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1 Biomechanical principles

Early concepts of load transfer within bone were developed and described by Frederic Pauwels [1]. He observed that a curved, tubular structure under axial load always has a compression side as well as a tension side. Using the eccentrically loaded femur as a model Pauwels, in the classical “load strain diagrams”, schematically demonstrated the compression and tension forces present within that bone while it was under axial stress (Fig. 3.2.3-1).

From these observations the principle of the tension band evolved, which describes how tensile forces are converted into compression forces by applying a device eccentrically or to the convex side of a curved tube or bone (Fig. 3.2.3-2).

**Fig. 3.2.3-1:** To illustrate the effectiveness of the tension band principle, Pauwels used photo-elastic models. Eccentric loading produces a stress-strain differential within the material. These differentials can be equalized by a tension band applied to the tension side. It acts as a counterweight to eccentrically applied compression.

a) Eccentric force (K) is applied at a distance from the neutral axis (0), producing a tensile force of 79 kp/cm² (Z) and a compression force of 94 kp/cm² (D).

b) A weak tension band (G) is applied to the tension side (left column), producing a resultant force (R) more closely aligned with the neutral axis of the material. The tensile force Z is reduced to 74 kp/cm² while the compression force (D) is decreased to 79 kp/cm².

c–f) The application of a progressively stronger tension band (G) produces and intensifies the shift of forces toward the neutral axis. The resultant force (R) is shifted toward neutral force 0 until the tension-optical lines become collinear as seen in (f). There is now an equally acting compressive force of 30 kp/cm² [1].
Since a fractured bone, if it is to unite, requires mechanical stability, as obtained, for example by compression, and reacts adversely under motion or repeated tension/distraction, it appears essential to neutralize such forces for the duration of the healing process [2].

This is especially important in articular fractures, which require early motion for a good functional outcome.

In those fractures where muscle pull during motion tends to distract the fragments, for example, fractures of the patella or olecranon, the application of a tension band will neutralize these forces and even convert them into compression when the joint is flexed (Fig. 3.2.3-3). Similarly, a bony fragment can be avulsed at the insertion of a tendon or ligament, for example, the greater tuberosity of the humerus, the greater trochanter of the femur, or the medial malleolus. Here too a tension band can firmly reattach the avulsed fragment allowing immediate motion of the involved joint.

Fig. 3.2.3-2: When applied to the tension side of the bone a plate acts as a dynamic tension band. 
a) The mechanical axis of the bone is not necessarily within the center of the bone. 
b) Under vertical pressure the curved femur creates a tension force laterally and a compression force medially. 
c) A plate positioned on the side of tensile forces neutralizes them at the fracture site provided there is cortical contact opposite to this plate. 
d) In case of a cortical defect, the plate will undergo bending stresses and eventually fail due to fatigue.
3.2.3 Tension band principle—C. Josten, G. Muhr

b) In the olecranon fracture the figure-of-eight wire loop acts as a tension band upon flexion of the elbow.

c) Application of the tension band principle at the proximal humerus with an avulsion of the greater tubercle. The wire loop is anchored to the humerus via a 3.5 mm cortex screw.

Fig. 3.2.3-3:
a) Illustration of tension band principle on a fracture of the patella. The figure-of-eight wire loop lies anterior to the patella and fracture. Upon knee-flexion the distraction forces (between quadriceps and tibial tuberosity) are converted to compression.

c) Application of the tension band principle at the proximal humerus with an avulsion of the greater tubercle. The wire loop is anchored to the humerus via a 3.5 mm cortex screw.
2 Concepts of application

Historically a circumferential wire loop—so-called cerclage—was originally described by Berger in 1892. Multiple modifications of the technique have been presented since [3–5], while others introduced the combination of wiring with screw or K-wire fixation [6–8]. K-wires or lag screws stabilize the fragments against rotational forces and may serve as anchorage for the tension band material.

The types of articular fractures with avulsed fragments that typically profit from fixation according to the tension band principle have already been mentioned. However, there are situations where this principle can also be applied in diaphyseal fractures, for example, the femoral shaft, or in delayed unions or non-unions where the presence of angular deformity indicates the tension side of the bone. Any internal or external implant must be applied to the tension side to neutralize these forces. Bony union will then occur quite consistently. This demonstrates that not only loops of wires, cables, resorbable and non-resorbable suture materials, but also a plate or an external fixator can fulfill the function of a tension band (Fig. 3.2.3-4).

A tension band that produces compression at the time of application, for example, at the medial malleolus, is called a static tension band as the forces at the fracture site remain fairly constant during movement of the ankle.

In the diaphysis angular deformity (convexity) indicates the tension side.

**Fig. 3.2.3-4:** Clinical example of an external fixator acting as a tension band.
- a) Symptomatic non-union after intramedullary nailing—note the hypertrophic area on the dorsal side of the tibia and the gap anteriorly.
- b) After removal of the nail, a unilateral external fixator in the sagittal plane was applied and full weight bearing encouraged. The non-union consolidated within 8 weeks, while the patient was immediately asymptomatic.
However, if the compression forces increase with motion, for example, in the patella with knee flexion, the tension band is called dynamic.

### 3 Operative technique

Fractures subject to distraction are at risk of displacement if movement occurs, for example, patella with knee-flexion or greater tuberosity during contraction of the supraspinatus muscle. By applying a figure-of-eight or simple loop to the front of the patella with good purchase in the patellar and quadriceps tendons respectively, an excellent tension band mechanism is created which compresses the fracture under dynamic load (Video AO51049). The 1.0 or 1.2 mm wire must be anchored as close to the bone as possible. It can either be directed through the insertion of the tendon with a large gauge needle or run around longitudinal K-wires (see Fig. 3.2.3-3a) (see also chapter 4.7). The tension band loop can also be placed through a 2 mm drill hole in the neighboring bone, for example, at the proximal ulna in olecranon fractures (see Fig. 3.2.3-3b) or around a screw head in the proximal humerus (see Fig. 3.2.3-3c).

As already mentioned, a plate or external fixator which is expected to function according to the tension band principle must be applied to the tension side of the bone or the convex side of a deformity or non-union (see Fig. 3.2.3-4). The following prerequisites are essential:

a) Bone or a fracture pattern that is able to withstand compression.

b) An intact cortical buttress on the opposite side of the tension band element.

c) Solid fixation that withstands tensile forces.

### 4 Pitfalls and complications

The most common complication is failure of the implant. A wire put under pure tension is very strong. However, if bending forces are added, it will break by fatigue quite rapidly. As this also holds true for plates, it appears essential that in the diaphysis the tension side of the bone is known and the opposite cortex is able to withstand compression forces (see Fig. 3.2.3-2). In the presence of a contralateral defect the plate is only load-bearing and repeated bending stresses invariably will lead to plate breakage by fatigue. A bone graft might be the answer to help to build up in due time a buttress in the cortex opposite to the plate.
5 Bibliography


6 Updates

Updates and additional references for this chapter are available online at:
http://www.aopublishing.org/PFxM/323.htm