9 Biomechanics of Tension Band Constructs for Fracture Fixation

Austin Edward MacDonald, Chetan Gohal, and Herman Johal

Introduction

Tension band constructs for fracture fixation have been described for well over 50 years [1, 2]. The principles behind tension bands were derived from biomechanical studies performed by Frederich Pauwels, who made substantial contributions to our understanding of the relationship between stress, load, and bone [1]. Pauwels used these forces as the basis of fixation constructs for specific fracture types, many of which were formally described and disseminated by the AO (*Arbeitsgemeinschaft für Osteosynthesefragen*) [1–4]. In the case of tension bands, the fundamental concept involves the conversion of distractive tensile forces into compressive forces that are distributed across a fracture site, creating a favourable environment for fracture healing. While there are specific requirements for successful application of tension band principles, these constructs can be used to treat a variety of long bone and peri-articular fractures using a range of implants. This chapter will review the essential biomechanical tension band principles and review examples of their effective application.

A. E. MacDonald · C. Gohal · H. Johal (✉)
Division of Orthopaedic Surgery, Department of Surgery, Hamilton General Hospital, McMaster University, Hamilton, ON, Canada
e-mail: johalh3@mcmaster.ca

Tension bands are most commonly used to treat olecranon or patella fractures; however tension band principles can also successfully be applied to treat long bone fractures (i.e. femur fractures) and other peri-articular or avulsion-type fractures (such as greater trochanter fractures, greater tuberosity fractures, malleolar fractures, or styloid fractures). All of these situations require an understanding that many bones throughout the body are eccentrically loaded, resulting in tension and compression surfaces. The tensile surface must be amenable to the application of fixation, while the compression surface must be intact and able to resist load [1–4]. Not only will this create a setting that promotes fracture healing, but it will also impart stability that will facilitate early mobility and functional recovery [5–9].

Key Concepts for Tension Band Constructs

Determine the Tension and Compression Surfaces of the Fracture

Pauwels originally described that under axial loads, many curved, tubular bones have tension and compression surfaces opposite to one another. When an eccentric load is applied, the curved or convex side of the bone is subject to

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tensile forces while the concave side experiences compression (Fig. 9.1) [1, 3]. This may be best conceptualized when thinking of a long bone such as the femur, where the bone is eccentrically loaded secondary to the body weight being applied through the femoral head and down the eccentric mechanical axis, instead of neutrally through the central anatomic axis (Fig. 9.2). This results in tension or torque being applied to the lateral side of the femur, with the medial side being compressed.

While this concept applies to curved, tubular bones with axial loads, it also applies to bones that move around an eccentric centre of rotation. These are often under torque secondary to the pull of muscle tendons or ligaments, with the tension surface being further away from the centre of rotation and the compressive surface being closer. Patella fractures provide the clearest example of this, where the patellar and quadriceps tendons apply tension to the non-articular surface of the patella, while the articular surface experiences compression, as it moves along the centre of rotation within the knee (Fig. 9.3a). Similar forces around other joints act on tendon or ligament avulsion fractures including fractures of the olecranon (Fig. 9.3b), shoulder tuberosities, greater trochanter, or ankle malleoli [3–9].

The resultant tensile and compressive forces from either an eccentric axial load or centre of rotation commonly results in a transverse fracture pattern, where the convex (outer) cortex is subject to tension and the concave (inner) cortex will be subject to compression. Without fixation, the fracture would be distracted, causing an unstable healing environment that promotes gapping and non-union. The mechanical function of a tension band construct is to work against these forces and convert this distractive torque into stable compression across the fracture site.

