History of External Fixation

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ORIGINS

The first description of what we today call an external fixateur was by Dr. Clayton Parkhill of nearby Denver, Colorado in 1894. He reported his first nine cases in 1897 with a follow-up publication with additional cases in Annals of Surgery in 1898. His description reflected the nature of medical publications and society at the time. "R.H., a healthy miner who had been a hard drinker. Left femur fracture in the middle third by the kick of a man." He enthusiastically highlighted the benefits of his external fixation technique: "We claim for this instrument: first that it may be easily and accurately adjusted, and prevents both longitudinal and lateral movements between the fragments; second, that nothing is left in the tissue that might reduce their vitality and lead to pain and infection; third, that no secondary operation is necessitated; fourth, that no method has ever before given 100.0% of cures."[1]

The benefits claimed by Dr. Parkhill in 1897 are still relevant today. Pins can be placed through the skin into bones or bone fragments without much additional soft tissue injury. Those pins can be used to re-align the limb (reduction) acutely and can be adjusted over time as needed. The fixator is removed once healing is achieved, leaving no permanent implants to cause pain or infection, or require subsequent surgery. Unfortunately, as with all techniques, the early claim of "100.0% cure" achieved in the first cases did not endure as the technique was applied to larger numbers by different surgeons for a greater variety of conditions. Parkhill also failed to highlight problems encountered with the technique that ultimately limited its efficacy and popularity.

Dr. Parkhill died 5 years later of appendicitis and was unable to continue his work. His partner, Dr. L Freeman, did continue to develop external fixation and developed the T handle for pin insertion, which is still used today. He also promoted distraction or "extension" for fractures that were shortened or overlapped.[2]

Working independently of Dr. Parkhill, Dr. Albin Lambotte of Antwerp devised his own system of external fixation in 1902. He also promoted the advantages: "The advantages of the fixateur are numerous and very real: the apparatus can be easily and rapidly installed; it has great rigidity. Open wounds can be easily dressed. It has the advantage over all the other methods of fixation that it can be completely removed without difficulty. Finally, the state of consolidation can be controlled before its removal. During the course of treatment, one can mobilize the limbs active and passively. These characteristics are considerable advantages for severe leg fractures. Thanks to fixture in numerous cases, I could avoid amputation that seemed inevitable."[3]

Lambotte identified many of the same advantages as Dr. Parkhill, including ease of application and removal. He highlighted the ability to immobilize the fractures while mobilizing the patients. He also recognized important mechanical considerations. Great rigidity could be obtained initially and then adjusted or dynamized to less rigidity as the fracture healed. He reported excellent clinical results, especially for severe fractures, but not the ambitious claim of "100.0% success."[3]

Roger Anderson of Washington reported on the use of external fixation in 1936 in SG&O, but some of the problems associated with the technique began to appear. "Seattle serum" as it came to be known, was the term applied to drainage around pin tracks. The lack of dynamization led to a high rate of non-union, and the rigid Anderson device became known as a "non-union machine." Surgeons had not learned the lessons of Lambotte.[4]

The next great advance in external fixation came from a Swiss surgeon, Dr. Raoul Hoffmann. He was a surgeon and carpenter who partnered with the Swiss instrument-making company, Jacquet Freres, to develop and tirelessly market a complete set of instruments and implants for external fixation in 1934. The "Hoffmann External Fixation Set" became the worldwide standard. It was updated by design surgeons, David Seligson and Gernot Aasche and others to the "Hoffmann II" in 1990. The Compact Hoffman was added for fixation of smaller bones and fragments (1992) followed by the Micro Hoffmann with 2- and 1.5-mm pins for the hand (1994). Carbon fiber connecting rods were used for the magnetic resonance imaging (MRI) Compatible Hoffmann series (1998).[5,6]

The Hoffmann 3 with design surgeon, Dr. Hans-Christophe Pape, was released in 2015 with reports of improved mechanical properties.[7] The Hoffman series were distributed in the United States (U.S.) by Howmedica in the 1980s, and worldwide by Stryker

since acquisition in 1998. It was modified and copied by other companies while maintaining the basic concepts of metal pins, pin-holding clamps, and connecting rods as well as a consistent set of instruments to apply the constructs.

1960 to 1980

The benefits and drawbacks of external fixation over non-operative treatment and internal fixation available at the time were recognized throughout the U.S. During this time, the primary use of external fixation was for severe open tibia shaft fractures. External fixation had the benefit of stabilizing the limb to prevent further damage from ongoing motion at the fracture site while mobilizing the patient. The frame also allowed easy access to wounds for observation and treatment. The stabilization could be achieved without introducing foreign body into the fracture zone and without additional destructive soft tissue dissection necessary for internal fixation. In general, the outcome of open tibia fractures treated by external fixation were superior to alternative treatments of casting or plating.

