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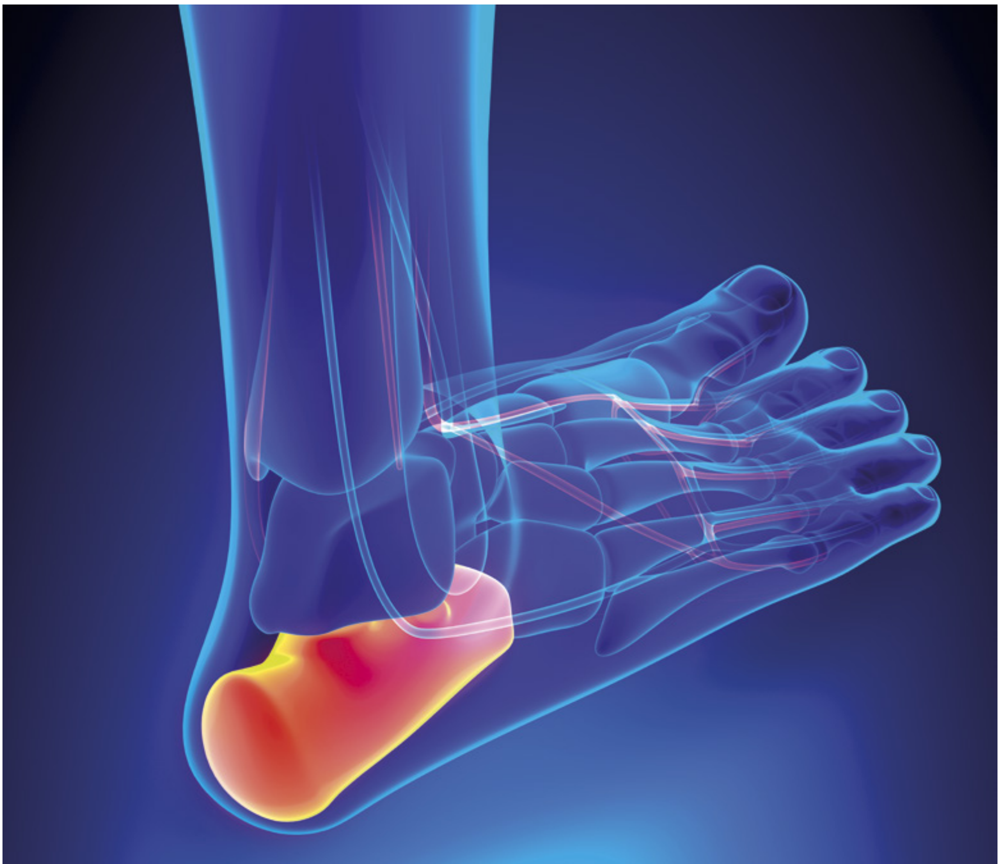
Vladimír Popelka

Treatment of calcaneal fractures



Dedication

To my son Vladko
who has decided to follow in my footsteps
and motivated me in my work,
and to my wife Inka
for her valuable support.

Vladimír Popelka

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GRADA Publishing

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TREATMENT OF CALCANEAL FRACTURES

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Obsah

Foreword

A key role in the function of the foot is played by the calcaneus to which the weight of the whole body is transmitted through the talus. With a powerful pull of the Achilles tendon attached to it, the calcaneus acts as a part of the lever arm which sets the foot in motion. In terms of morphology, it is one of the most complex bones of the human body. Anatomical reconstruction of a broken calcaneus is one of the prerequisites for restoration of its important functions.

Operative treatment of calcaneal fractures is both a big challenge and responsibility for all orthopaedic surgeons. One false step in the surgery may have fatal consequences. Sometimes the surgery resembles solving a 3D puzzle where each piece must be accurately positioned, to achieve the correct shape. Understanding the principles of treatment of calcaneal fractures requires long-term efforts, systematic study and ample practical experience.

There is no comprehensive publication in the Slovak literature that would deal with calcaneal fractures. The Czech literature contains two valuable monographs in this field, namely Wondrák: Zlomeniny kosti patní (1964) and Stehlík and Štulík: Zlomeniny patní kosti (2005), which, however, are rather out of date or provide only a one-sided picture of treatment of calcaneal fractures.

The aim of this textbook was to offer surgeons the possibility to find an optimal method of treatment of this injury, as well as to provide medical students with the essential details concerning this issue.