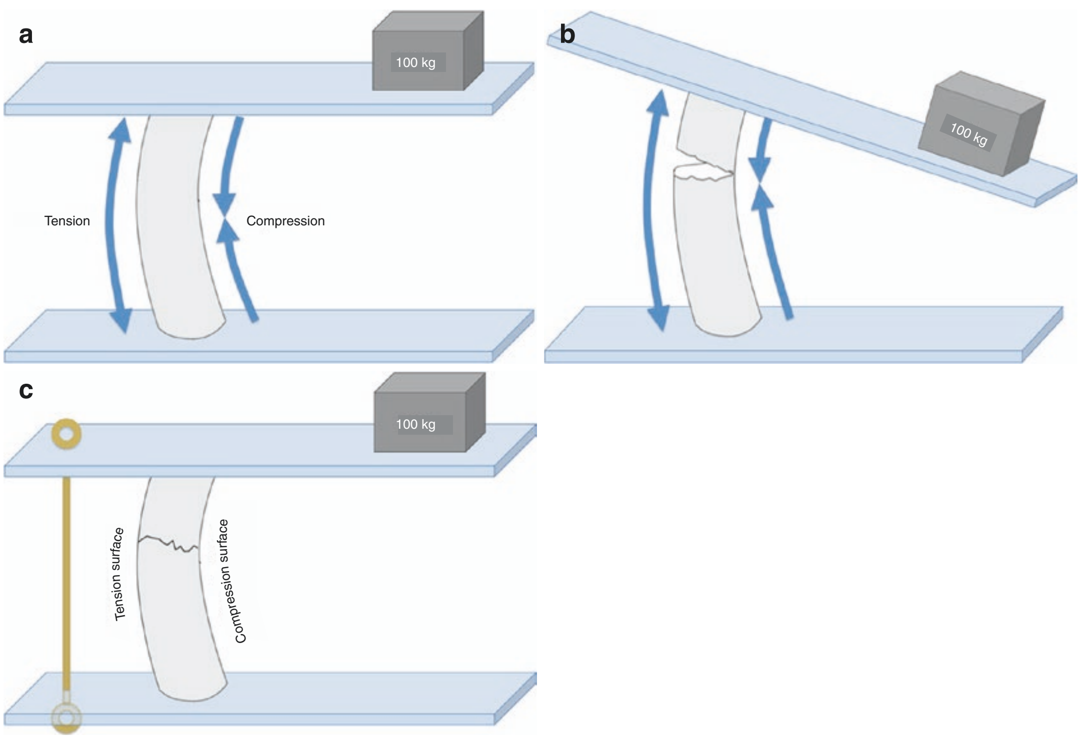

Fig. 9.1 The application of an eccentric axial load on a tubular bone will result in a creation of a tension surface along the curved (outer) cortex and a compression surface along the concave (inner) cortex (**a**). These forces result in distraction across a fracture site (**b**), which can be neutralized with a tension band placed appropriately along the outer cortex, converting tensile forces into compression ones (**c**)

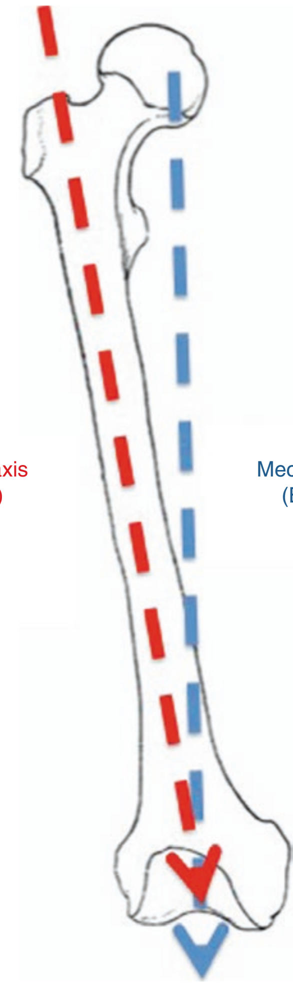

Fig. 9.2 Depiction of the eccentric axial load placed along the mechanical axis (*blue dotted line*) of the femur, which sits outside of the central anatomic axis (*red dotted line*)

Ensure the Fracture Can Withstand Stable Compression, with an Intact Opposite Cortex

Prior to applying tension band techniques, the surgeon must ensure that the fracture pattern is amenable to this type of fixation. Transverse fractures due to bone failing under tensile stress are best suited for tension band constructs. If placed appropriately, tension band fixation should be able to neutralize the forces distracting the fracture along the tensile surface, ideally converting them into a steady, compressive force at the fracture (Fig. 9.4a). If the fracture cannot withstand compression, a tension band construct will not work.