1980s

External fixation to healing was the standard treatment of open tibia shaft fractures in the U.S. from 1980 to 2005.[8] In the 1980s, the role of external fixation expanded to other open fractures of the upper and lower extremity. The benefits of external fixation in the treatment of peri-articular fractures were also recognized. Distal radius fractures were treated with joint spanning fixators and achieved reduction by "ligamentotaxis."[9] When tension was placed across the wrist joint by a distraction force held by the frame, a spontaneous reduction of distal radius articular fragments with capsular attachment would occur. Results were superior to the alternative treatments available at the time. It was very difficult to maintain position after closed reduction in a cast. Internal fixation techniques available at the time were not able to obtain good purchase on the small, often osteoporotic fragments. Dorsal plates interfered with extensor tendon gliding and limited functional results.

Other peri-articular fractures successfully treated with external fixation in the 1980s included comminuted distal femur and proximal tibia fractures and distal tibia fractures. External fixation was the standard treatment for most distal radius fractures in the U.S. from 1985 to 2005. It has largely been supplanted by the volar locked plate (VLP) although recent publications indicate the long-term outcome of the two techniques is similar, and the advantages of VLP are mostly transitory and convenience.[10,11]

The incidence and impact of pelvic ring disruptions associated with blood loss and death increased in the U.S. in the 1980s. External fixation was used to reduce and stabilize pelvic ring disruptions to decrease blood loss and death rates.[12] Originally, pins were placed in the left and right iliac crest. Later, more stability was achieved with anterior to posterior pins in the supra-acetabular area. The development of percutaneous ilio-sacral screws and retrograde rami screws by Routt has significantly reduced the indications for external fixation for definitive treatment of the pelvic ring disruptions.

Acute resuscitation frames remain a standard component of most trauma protocols. However, the development of small implants (Mini-Hoffmann and other) allowed for the application of external fixation to smaller bones including foot, hand, and clavicle. The advantages of external fixation of the mid-foot and fingers are that fractures can be temporarily stabilized across joints during healing without permanently immobilizing the joint.

DeBastiani developed the Dynamic Axial Fixation system in 1986 with a telescoping body, which allowed slight axial compression while maintaining angulatory and translational stability. These were marketed in the U.S. by OrthoFix and EBI.[13]

1990s

Ilizarov in Russia had developed a technique of external fixation using tensioned, small diameter wires and circular frames that became known in the western world with the fall of the Iron Curtain.[14] He used this method to treat a wide variety of acute fractures. He also discovered and promoted the concept of distraction osteogenesis where bone that was osteotomized in a very precise manner and carefully progressively distracted over time would produce new bone that would remodel into normal bone. The ring fixator was a key element for successful distraction osteogenesis, which enabled the treatment of a variety of post-traumatic reconstruction conditions, including infected non-unions and mal-unions, and segmental bone defects.

The biological basis for distraction osteogenesis was delineated by Kenwright and others using mini-external fixators with distraction in a rabbit model. The contention of Ilizarov of a dramatic increase in vascularity to limbs undergoing distraction osteogenesis was demonstrated. This hypervascularity of the limb undergoing distraction osteogenesis helps to resolve infections and heal non-unions. There were even reports of performing distraction osteogenesis on the limbs of patients with Buerger's disease (thromboangiitis obliterans).[15] These patients had no bone pathology, but non-healing ulcers of their feet recalcitrant to treatment. Placement of an external fixator with distraction osteogenesis resulted in a hyper vascular response to the limb, which resulted in healing of the recalcitrant skin ulcers. This illustrates one of the non-bony pathological conditions that can benefit from treatment with external fixation.

Another development in the 1990s was the articulated external fixation for joint injuries and peri-articular fractures. It was recognized that distal tibia plafond fractures treated non-operatively had a high rate of early post traumatic osteoarthritis (PTOA). Open reduction and internal fixation (ORIF) became popular to improve the reduction and reduce the rate of PTOA. However, routine plating of distal tibial plafond fractures in the 1980s resulted in a very high rate of disastrous soft tissue breakdown. The iatrogenic consequences were often unreconstructable infections that led to amputation. The articulated external fixators developed by EBI and Orthofix were a popular alternative that markedly reduced the rate of iatrogenic soft tissue problems and gave reasonable functional results.[16] The external fixators were not only articulated to allow ankle motion during healing, but they were also axially dynamic, which allowed small amounts of compression during ambulation that stimulated timely fracture healing. Large articular fragments could be percutaneously reduced and stabilized with internal fixation screws. Tracy Watson advocated a similar, but different technique using a non-articulated circular frame with beaded tensioned wires for articular reduction of distal tibia plafond fractures with similar results.[17] Disastrous soft tissue breakdown was avoided, and reasonable function achieved.