The textbook presents a chronological overview covering anatomy, biomechanics, diagnostics, classifications, followed by clinical chapters on individual operative techniques of treatment of calcaneal fractures. Each chapter reflects my personal clinical experience and views I have acquired during my more than twenty-year career. Based on this experience I have developed my own therapeutic concept which is presented in the conclusion.

I would like to express my gratitude to Professor H. Zwipp and his colleagues for all the knowledge and experience they shared with me during my study stay at the Department of Trauma and Reconstructive Surgery in Dresden, to Professor R. Sanders for valuable consultations, and to Assoc. Professor J. Mentel, Head of the Anatomical Institute of the Faculty of Medicine of the Slovak Medical University in Bratislava for providing me with the possibility of obtaining anatomical specimens of the foot which I used in the textbook.

I also highly appreciate the support and assistance provided by my colleagues from the Department of Trauma Surgery of the Slovak Medical University in Bratislava during individual surgical procedures.

1 INTRODUCTION

Treatment of displaced intra-articular fractures and surgical management of post-traumatic calcaneal deformities are among the most challenging procedures in traumatology and orthopaedic surgery. Already in the past, L. Böhler and R. Watson–Jones considered calcaneal fractures as the most severe and in general insoluble injury to the bones of the human body. Many methods had been developed during the history of treatment of these fractures but none of them had brought satisfactory results.

Actually, no consensus has been reached yet on the optimal method of reduction and fixation of these fractures. Most trauma surgeons dealing with calcaneal fractures had to cope with various pitfalls of numerous operative techniques. On the one hand, percutaneous techniques using Kirschner wires or screws were less invasive, but the constructs were not stable and often resulted in displacement of bone fragments during treatment. On the other hand, accurate open reduction and internal fixation were associated with a risk of wound infection. The current trend in treatment of calcaneal fractures remains geared towards the patient-specific therapeutic concept with the choice of an optimal method in view of the fracture pattern and the patient´s individuality.

However, no matter what method of treatment is used, the main goal is always an anatomical reconstruction of the shape of the calcaneus and the articular surfaces, which is a guarantee of a well-functioning foot.

The basis of a proper treatment is an exact diagnosis and a maximum amount of information about the fracture pattern. The currently most valuable imaging method is CT scanning with 3D reconstruction, showing exactly the course of fracture lines and extent of displacement of fragments. Based on a CT finding, the surgeon classifies the fracture and decides about the method of treatment. Treatment of calcaneal fractures requires a good spatial orientation, with a clear concept for restoration not only of articular surfaces but also of the entire external configuration of the calcaneus. A profound knowledge of biomechanics of the foot and anticipation of the impact of the surgery on other joints and the foot are critical to an effective repair of the calcaneus.

A good result of the treatment requires reconstruction of bones as well as adequate soft tissue management. Soft tissues require delicate manipulation as they can be easily further damaged after the injury. An inconsiderate surgical intervention causing damage to the skin, subcutaneous tissue and other soft structures, as well as improper timing of the surgery often result in severe wound healing complications.

Of no less importance is cooperation with a physiotherapist, particularly in case of operative treatment. Rehabilitation therapy can eliminate sequelae of the injury and support the results of our surgical efforts. Another important issue are socioeconomic aspects of calcaneal fractures. Of 96% of working-age patients in our series, 12% became disabled. A total of 31% of patients had to change their job; duration of treatment and inability to work for more than half a year was recorded in 85% of patients and up to 34% of patients developed permanent sequelae.

2 FUNCTIONAL ANATOMY

The heel bone (calx (Greek), calcaneus, os calcis (Latin)) is the largest tarsal bone and at the same time a highly important anatomical unit of the foot. It projects posteriorly behind the vertical posterior aspect of the lower leg to form the **calcaneal tuberosity**. Its upper part serves for attachment of a robust calf muscle through the Achilles tendon. The calf muscle pulls up the posterior part of the calcaneus acting as an effective lever in plantar flexion of the entire foot in the ankle joint. This powerful pull is responsible also for certain patterns of calcaneal fractures. It is primarily the type of injury specified by Essex-Lopresti as a tongue type fracture, where the talus hits the central part of the calcaneus and the simultaneous proximal pull of the calf muscle causes rotation of the posterior articular facet and avulsion of the upper part of the posterior calcaneus.[(17)] At the same time the talus hits the posterior articular facet obliquely. An opposite mechanism is used to reduce this fragment, i.e. rotation of the fragment distally with the foot in extension. The first to reduce a tongue type fracture in this way was Westhues in 1934 and since then this method of reduction has been referred to as the Westhues manoeuvre.[(76)] In joint-depression type fractures the pull of calf muscle is eliminated by flexion of the foot and the impact force of the talus acts perpendicular or almost perpendicular to the posterior articular facet.[(76)]