The compression side of the bone has a particularly important role as a buttress. For tension band fixation to be successful, the compression surface must be intact or reconstructed with stable bony apposition. If unable to do so, as in comminuted fractures, there will be less resistance to compression forces across the fracture site (Fig. 9.4b) [3, 10]. This will either result in immediate loss of reduction and fixation or increased motion at the fracture leading to delayed or non-union and failure of hardware [3, 10]. Therefore, tension band constructs are not typically indicated in the context of comminuted fractures, which are better served with more rigid, bridging fixation.

Apply Fixation to Withstand Tension

Placing fixation along the convex, or tension, side of the bone will allow the implant to resist the stress of tensile forces and convert them into compression (see Fig. 9.4a) [1, 3, 10]. Conversely, placing fixation on the concave, or compression, side of the fracture permits unresisted tensile forces to act along the convex cortex, leading to ongoing distraction and gapping at the fracture site (Fig. 9.4c).

Tension band constructs can be applied along the tensile surface as either static or dynamic fixation, dependent on the forces being resisted and applied by the implants [1–3]. Both provide compression forces at the fracture site, with static constructs maintaining a relatively constant force during loading and dynamic constructs providing increasing force and the tensile load escalates [3, 4]. At the time of application, static tension band constructs are maximally loaded in compression, and there is little fluctuation with eccentric forces [3–7]. Conversely, dynamic tension bands can impart further compression as it resists increasing tensile loads during joint movement or weight-bearing [8, 9, 11].

Numerous implants may be applied on the tension surface, including cerclage wires, cables, sutures, and plates, as well as appropriately

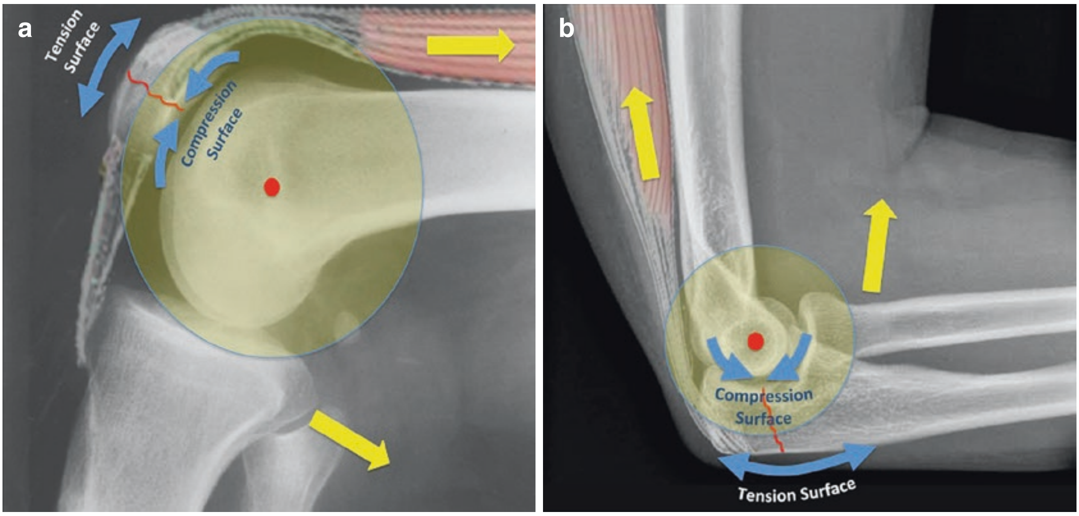

Fig. 9.3 Radiographs with superimposition of the main forces (*yellow arrows*) and muscles acting to create tensile and compressive forces as the patella (**a**) and the olecranon (**b**) move along their respective centres of rotation (*red dot*). The patella experiences tension from pull of both the patellar and quadriceps tendons as the knee flexes secondary to contraction of the hamstrings. The olecranon experiences tension from the pull of the triceps as the arm flexes secondary to contraction of the biceps

