIENTS AND METHODS

This series comprised 338 patients (231 males and 107 females) with an average age of 33 years (range 7 to 82 years). Of these patients, 288 presented with fresh fractures (195 with single lesions and 93 with polytrauma); there were 239 closed and 49 open fractures. A further 50 patients presented with ununited fractures, the majority of which were less than nine months from injury and, therefore, were technically delayed unions; 14 of these 50 (28%) had extensive bone loss and were infected, while a further 12 (24%) had a history of discharge or were actively discharging. The sites of involvement for

fresh fractures and delayed unions were as follows: 117 femora, 160 tibiae, 44 humeri, 1 radius and 16 pelvic fractures.

The treatment of the 288 fresh fractures consisted of application of the DAF unit as soon as possible after injury. A single self-tapping, tapered screw was inserted through both diaphysial cortices in one fragment, following a predrilled track using screw and drill guides. A locator template was placed on this screw and the remaining three screws above and below the fracture inserted in a similar manner. In tibial lesions, the screws were invariably introduced from the medial cortex so as to stop short of the peroneal nerve and vessels in the lateral compartment. Femoral lesions were approached from the lateral aspect of the thigh; flexion and extension of the knee under anaesthesia was performed in order to elongate the incisions in the fascia lata and vastus externus sufficiently to permit a full range of knee movement.

After insertion of the screws, the ball-jointed external bar was set to an appropriate length and clamped to the screws. Final reduction of the fracture was then effected. When image intensification or radiographs confirmed that reduction was adequate, the cams were locked against the ball joints and the telescopic central bar locked in the external sleeve. The average time required to apply the apparatus was 15 minutes (range 10 to 20 minutes).

Fig. 2
Tibial fracture with fixator in place.

Physiotherapy for the adjacent joints was begun on the second postoperative day and the dressings where the screws entered were changed daily. Patients with simple closed fractures were usually discharged from hospital by the fourth postoperative day; partial weight-bearing on crutches began at this time, provided that the fracture was stable. At the first radiographic indication of periosteal callus (at approximately three weeks) the set screw blocking axial movement (telescoping) was loosened and dynamic loading begun. Loading in this

system is uni-axial; bending or torque moments are prevented by the design of the bar. Clinical assessment of progress was greatly facilitated by the ease with which the fixator could be removed and replaced. By about four months, or when union was complete, external fixation was discontinued.

Because of their conical design, the screws were easily removed in the outpatient department without anaesthesia. Once the external fixation device had been removed, the patients were able to return to full function immediately, without protective casting, since graduated weight-bearing had been possible with the fixator in place (Fig. 2).

For patients with infected delayed union or loss of substance (or both), the dynamic axial fixator was applied to align and stabilise the lesion. Attempts were made to control infection by local and systemic measures. Skin cover was completed and fresh autogenous cancellous bone grafts added when indicated. In many of these patients, two to three months were required to prepare the site for bone grafting. The fixator and screws remained in place for this initial period plus the six or more months required for union in such complex cases.

RESULTS

The overall success rate for the 288 fresh fractures, whether open, closed or associated with polytrauma was 94%. A successful outcome implied healing with less than 5° of angular deviation or rotation, less than 1 cm of shortening with the patient restored to full weight-bearing without the need for external support, and a full range of associated joint movements. None of the cases in the present study fell outside these limits. Details are

Table I. Healing rates for fresh fractures

Fracture location	Healed	
	Number	Percentage
Closed		
Tibia	83/91	91
Femur	90/92	98
Humerus	39/40	98
Pelvis	16/16	100
Open		
Tibia	35/40	88
Femur	8/9	89

given in Table I and illustrative examples in Figures 3 to 36; the equipment is shown in Figures 37 to 40. The average healing rate for open and closed cases varied by only 8.25%, with the advantage in favour of the simpler fractures. The average time to union is given for each anatomical site in Table II. It ranged from 3.4 months

for closed fractures of the humerus to 6.5 months for open fractures of the femur.