Another use of external fixation in the 1990s was for adolescent and pediatric femur shaft fractures. Standard treatment at the time was skeletal traction for weeks (1 week for every year of age of the patient was the standard algorithm) followed by spica body cast. The external fixation again allowed reduction and stabilization of the bone with mobilization of the patient, so that prolonged hospitalization was not required. A body cast with associated problems was also avoided. Very good results were achieved.[18] From 1990 to 2000, external fixation became a common treatment for patients ranging from 6 years old to 15 years old in the U.S. Unfortunately, many of the popular frames at the time were designed for adult bone and not the smaller, pediatric bone and thus, were too stiff. Surgeons again repeated the rigidity mistakes of Anderson and high rates of re-fracture after frame removal and apparent "healing" occurred.[19] Subsequently, flexible nails were developed and replaced the external fixation as the most popular operative treatment for pediatric and adolescent femur shaft fractures.

2000 to 2020

2000 most likely represented the zenith of external fixation in the U.S. for a wide variety of fractures, post-traumatic reconstruction, and other conditions. At that time, I personally performed about 200 fixator cases per year, and the UNM Orthopedic Department performed about 400 per year.

There were modifications of the method of Ilizarov in the U.S. Stuart Green modified the technique with the use of Rancho Cubes and hybrid frames that used a combination of large diameter half pins and tensioned, skinny wires. The Taylor Spatial frame system was developed based on the Stewart Platform technique to more accurately restore alignment to displaced and malunited fractures.

The concept of staged external fixation, rather than treatment to healing, was popularized. Sirkin identified that a temporary period of external fixation for distal tibia plafond fractures followed by a delayed formal ORIF gave promising results of reducing the frequency of soft tissue slough while obtaining the benefits of better reduction of the fracture fragments than could be achieved with external fixation to healing techniques.[20] This has become the standard of treatment for most distal tibia plafond fractures. Staged external fixation for damage-control purposes has also gained popularity. A polytrauma patient in extremis can be initially stabilized with a damage-control external fixator that adds minimally to the metabolic burden of blood loss, soft tissue dissection, and medullary content to the lungs through the bloodstream. The limb is immobilized while the patient is mobilized without additional metabolic burden. Several weeks later, once the patient's overall condition has stabilized, the femoral shaft external fixator can be converted to a standard nail, obtaining the longer-term benefits of internal fixation while eliminating the short-term drawbacks. A similar approach to pelvic ring disruptions has also been developed. The "Infix" is a temporary fixator placed beneath the skin, which stabilizes the bone but avoids the pin track and prominence problems of external fixation. Temporary external fixation during resuscitation followed by definitive internal fixation, especially of the posterior pelvic ring through ilio-sacral screws, is a technique popularized by Routt.[19]

Improvement in techniques for managing open wounds and limiting the dissection necessary for tibial internal fixation has led to an expanding indication for nailing of open tibia shaft fractures, especially lower grade injuries without contamination. The use of free flaps and wound VACs has allowed for earlier and better management and coverage of the open wounds, and acceptable rates of infection after nailing of open tibia fractures have been described. Internal fixation offers the potential for "fix and forget" that is not available from external fixation, which requires frequent follow-up for recognition and treatment of a variety of problems and complications including pin track infections, loss of reduction, cumbersome frames, and patient complaints.

A new treatment of the osteoarthritic ankle joint using distraction external fixation (with or without motion) and chondrolplasty became available in the last 20 years and is gaining popularity.[20] This represents a new indication for external fixation beyond fractures, namely to facilitate articular reconstructions and treatments of osteoarthritis to rival arthrodesis and implant arthroplasty.

CURRENT to 2022

External fixation in 2022 remains a popular treatment for limited indications. The most common current indication is as a temporary frame for staged treatment of peri-articular fractures, particularly the distal tibial plafond.

Temporary external fixation is also currently indicated for damage control. There is still a role for external fixation in skeletal reconstruction, especially infected non- unions, segmental bone defects, and complex reconstructions. External fixation for lengthening has somewhat been replaced by internal fixation techniques. External fixation is currently popular in resource-poor environments and wartime situations for acute closed and open fractures. Innovative uses of external fixation for conditions other than fractures continue to be developed (e.g. Buerger's disease, ankle arthritis). The lessons of the past are important as we re-discover the advantages and drawbacks of this powerful technique for stabilizing bones and bone fragments.

CONCLUSIONS

External fixation is an effective technique for managing a variety of fractures and post-traumatic conditions. The origins of external fixation were in Denver and Belgium over 120 years ago, and the principles have remained largely the same. There are a variety of problems and complications that limit the utility of external fixation as definitive treatment, so the current indications are mostly temporary techniques, or situations where alternative internal fixation techniques are not available or advisable.

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