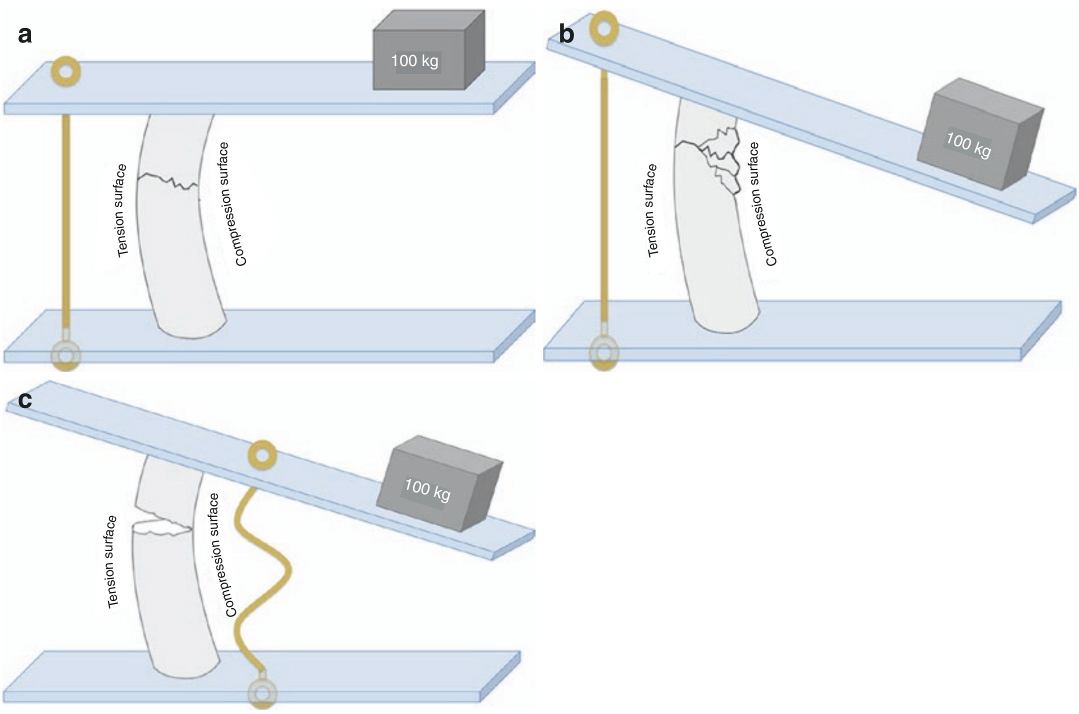

Fig. 9.4 When appropriately placed on the tension side of the bone, a tension band is able to neutralize axial loads if there is a stable, intact medial cortex able to withstand compression (**a**); however if there is substantial comminution unable to resist compression (**b**), or if the hardware is placed on the compression side allowing unresisted distraction, the construct will fail (**c**)

applied intramedullary nails and external fixators [3–11]. The most commonly applied constructs involve cerclage wires (placed through tendons, ligaments, or transosseous drill holes) that are looped around Kirschner wires (K-wires) or passed through cannulated screws placed within the bone, perpendicular to the plane of the fracture. The cerclage wires are then twisted and loaded in compression on the convex surface to impart stability to the fragments as they squeeze together, in line with the plane of the K-wires or cannulated screws. Tension band plating is also commonly applied in curved diaphyseal bones, such as femoral shaft fractures, that undergo varus bending with axial loads. Laterally placed plate fixation provides torque conversion to neutralize the tensile forces acting at the convex cortex. These plates work best when applied in compression, to further load the fracture site and biomechanically optimize the healing environment.

Case 1

A 29-year-old female sustained a mechanical fall on ice. She fell backwards and landed with a direct blow to her elbow. She sustained an isolated, closed transverse fracture to her olecranon with a fracture fragment involving approximately half of the articular surface (Fig. 9.5a, b). A tension band construct was used as for surgical stabilization of her fracture to facilitate early range of motion (Fig. 9.5c, d). A standard posterior approach to the olecranon was used, and anatomic reduction was obtained and maintained using a standard reduction clamp. Two parallel 1.8 mm Kirschner wires were placed in a posterior to anterior direction, perpendicular to the plane of the fracture. A cerclage wire was then passed through a transosseous hole distal to the fracture and looped in a figure-of-eight fashion over the tension surface of the proximal ulna. The wire was then passed deep to the insertional fibres of the triceps tendon on the proximal fracture fragment and anchored by the bent ends of the K-wires proximally. The construct was tensioned through twisting of the wire ends, with the knot bent and impacted against the bone to avoid prominence.