For the 50 patients with delayed union or non-union, the overall success rate was also 94% with little variation between patients who presented with a simple lesion and those with loss of substance and infection (Table III and Figs 27 to 36). From Table III, however, it is clear that union took nearly two months more, on average, to become complete in these ununited fractures. There were 16 femoral fractures in this group, 29 tibial fractures, 4 of the humerus and 1 of the radius.

Table II. Time to union in fresh fractures

Fracture location and type	Average time to healing (months)
Closed tibia	3.6
Open tibia	5.25
Closed femur	4.4
Open femur	6.5
Closed humerus	3.4
Closed pelvis	3.5
Overall average	4.4

Table III. Time to union in ununited fractures (delayed unions and non-unions)

Nature of fracture	Number healed	Time to union (months)
Simple	34/36	4.7
Loss of substance and/or infection	13/14	6.5

Complications. Table IV lists the complications encountered. Of note are the low rates of infection of pin (screw) tracks and loosening (14 out of 1525 pins; 10 patients). Pin tracks were regarded as infected if seepage or inflammation persisted despite antibiotic therapy and if followed by loosening. Pins were recorded as loose if they could not be retightened with a half turn of the tapered screw, in which case they were removed. Eight cases

Table IV. Complications (and percentage of patients in which they occur)

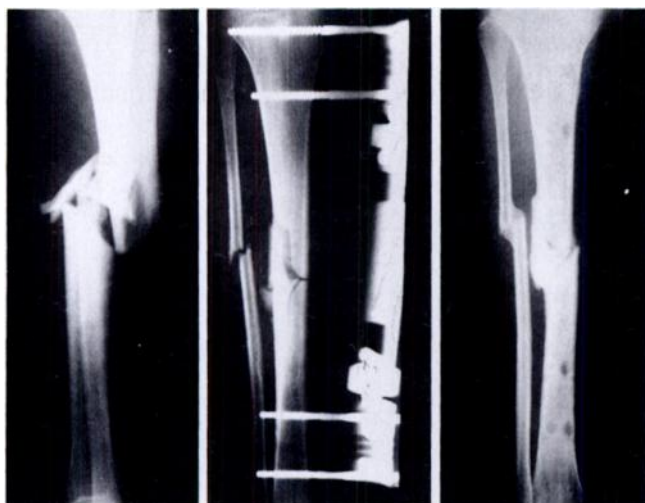|	Fresh fractures	Delayed unions and non-unions	Total
Pin-track infection and loosening	8/1300 pins	6/225 pins	14/1525 pins (in 10 patients)
Instability of frame	8	0	8 (2.4%)
Deep infection	1	0	1 (0.3%)
Temporary joint limitation	7	0	7 (2.1%)
Refracture	7	0	7 (2.1%)

Fig. 3   Fig. 4   Fig. 5

Open fracture of the tibia which, after reduction and fixation, healed in 6.5 months.

Fig. 6   Fig. 7

Transverse fracture of the shaft of the femur which healed in 4 months with periosteal callus which formed after dynamic compression.
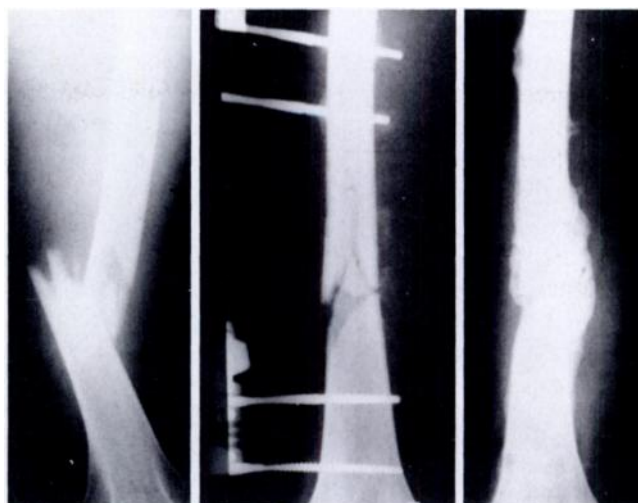