The lateral wall of the calcaneus (Fig. 1) is steep and is formed by a fine cortical bone, "the lateral bulge", which is one of the thinnest bone structures of the calcaneus. This lateral surface is therefore most commonly damaged in intra-articular calcaneal fractures caused by axial force. Part of the lateral surface of the calcaneus is a small prominence, the peroneal trochlea, which serves together with strong fibrous peroneal tendons sheaths and lateral retinacula as a pulley for these foot stabilizers. The **fibularis brevis tendon** courses anterior to or above the fibularis longus and inserts on the base of the fifth metatarsal. The **fibularis longus tendon** goes posterior to the peroneus brevis tendon at the level of the lateral calcaneal wall, then continues under the foot to attach to the medial cuneiform and the base of the first metatarsal. The calcaneofibular ligament runs from the tip of the lateral malleolus toward the calcaneal tuberosity and may get ruptured in fracture-dislocations of the lateral wall. Other stabilizers of the fibular malleolus include the anterior and the posterior talofibular ligaments.[(6, 15)]

An important structure from the surgical viewpoint is the **sural nerve** on the lateral surface of the calcaneus. It travels down the lower leg within the subcutaneous tissue, along the lateral border of the Achilles tendon and at the level of the lateral malleolus contours the lateral border of the peroneal tendons. At the level of the fifth metatarsal base, the sural nerve ramifies into its lateral and medial terminal branches. In the extended lateral approach, with the incision passing close to this nerve, caution has to be taken to avoid its damage or entrapment by suture, which may cause unpleasant numbness of the lateral side of the foot or pain in the course of the nerve.

Blood supply to the lateral surface of the calcaneus is provided by the calcaneal branches of the peroneal artery in the posterior part, by the anterior lateral malleolar artery from the anterior tibial artery in the middle part and by the lateral tarsal artery in the anterior part. The three arteries are mutually interconnected forming a chain of anastomozing blood vessels.[(7)]

The medial wall of the calcaneus (Fig. 2) is concave and its contour forms the so called *Shenton line* that can be seen on axial radiographs. Its assessment is important for evaluation of displacement between the tuberosity and sustentacular fragments. Protruding anteromedially is a bony process, the **sustentaculum tali**. This part of the calcaneus is formed by a strong bone which supports the talar body and serves as a centre of transmission of the body weight to the medial side of the foot. Isolated fractures in this region are rare and are caused only by direct impact force acting on the medial side of the foot (e.g. in motorcycle accidents the sustentaculum gets fractured by the foot hitting the pedal). On the inferior surface of this medial process is a groove for the tendon of flexor hallucis longus tendon. Unlike other tendons on the medial side of the foot (the tibialis posterior, the flexor digitorum longus), the flexor hallucis longus rests on the medial wall of the calcaneus and in fracture-dislocations in this area and in the area of sustentaculum it gets interposed between the fragments.

This is the cause of failure of reduction, requiring revision of the tendon and its release from the medial approach. Only then the fracture is reduced.

Fig. 1: Lateral wall of the calcaneus, the calcaneofibular ligament and peroneal tendons

Fig. 2: Medial wall of the calcaneus, showing tendons of the tibialis anterior, the flexor hallucis longus, which passes over the flexor digitorum longus

The foot is **innervated** primarily by the tibial nerve that splits into two branches to supply sensation to the skin on the medial side of the foot and the foot sole. The posterior branch of the tibial nerve gives off the calcaneal branches at different levels.

Blood supply to the foot is provided mainly by the posterior tibial artery (Figs. 3, 4) which passes above the medial side of the calcaneus and at the level of the foot sole it divides into the medial and lateral plantar arteries.[(6)]

Figs. 3, 4: Important structures on the medial side of the foot (in posterior-anterior direction the flexor hallucis longus, neurovascular bundle, the flexor digitorum longus and the tibialis anterior)

Three articular facets on **the superior surface** of the calcaneus (Figs. 5, 6) communicate with the talus. The largest of them is the posterior convex facet which is part of the **subtalar joint**.