Postoperatively, the patient was allowed to perform a range of motion as tolerated immediately and permitted perform resistance exercises at 6 weeks. At her 3-month follow-up appointment, she had complete radiographic union of her fracture, with range of motion at the elbow from 15 to 150 degrees of flexion with full supination and pronation (Fig. 9.5e, f). She was discharged by her 6-month visit, with full clinical recovery.

Why This Works

In transverse fractures at the olecranon, the proximal fragment distracts secondary to the pull of the triceps tendon during muscle contraction. At the fracture site, the tensile forces are most prominent at the outer, curved cortex of the proximal ulna, while the compressive forces are concentrated at the articular surface. The goal of the tension band wire construct is to convert the dynamic distraction force during elbow motion into a compression forces across the articular surface during motion of the elbow. Compression at the fracture site was obtained intraoperatively using a clamp, with the implant providing further compression through loading as the wire ends were twisted. This provided immediate stable fixation at the fracture site, which only increased with further tension from the pull of the triceps.

Case 2

A 54-year-old male tripped forward while going up a flight of stairs, landing with a direct impact of his flexed knee against the riser. He sustained an isolated, closed primarily transverse fracture to his patella with only minimal comminution at the site of impact on the non-articular surface (Fig. 9.6a, b) A tension band construct was used as for surgical stabilization of her fracture to facilitate early range of motion (Fig. 9.6c, d). A standard anterior approach to the knee was used, and reduction was obtained and maintained using a standard reduction clamp, focusing primarily on anatomic restoration of the simple transverse articular fracture line. Two parallel 4.0 mm

