THE MECHANISM OF TARSO-METATARSAL JOINT INJURIES

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Fractures and fracture-dislocations involving the tarso-metatarsal region have been known for many years. In spite of this recognition, there remains considerable conflict of opinion regarding the incidence, mechanism, treatment and prognosis of the injury (Aitken and Poulson 1963).

The purpose of this paper is to discuss the possible mechanisms of injury as studied from a series of twenty clinical cases of tarso-metatarsal joint injury collected by the author.

ANATOMY

Ligaments—The heads of the metatarsals are joined by transverse ligaments. Similar transverse ligaments join the bases of adjacent metatarsals with one exception: there is no ligamentous connection between the base of the first and second metatarsal (Fig. 1). Nevertheless, in line with the proximal recess of the second metatarsal base, there is an oblique ligament joining the medial cuneiform to the second metatarsal base. The significance of this ligament (Collett, Hood and Andrews 1958) in anchoring the base of the second metatarsal is apparent because it tethers the small base fracture to be described.

Figs. 1 and 2. Figure 1—The ligamentous attachments between the medial cuneiform and the base of the second metatarsal bone. Figure 2—The recessed, locked position of the base of the second metatarsal is shown in a cadaveric foot. A wire marker is inserted into the communicating branch of the dorsalis pedis artery between the first and second metatarsal bones.

Other than the ligamentous support offered to the tarso-metatarsal joint, additional soft-tissue structures—fascia, tendons and muscles—are abundant on the plantar aspect. This anatomical arrangement confers protection on the plantar aspect of the tarso-metatarsal joint but only supports it poorly on the dorsal aspect.

Joints—Because of the proximal recess of the middle cuneiform bone, the base of the second metatarsal is firmly locked in a mortise formed by all the cuneiform bones (Fig. 2). The remainder of the tarso-metatarsal joints are in the same curvilinear plane. The second
MECHANISM OF INJURY

There are two major mechanisms of injury—the direct and the indirect (Rainaut, Cedard and D’Hour 1966). The indirect mechanism is far more common and less understood than the simple direct injury.

**Direct mechanism**—In this there is crushing injury of the foot with involvement of the tarso-metatarsal region. With this mechanism, any degree of dislocation and any number of fractures occur. There is no specific pattern or distinctive appearance to this type of injury (Francesconi 1925).

**Illustrative Case Reports**

**Case 1**—A thirty-four-year-old labourer sustained a crushing injury to the foot when struck by a heavy weight. Radiographs showed fractures of the base of the first metatarsal, the calcaneus, the navicular and the medial malleolus. As well as the tarso-metatarsal involvement at the first ray, there was also a mid-tarsal dislocation (Fig. 3).

**Case 2**—A man aged forty-two sustained a compound fracture-dislocation involving the tarso-metatarsal region when a heavy drum struck his foot. Radiographs showed a tarso-metatarsal dislocation and fractures including the base of the fifth metatarsal, base of the fourth metatarsal, cuboid and navicular bones (Fig. 4). This patient also had a fracture involving the knee.

**Indirect mechanism**—The pattern of the fractured metatarsals and the configuration of the tarso-metatarsal joint complex suggest that the commonest mechanisms involved in producing this injury are violent abduction of the forefoot, or plantar-flexion of the forefoot. Frequently these displacements occur simultaneously.

**Abduction injuries**—When the forefoot is violently abducted, the brunt of this strain is applied to the fixed base of the second metatarsal (Fig. 5). As the remaining metatarsals slide _en masse_
at the joint surface, the second cannot move until it fractures. As the abduction or valgus force increases, some or all of the metatarsals are shifted laterally. The cuboid bone is crushed at its lateral aspect by the displacement of the lateral metatarsals. The fractures of the cuboid and second metatarsal bones are the pathognomonic signs of this abduction type of tarso-metatarsal joint disruption. Various patterns of fractures of the metatarsals may be observed, frequently fractures of the metatarsal necks, or oblique fractures at the bases (Fig. 6).

ILLUSTRATIVE CASE REPORTS

Case 3—A woman aged nineteen was the driver of a car which struck a tree. Radiographs of her right foot revealed a fracture of the second metatarsal shaft and a minor crush fracture of the cuboid bone (Fig. 7).

Case 4—A girl aged eleven years caught her outstretched left foot in the snow while riding downhill on a toboggan. The radiograph of her foot showed fractures of the necks of the first, second and third metatarsals, and an extensive crush fracture of the cuboid bone (Fig. 8).
Experimentally, the identical pattern of the fractures and dislocation can be produced on cadaver specimens simply by abducting the forefoot while the hindfoot is maintained in a fixed position (Fig. 9).

\[ \text{FIG. 9} \]
Simple abduction strain applied to cadaveric forefoot with hindfoot fixed. Note the fracture of the base of the second metatarsal, the lateral shift of the metatarsals, and the crushing of the cuboid bone.

*Plantar-flexion injuries*—It is believed that tarso-metatarsal injuries also occur when the forefoot is forced into a plantar-flexed position. Acute plantar-flexion injuries occur in two ways. In the first mechanism violence is applied to the heel in line with the axis of the foot when the toe is fixed (Fig. 10). As described in the earlier literature such a mechanism occurred when cavalrymen were thrown from their horses. The horse in turn tumbled to the ground, falling heavily on the sprawled soldier, literally pinning his foot to the ground.

**ILLUSTRATIVE CASE REPORTS**

In the current series of cases two patients sustained this type of injury.