Figs. 5, 6: Upper surface of the calcaneus, articular facets, coxa pedis and sinus tarsi

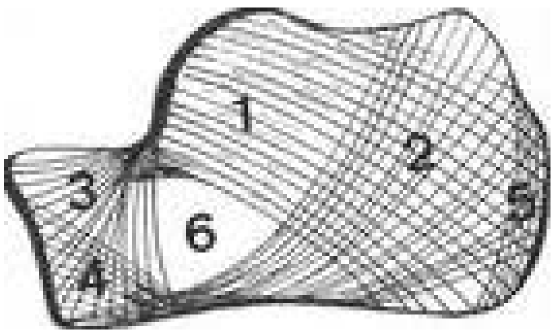
The subtalar joint, enclosed by a fine joint capsule, communicates only with the adjacent articular facets of the talus and the calcaneus.

Its stability is ensured by **the strong posterior, lateral and medial talocalcaneal ligaments** and the strongest **talocalcaneal interosseous ligament** which is part of the sinus tarsi. The sinus tarsi is a cavity formed by the corresponding grooves of the talus and the calcaneus between the subtalar and talocalcaneonavicular joints. The two mentioned medial articular facets of the calcaneus which may be sometimes fused into one facet, articulate with the inferior surface of the head of the talus. Together with the concave articular surface of the navicular bone they form a socket for the talar head, referred to as "**coxa pedis**" or **the talocalcaneonavicular joint**. The inferior part of the mentioned articulation is reinforced by a strong fibrocartilaginous plate formed by the plantar calcaneonavicular ligament, which together with part of the tendon of the tibialis posterior muscle and sustentacular articular facets of the calcaneus provide a strong support to the talar head. The subtalar and the talocalcaneonavicular joints do not communicate with each other, being separated by the sinus tarsi.(65)

The anterior part of the calcaneus projects anteriorly to form the **anterior process** which bears a concave-convex articular surface articulating with the cuboid.(6)

The shape and bone architecture of the calcaneus play a key role in the static stability of the foot. The weight of the body is transmitted through the talus medially to the sustentaculum and laterally to the fanning out trabeculae of the calcaneus and further to the longitudinal arch of the foot and the forefoot. Depending on the magnitude of the force transmitted by the weight of the body to the calcaneus the density, or strength of the bone is changing. At the site of the highest lateral loads, i.e. under the posterior articular surface of the calcaneus, there is a compact bone, up to 1cm thick, referred to as "thalamus calcanei", while the strongest cancellous bone is situated in the area of the calcaneal tuberosity and the sustentaculum tali. On the contrary, under the trabeculae, in anatomical terms at the site under the angle of Gissane, there is a zone with a very sparse trabecular structure, **the neutral triangle**, also termed as trigonum calcis or a pseudocystic triangle. In joint-depression type fractures the talus usually hits the posterior articular facet, which is depressed into this weakest portion of the calcaneus, the neutral triangle (Fig. 7).

Fig. 7: Trabecular system of the calcaneus with the negative triangle(78)