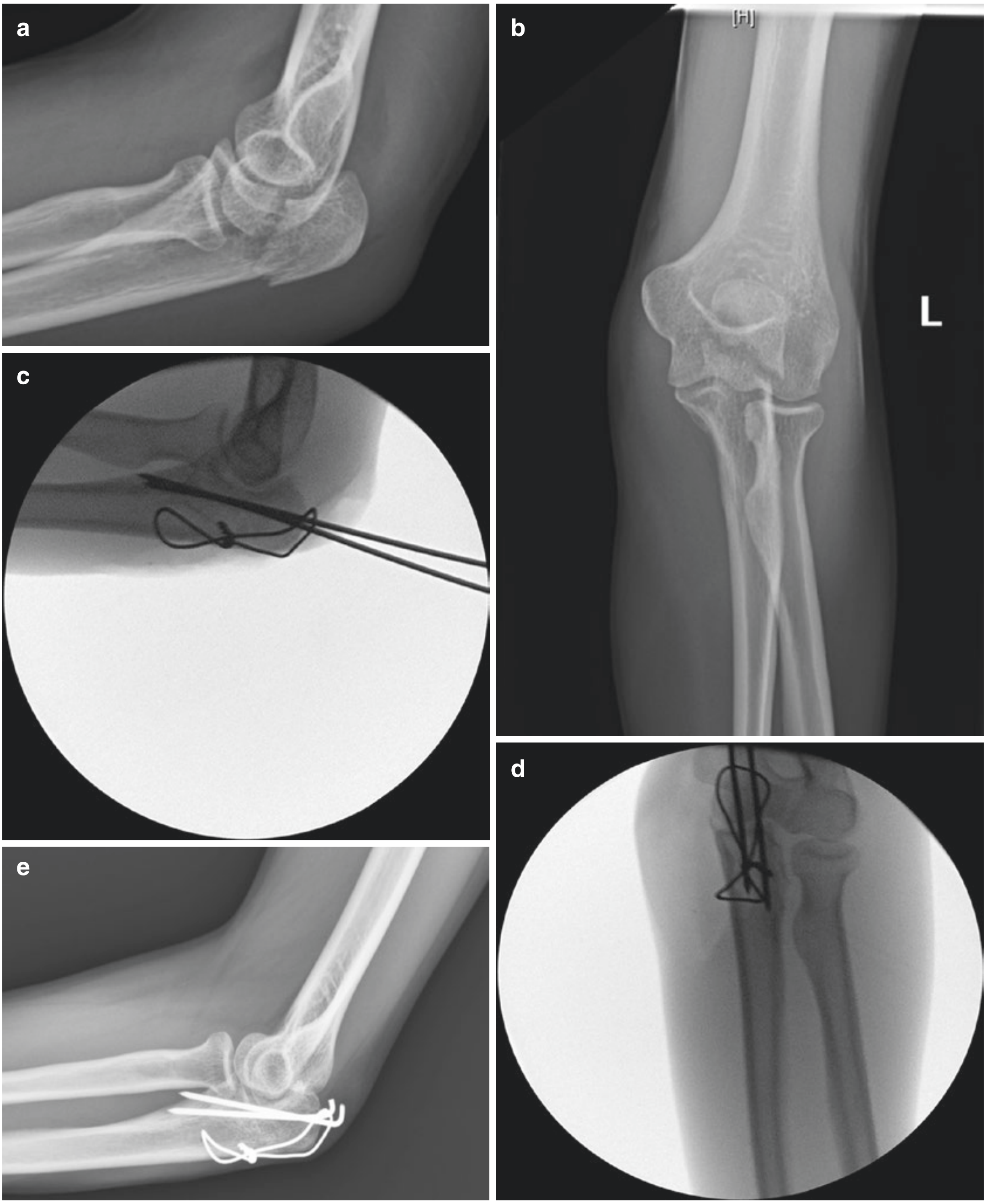

Fig. 9.5 Injury (**a**, **b**) intraoperative (**c**, **d**) and 2-month (**e**, **f**) radiographs of an elbow with a displaced, transverse olecranon fracture treated with a tension band wire construct using K-wires and a figure-of-eight cerclage wire

partially threaded cannulated screws were then placed longitudinally within the patella, perpendicular to the plane of the fracture. Careful attention was paid to ensure that the screws were adequately buried and not prominent at either side of the patella. The centrally cannulated portion of each screw can facilitate passage of a 1.4 mm cerclage wire, which was fed through

Fig. 9.5 (continued)

each screw and tensioned over the curved, outer tensile surface of the patella.

Postoperatively, the patient was allowed to immediately weight-bear with the leg in a knee immobilizer and to begin gentle range-of-motion exercises by 4 weeks. At his 2-month follow-up appointment, radiographic union was achieved (Fig. 9.6e, f), with range of motion being from 0 to 110 degrees of flexion. The patient reached functional recovery of range of motion and strength by the 4-month follow-up visit.

Why This Works

In transverse patella fractures, the proximal and distal fragments are distracted from each other secondary to the pull of the quadriceps and patellar tendons, respectively. The tensile forces are most prominent at the outer, curved cortex of the patella, while the compressive forces are concentrated at the articular surface. The goal of the tension band wire construct is to convert the dynamic distraction force into a compression force across the articular surface during motion of the knee. Compression at the fracture site was initially obtained intraoperatively using a clamp, as well as the partially threaded cannulated screws which provided interfragmentary compression.

By ensuring that the screw heads were countersunk, and that the ends of the screw were not prominent, the cerclage wire was able to impart further compression through loading of the construct as the wire ends were twisted. This held the fragments together, as they moved along the plane of the screws to compress across the fracture site.

Case 3

A 76-year-old male fell down several rungs of a ladder sustaining an injury to his right thigh. He had a previous stemmed right total knee