Fig. 8   Fig. 9   Fig. 10

Fig. 11

Figures 8, 9 and 10—Open, comminuted fracture of the femoral shaft which healed in 6.5 months. Figure 11—This patient, who also had a tibial fracture, was nevertheless able to bear weight and to walk.
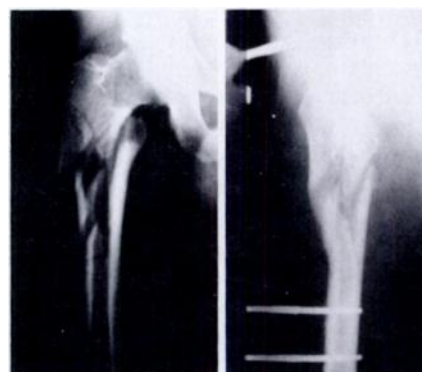

Fig. 12   Fig. 13

In order to reduce this subtrochanteric fracture the proximal screws were placed in the ilium using a "T" clamp attachment.

healed after subsequent casting, and two after reapplication of the fixator, but all of these have been classified as failures.

Other minor problems occurred in 23 patients. These included seven instances of temporary limitation of joint function. Four of these resolved completely with physiotherapy, one with manipulation under anaesthesia, and two with further surgery; the latter two were classified as failures. In eight cases the frame was not completely stable because of excessive re-use of the articulating components; all these cases healed without angulation or rotation once the stability of the frame had been restored. The one case of deep infection was an infected open fracture which ultimately required amputation.

All seven cases of refracture (5 femora, 1 humerus and 1 tibia) occurred within 10 days of removing the frame and at the site of the original fracture. Four were again treated with the axial fixator and three with casting. All healed within 90 days but they were classified as failures.

DISCUSSION

The purpose of this study was to document the efficacy and safety of the DAF system in clinical practice. The biomechanical advantages were already known from laboratory testing. In practice, the system has proved to be easy and quick to apply in the operating theatre. Furthermore, its versatility permits simple angular adjustment at any time during fracture healing before union is solid. Patients left hospital early, and rapidly returned to normal function. They found the lightweight, smooth, single bar to be quite acceptable in their daily activities.

In the past, many surgeons have reserved external fixation for patients with complex fractures. These

Fig. 14   Fig. 15

Fig. 16   Fig. 17   Fig. 18

Figures 14 and 15—Comminuted supracondylar and intercondylar fracture of distal third of femur. Figures 16, 17 and 18—Internal fixation of intercondylar fracture with screws, and treatment of supracondylar fracture with axial fixator in distraction, resulted in healing in satisfactory position.

Fig. 19   Fig. 20   Fig. 21

Fig. 22

Figures 19, 20 and 21—This fracture healed in 3 months. Figure 22—Note that the fixator permitted full movement at the shoulder and elbow.

fractures were often associated with loss of soft tissue or of bone (or both) and were frequently infected. Undoubtedly, the complexity of some fixators, the frequency of malalignment (reported by Kimmel in 1982 to be as high as 39% in severe tibial fractures), pin complications, and the cumbersome nature of the equipment limited their use.

When a single bar is employed, as advocated by Burny, application is easier, and the patient finds it less cumbersome. These factors may have contributed to his application of the method to simple fractures. Furthermore, Burny seeks to avoid total rigidity in order to promote callus formation. Certainly, there is ample evidence from the studies of Sarmiento and Dehne

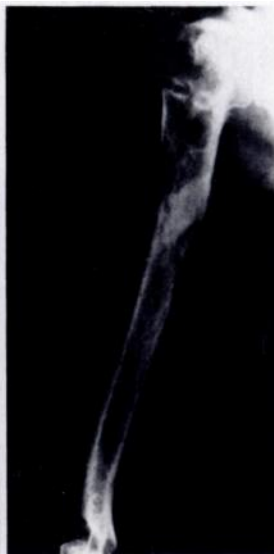Fig. 23   Fig. 24   Fig. 25   Fig. 26

For fractures of the proximal third of the humerus the "T" clamp adaptor is used. Note that the distal and lateral position of the screws avoids damage to the radial nerve. The most distal screw is placed first, through the lateral epicondyle. The distal screws are both cortical. This fracture healed in 3.5 months.