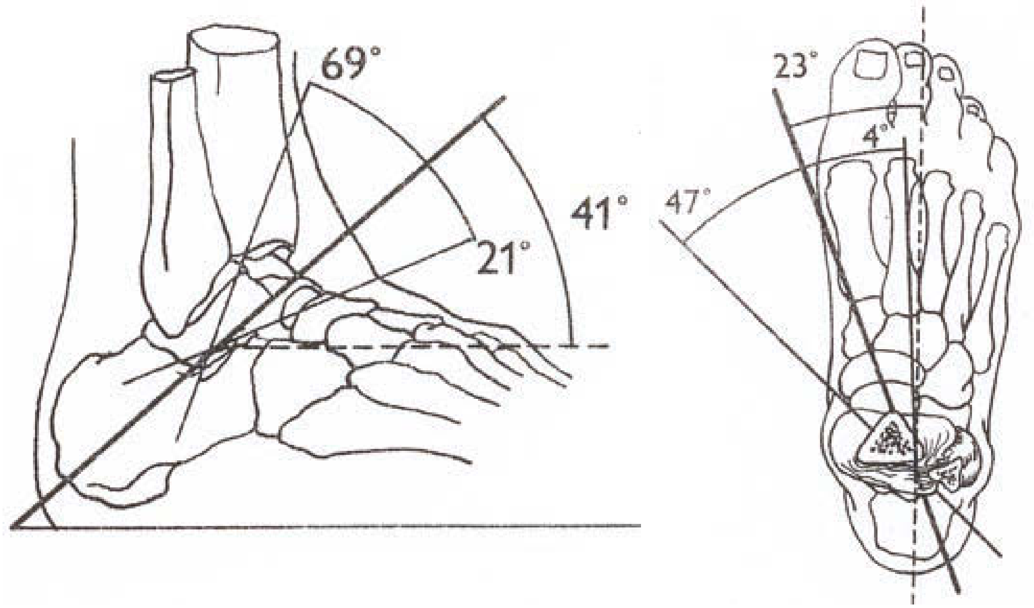


Axial loading is absorbed by the specifically adapted bone structure of the calcaneus and the elastic ligamentous connections of the calcaneus with other tarsal bones, and elastic fat pads and the thick skin of the calcaneus. Higher plantar pressure results in flattening of the transverse and longitudinal arches of the foot, with reduction of the height of the foot sole by up to one half, and its simultaneous widening.(6, 78)

3 BIOMECHANICS OF THE SUBTALAR JOINT

Proper understanding of biomechanics of the subtalar joint and the joints cooperating with it is essential for treatment of intra-articular fractures and post-traumatic deformities of the calcaneus. The subtalar joint is formed by articulation between the largest posterior talar articular surface of the calcaneus and the inferior surface of the talus (the posterior calcaneal articular surface of the talus). The subtalar joint, with convexity of the lateral side, is the chief site within the foot for generation of eversion and inversion movement. The axis of the subtalar joint courses obliquely and connects the posteromedial border of the ankle and the latero-plantar border of the calcaneus. In the transverse plane, it deviates about 23 degrees medial to the long axis of the foot with the range of motion in this plane of 4-47 degrees. In the horizontal plane, the axis deviates about 41 degrees, with the range of motion of 21-69 degrees (Figs. 8, 9). Due to the oblique course of the axis of the subtalar joint, each rotation of the lower leg with a fixed foot generates movement in the subtalar joint. External rotation results in inversion of the foot together with elevation of its medial side and depression of the lateral side, while internal rotation has an opposite effect. In case of a flat foot, the axis of the subtalar joint runs more horizontally than in a normal foot, which results in greater mobility of this joint and a greater range of motion.

Figs. 8, 9: Axis of movement of the subtalar joint in both planes according to Inman[24]



The first to describe the axis of movement of the subtalar joint in the sagittal and transverse planes was Meyer.[39] Biomechanics of the talus and its surrounding joints was dealt with in greater detail by Manter in 1941, who compared the movement of the talus to screw motion, i.e. a shift along the oblique axis accompanying the rotation. The subtalar joint behaves like a screw with a right-hand thread on the right side and a screw with a left-hand thread on the left side. He also focused on the course of the axis of the subtalar joint. Inman based his work on the Manter´s studies and added individual variations of the course of the subtalar axis. He concluded that the range of screw motion is specific to each individual. He also developed a model of movement of the subtalar joint during rotation of the lower leg.[36]

The **subtalar joint** is moving also during gait when inversion occurs at heel-strike, and progresses to eversion during mid-stance phase. During the gait cycle, the range of motion in the subtalar joint of a normal foot is about 6 degrees, as compared to 12 degrees in a flat foot.[13]

The subtalar joint and the ankle joint form one functional unit. The ankle joint forms the proximal junction of the talus with the lower leg, while the subtalar joint the distal junction with the foot sole (Fig. 10). Inclination angles of axes of both joints are interdependent. In a stiff ankle, there occurs a compensatory mechanism with an increased external rotation of the foot and a range of motion larger in the subtalar joint and reduced in the ankle joint. Therefore individuals after ankle fusion walk in external rotation, to allow the subtalar joint to take over part of the motion of the ankle. At the same time increase of external rotation by 10 degrees is in terms of ankle fusion functionally more beneficial. On the contrary, during in-toeing gait the range of motion is larger in the ankle and reduced in the subtalar joint. The compensatory mechanism in patients after subtalar fusion is walking with internal rotation. Symbiosis of the ankle and the subtalar joint allows mutual compensation, a disorder of this compensatory mechanism results in overloading of the healthy joint and its "wear and tear" damage.