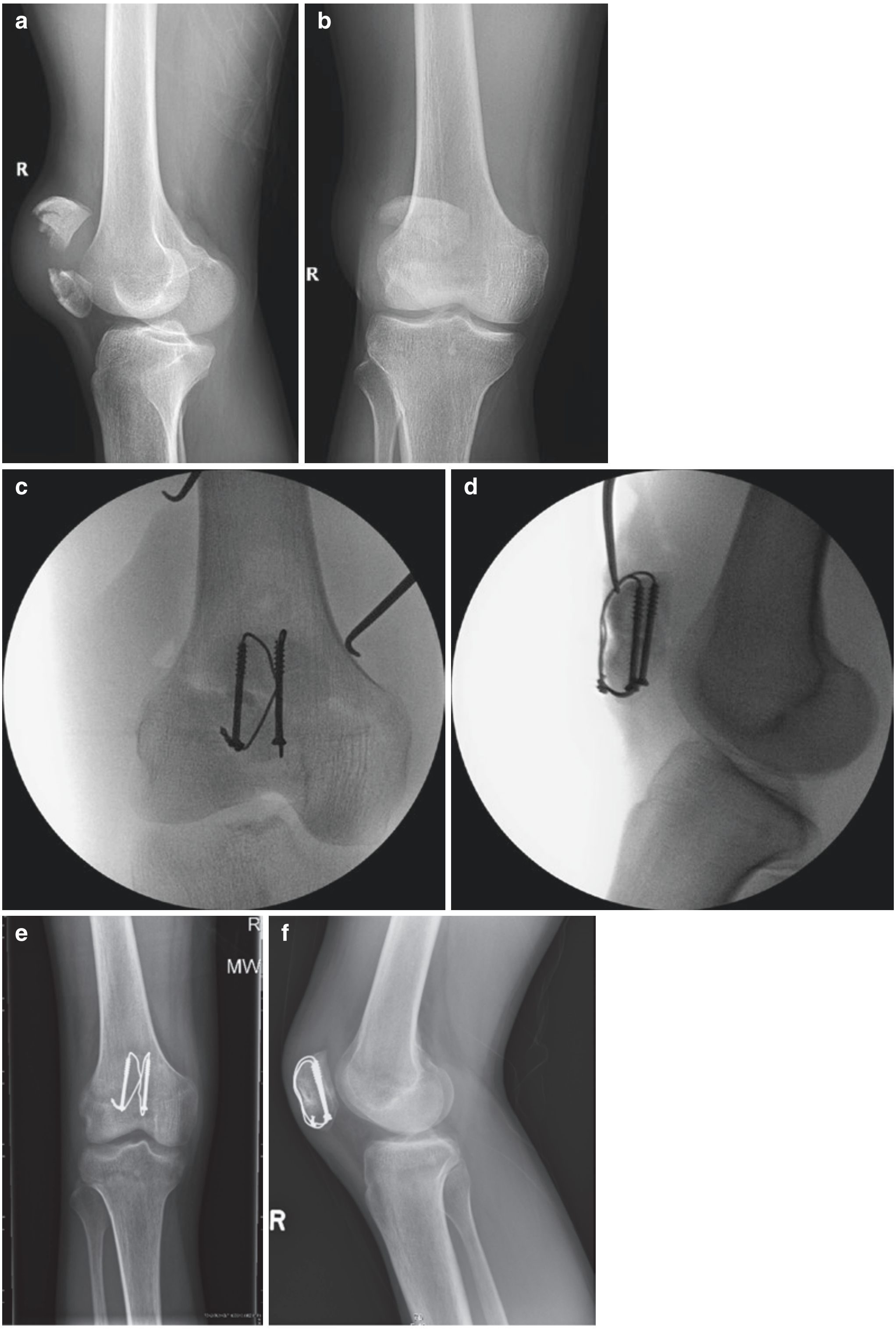

Fig. 9.6 Injury radiographs of a displaced, transverse patella fracture with minimal comminution along the non-articular surface (**a**, **b**). Intraoperative fluoroscopic images showing placement of a cannulated screw and cerclage wire tension band construct (**c**, **d**). Four-month radiographs showing fracture union (**e**, **f**)

arthroplasty (TKA) placed 10 years earlier and did not have any antecedent thigh pain. Radiographs confirmed an oblique femoral shaft fracture ending just proximal to the stem of the femoral component (Fig. 9.7a–c). Open reduction and internal fixation was chosen as the TKA appeared to be stable. Intramedullary nailing was not an option secondary to the stemmed femoral component, and plate fixation was selected. A lateral approach to the left femur was used, and the fracture was anatomically reduced using traction and clamps. Cortical keys, including a transverse medial component, helped to maintain the reduction, and an interfragmentary screw was also placed to compress along the main oblique fracture line. A long distal femoral locking plate was positioned and secured. The plate was applied initially using non-locking fixation, followed by locking fixation distally to ensure stable fixation around the femoral TKA component. Postoperatively, the patient was allowed increased range of motion and weight-bearing over the first 8 weeks. At his 2-month follow-up appointment, radiographic union was progressing (see Fig. 9.6e, f), with range of motion being from 0 to 100 degrees of flexion and the patient able to mobilize with a walker.