attesting to the importance of function and controlled movement at a fracture site in stimulating a bulky repair response (Sarmiento 1967, 1974; Dehne et al. 1961; Dehne 1969). In contrast with the present study, in earlier reported studies with single bar systems malunion remained a significant problem; Edge and Denham (1981) reported 55% with malunion and Court-Brown and Hughes (1982) 37.5%.

loss of substance, infection and delayed union. The method achieved union equally successfully in all situations.

It is thought that a practical test of the biomechanical adequacy of any external skeletal fixation system is the number and severity of pin complications. If this assumption is correct, the advantage of the present system is clearly seen. In recent reports of other systems,
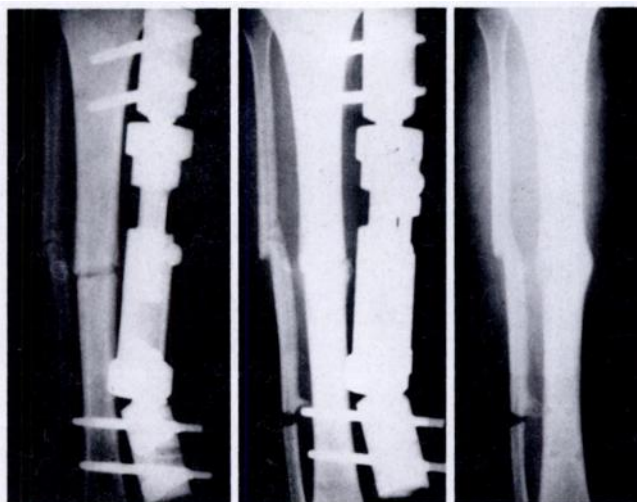
Fig. 27   Fig. 28   Fig. 29

Delayed union (5 months) of a fractured tibia and fibula. After fibular osteotomy and use of the axial fixator with static compression, healing occurred in 5 months.
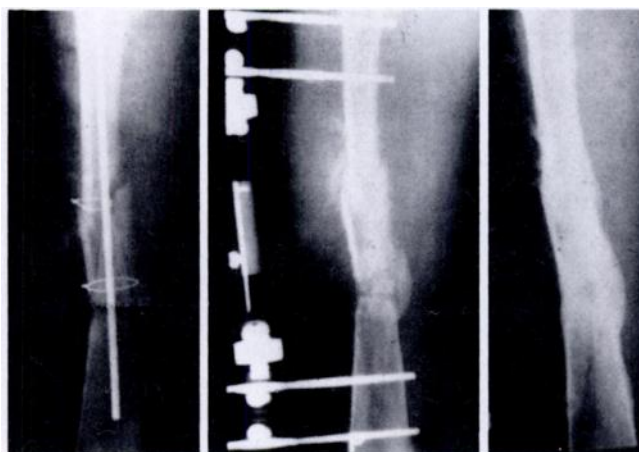
Fig. 30   Fig. 31   Fig. 32

Atrophic non-union of the femur following failure of internal fixation. After removing the metal and applying the fixator, healing occurred in 5.5 months.

The DAF method described in this paper makes it possible to adhere to the biological principles of ambulatory fracture care without sacrificing a sound anatomical result. Shortening and malunion were rarely seen, and when they were, they could easily be corrected during treatment, since the patients were reviewed at regular intervals, particularly in the early stages of treatment. Because the system was simple, safe and effective we included significant numbers of simple fresh fractures, as well as treating the more complex ones with

pin-track infection or loosening has been reported to be 30% (Burny 1979), 42% (Edge and Denham 1981) and 27% (Court-Brown and Hughes 1982). These were with single bar units. Figures reported with Hoffman units are 30% by Green and Bergdorff (1980) and 37% by Edwards (1979).

Other advantages of the DAF system are that the patient can use the limb without the screws becoming loose, and that the final removal of the screws is an outpatient procedure. The distal ends of the screws do

not penetrate the skin, so that their removal does not compromise sterility; their extraction is facilitated by the tapered design.