**Case 5**—A man aged thirty-seven was riding in the front scoop of a cruising bulldozer. His feet were dangling over the edge of the scoop, which violently bounced as the machine proceeded over rough ground. With a particularly violent bounce, the scoop pinned the man's feet to the ground, producing a tarso-metatarsal fracture-dislocation of the left foot (Fig. 11).

**Case 6**—A man aged forty-one was riding on the hood of a tree-loading machine, which includes a front end attached scoop. The scoop was inadvertently raised towards the front of the radiator of the machine, pinning both the patient's feet. Bilateral tarso-metatarsal fracture-dislocations occurred (Fig. 12).

The second mechanism producing acute plantar-flexion injury of the forefoot is by far more common. In this instance the ankle joint is in a plantar-flexed position at the time of
Case 5—Acute plantar-flexion of the tarso-metatarsal joint with fractures of metatarsal bases and dislocation.

Case 6—Lateral radiographs of both feet with tarso-metatarsal dislocations. Note the severe displacement of the first metatarsals as well as the dislocation of the metatarso-phalangeal joints. The left foot (above) also shows a subluxation of the mid-tarsal joint.
injury, as when a dancer is on her toes. In this position the relationship of the foot as a short lever arm to the lower leg is lost. The foot then becomes part of the long lever of the entire lower leg. The tibia is in the same relative axis as the tarsal and the metatarsal bones. The hindfoot and midfoot are reasonably well supported by ligaments, major tendons and the interlocking of the tarsal bones. The forefoot lacks tendinous and ligamentous support, notably on the dorsal aspect. The major bony reinforcement of the forefoot is supplied by the fixed second metatarsal base. The tarso-metatarsal joint is the vulnerable point of this long lever arm.

With the lower leg and foot in the same linear axis, a force applied to the end of the foot will be transmitted along the axis (Fig. 13). Should the line of force move dorsal to the tarso-metatarsal joint, as the force increases, the weaker dorsal aspect of the joint complex eventually disrupts (Quénu and Küss 1909, Francesconi 1925). The entire joint complex may dislocate without concomitant fractures. Usually fractures occur as the forefoot does not simply hinge into plantar-flexion, but twists into a pronated or supinated position (Gissane 1951, Jeffreys 1963). By the time a radiograph is taken, the dislocated joints may have partially or completely reduced spontaneously. The fracture pattern of the tarsal and metatarsal bones may be the only clue to the extent of the injury.

ILLUSTRATIVE CASE REPORTS

Case 7—A man aged nineteen lost his footing from the lowest rung of a step ladder. His left foot violently struck the ground in the “tip-toe” position. Radiographs showed a complete dislocation of the tarso-metatarsal joint. The only fracture was a small flake of bone avulsed from the medial side of the first metatarsal bone (Fig. 14).

Case 8—A woman aged twenty-six stepped into a shallow hole while wading in water at a beach. She sustained fractures of the second metatarsal base and cuboid bone, as well as a tarso-metatarsal dislocation (Fig. 15).

Of current interest is the frequency of this plantar-flexion type of injury to the tarso-metatarsal joint in road accidents (Badger 1967). Seven of these collected cases were involved in head-on collisions. All were occupants of the front seat. At the moment of impact the outstretched foot violently strikes the vertical fire wall, producing the typical foot injury. The injury may also occur with longitudinal compression of the foot as it is squeezed between the fire wall and the broken, forwardly displaced front seat.
Figure 15—Case 8. The classical antero-posterior radiograph of the tarso-metatarsal fracture-dislocation. The injury occurred with acute hyperflexion of the tarso-metatarsal joint. Figure 16—Case 9. Bilateral tarso-metatarsal fracture-dislocation sustained when the feet were driven into the fire-wall of a car in a front-end collision.

**Case 9**—A woman aged forty was driving a car which was involved in a front end collision. She sustained bilateral compound tarso-metatarsal injuries. On the left foot there was a laceration on the dorsal aspect of the foot exposing all of the tarso-metatarsal joints and revealing a complete dislocation (Fig. 16).

On the right foot there was bursting of the skin on the dorsum of the foot at the tarso-metatarsal level, but without exposure of these joints. This injury included a lateral dislocation as well as a dislocation in a plantar direction.

**Case 10**—A woman aged fifty-four had been involved in a front end collision thirteen years previously. She recalled her futile attempt to step on the imaginary brake pedal at the moment of collision. Her present radiograph showed an old tarso-metatarsal injury with persisting deformity (Fig. 17).

Experimentally, this acute plantar-flexion injury can be reproduced on cadaver specimens, demonstrating primarily the vulnerability of the dorsal aspect of the tarso-metatarsal joint complex. A simple press machine was designed to apply force along the axis of the tibia.
the ankle fixed in a position of maximum plantar-flexion. As the load was increased, disruption of the dorsal aspect of the tarso-metatarsal joint occurred, the forefoot angulating into a plantar-flexed position (Figs. 18 and 19). In one of the nine cadaver specimens tested, fractures of the necks of the metatarsals occurred, similar to those in some of the clinical cases.
SUMMARY

1. Twenty cases of tarso-metatarsal joint injury have been studied with regard to the mechanism of injury, and experiments have been done on cadavers to confirm clinical impressions.

2. Injuries of the tarso-metatarsal joints occur by direct and indirect mechanisms, the latter being more common.

3. Indirect injuries occur in at least two ways—namely, acute abduction of the forefoot and plantar-flexion of the forefoot.

4. Most of the indirect injuries occur when the ankle joint is in a plantar-flexed position.

5. Whereas this foot injury once gained prominence on the field of battle amongst cavalrmen, it is currently associated with the motor car, the step ladder, the toboggan, the joy-rider, and commonly the simple misguided step.

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REFERENCES