Why This Works

Among the several functions served by this plate, it works as a tension band as it neutralizes the tensile forces acting at the lateral femoral cortex described earlier in this chapter. Despite being primarily oblique, the simple fracture line had a transverse medial component that allowed restoration of a stable buttress along the medial cortex, able to withstand compressive forces. To add further stability, an independent interfragmentary screw was placed along the long, oblique component of the fracture more proximally. While with this facilitated anatomic reduction, this construct would still be far from adequate to resist the tensile forces that would work to distract the fracture under physiologic loads with weight-bearing. Therefore, a rigid lateral plate was placed to neutralize the tensile forces and convert them into

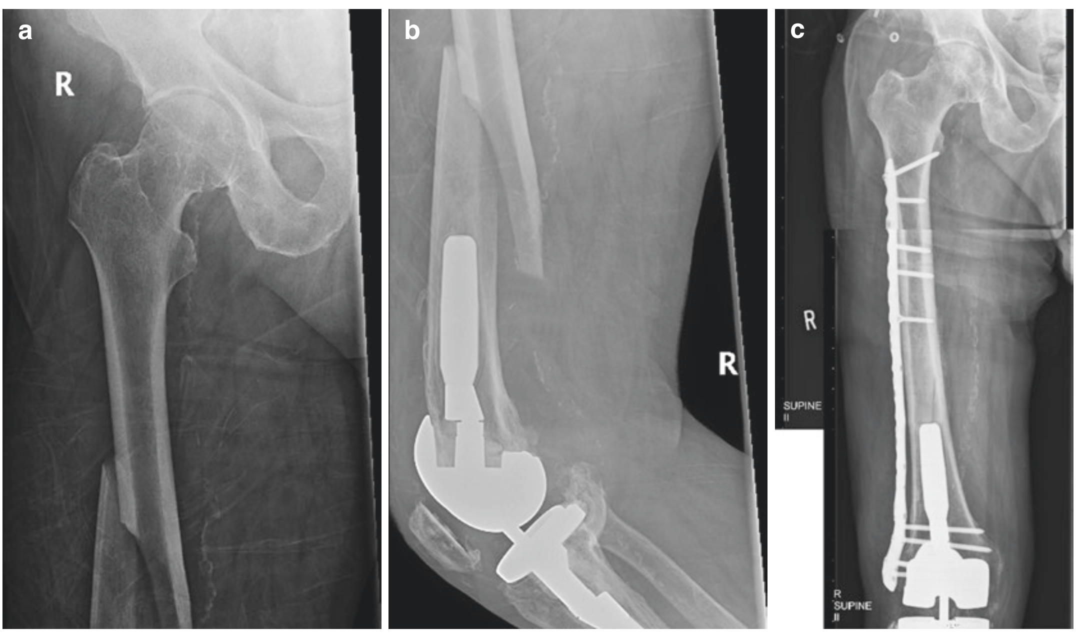

Fig. 9.7 Injury radiographs of a displaced, periprosthetic femoral shaft fracture with a simple fracture line proximal to a stable, femoral stemmed knee arthroplasty component (**a**). Postoperative radiograph showing a long lateral femoral plate acting as a tension band, with stable medial cortical apposition (**b**, **c**)

compressive forces across the anatomically reduced fractures thereby encouraging primary boney healing.

Conclusion

Many fractures throughout the body undergo eccentric axial loads or torque, making tension band constructs a viable option for achieving boney union. This is dependent on both the characteristics of the fracture and effective application of the biomechanical principles involved. The goal of tension band constructs is to convert a distractive, tensile force into a steady compressive force across the fracture site. This requires an understanding of how various bones are eccentrically loaded and where tensile and compression forces act to distract fracture fragments. These forces can be resisted and neutralized via fixation placed along the tension surface using a variety of implants, which work to either statically or dynamically convert tensile forces into compressive ones to promote fracture healing. Stable boney apposition at the opposing cortex provides an intact buttress able to resist the interfragmentary compression, imparting strength and stability to the overall fracture construct. This facilitates earlier weight-bearing of eccentrically loaded long bone fractures, as well as earlier range of motion of peri-articular fractures rotating around an eccentric centre of rotation, subject to tension from tendons or ligaments. In this manner, an appropriately used tension band construct can both accelerate fracture healing and promote early improvement of clinical outcomes, valued by both patients and surgeons alike.

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