The percentage of patients healed and the time to union are the most important measure of biomechanical adequacy. By both criteria, the DAF technique equals or exceeds other methods with an overall success rate of

Olerud (1977) and by Edwards (1979). Interestingly, Kimmel (1982) found a 13% non-union rate in 27 patients with complex tibial fractures. Our results also suggest, as do recent studies comparing rigid and flexible plates for internal fixation (Tayton and Bradley 1983; Tayton *et al.* 1982), that controlled movement may have a beneficial effect on fracture repair.

| Fig. 33 | Fig. 34 | Fig. 35 | Fig. 36 |

Atrophic non-union of the femur following failure of internal fixation with plate and screws. This fracture healed in 6 months with the axial fixator combined with a cancellous bone graft.
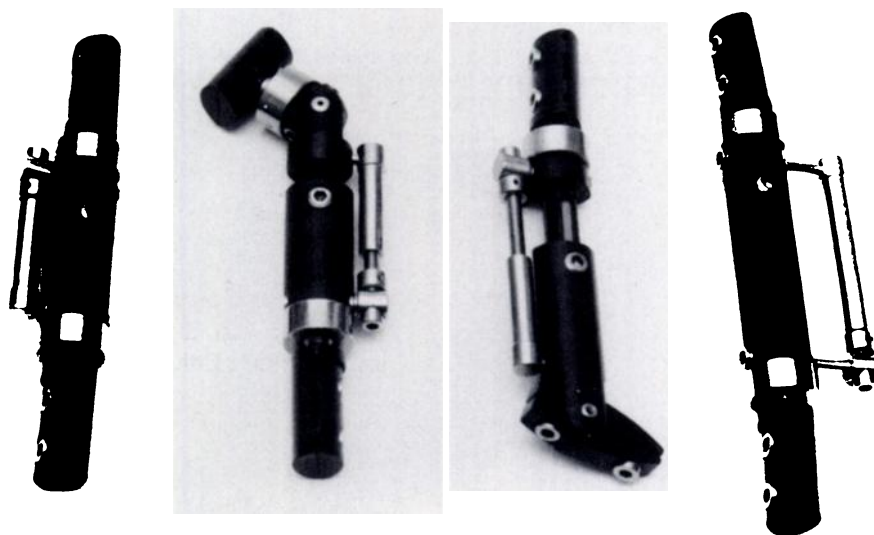

| Fig. 37 | Fig. 38 | Fig. 39 | Fig. 40 |

The dynamic axial fixator and accessories: bodies are made of anodised aluminium light alloy with stainless steel linings at bearing surfaces. Note compressor/distractor in place on each device. Figure 37—Short model: the length between the closest screws is 15 cm with 4 cm extension; weight 580 g. Figure 38—Short model with "T" clamp and articulated body which permits distraction coupled with joint movement. Figure 39—Short model with articulated body which is suitable for fractures of the ankle; this permits distraction coupled with ankle movement. Figure 40—Long model: the length between the closest screws is 18.5 cm with 8 cm extension; weight 650 g. The compressor/distractor is partly pulled out in order to illustrate the method of insertion.

94% and an average time to union of less than four months for closed fractures, and about six months for open fractures. Thus, in a series of 1421 tibial fractures, Burny (1979) reports a 91.5% healing rate, with three months to union for simple fractures and six months for complex. Benum and Svenningsen (1982) report a time of eight months before full weight-bearing was allowed, and similar times have been reported by Karlstrom and

The versatility and axial stability of the DAF system is such that it can also be used effectively in conditions other than fractures. For example, it has proved effective in lengthening the shafts of adult bones, in fixing diaphysial osteotomies and in arthrodesing joints. It has also been used for symmetrical lengthening of growth cartilage, for correction of angular deformity through asymmetrical lengthening of the growth plate, for the

restitution of joint function through articulated distraction, and for the correction of certain severe paediatric malformations. These applications will be the subject of further reports.

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