Fig. 10: Relationship between the ankle and the subtalar joint

Another joint, closely cooperating with the subtalar joint, is the **Chopart joint** (talonavicular and calcaneocuboid joints). During mid-stance phase, with the subtalar joint in eversion, axes of both the talonavicular and calcaneocuboid joints run parallel, the joints are more mobile and the foot can better adapt to the ground. At heel-strike, with the subtalar joint in inversion, axes of the two mentioned joints diverge, the motion gets reduced and the stability increases. In fact, the function of the Chopart joint is controlled by the subtalar joint and these two joints control foot flexibility during gait.

The Chopart joint allows rotational movements in the sense of abduction-adduction, plantar flexion-dorsiflexion, pronation-supination. Under normal conditions, the range of these movements is relatively small, but it may be increased by compensation for limitation of the range of motion in the ankle or the subtalar joint. As a result, the stabilization mechanism of the Chopart joint disappears after fusion of the subtalar joint and the range of duction movements increases by compensation.[13]

4 INCIDENCE AND MECHANISM OF INJURY

4.1 Incidence

Although calcaneal fractures are the most frequent injuries to the tarsal bones, they account for only 2–3% of all fractures. The share of intra-articular fractures is as high as 60 – 75%.[1, 2, 58, 81, 82]

They are more common in men than in women with the 5:1 ratio, which is most probably associated with the type of occupation.

Zwipp et al. analyzed a group of 553 intra-articular calcaneal fractures in 78% of men and 22% of women, with the mean age of 41.7 years, and found out that concomitant injuries included predominantly fractures of the lumbar spine (10%); 26% of patients had also other lower limb fractures. A total of 10.2% were open fractures, 11.5% were bilateral fractures and 22% of fractures were part of multiple trauma.[80]

4.2 Mechanism of injury

Intra-articular calcaneal fractures are most frequently caused by axial force when, in a **fall from a height**, the patient´s weight concentrates on the heels on landing, with the knees in extension. This mechanism is most often seen in men, particularly construction workers working at heights, roofers, carpenters, or in home injuries caused by a fall from a ladder or other elevated platforms.

Another group are injuries due to **motor-vehicle accidents**, when the heel hits directly the car floor. These injuries are mostly sustained in frontal automotive crashes, when during deceleration the driver´s forefoot is on the brake pedal and the hindfoot hits the car floor. Another group of patients includes motorcyclists in case of which the heel hits the foot pedal. Additional groups include home and sports injuries.

Analysis of mechanism of injury in patients operated on in the period of 2007–2014, at the Department of Trauma Surgery of the Slovak Medical University (KÚCH SZU) in Bratislava, Slovakia

Falls from a height

The **distance of the fall** is a very important parameter when taking the patient´s medical history, as it indicates the energy of the trauma. Of the total number of 122 patients in our cohort, 113 (92.6%) patients sustained a calcaneal fracture following a fall from a height, reported by the patients in the range between 0.5m and 50m. Elderly patients with osteoporosis typically sustained calcaneal fractures during a fall from extremely small height. The shortest distance of the fall was reported by a 64-year old woman who sustained a fracture after a jump from a footstool about 0.5 m high. The longest distance of the fall was recorded in case of a 51-year old man who fell during paragliding from about 50m. Long distance falls were usual also in suicidal falls (jumping off tall buildings). Analysis of patients who sustained a calcaneal fracture after a fall from a height is shown in Table 1.

In addition to the distance of the fall, another important factor is **quality of the landing surface and shoes**. In general, direct landing on a hard surface (pavement, road, concrete surface) results in comminuted fractures of the calcaneus. However, we did not make an exact analysis of patients in this respect.

Table 1: Causes of falls from a height

Mechanism of injury – fall	Number	%
Fall from ladder	23	20.3
Fall from elevated platforms	22	19.5
Fall from roof or another part of a house	16	14.2
Fall from tree	13	11.5
Fall from scaffolding	11	9.7
Fall from stairs	7	6.2
Fall during sports activities	6	5.3
Suicidal fall from a tall building	3	2.7
Others (home injuries)	12	10.6
TOTAL	**113**	**100**

Conclusions

Our analysis has shown that a majority of falls from a height occurred in connection with activities at work or at home. The professions with the highest exposure included construction workers (carpenters, plumbers, bricklayers). Home injuries were typically caused by falls from a ladder during reconstructions of the house or during fruit picking from a ladder.

Falls from elevations included jumps from a low wall, fence, or even from the stage at a disco show, jumping from one balcony to another, from the swimming pool ladder etc.

In the group of other injuries sustained at home we included a fall from a footstool, a table, fall during hanging curtains, cleaning of a chandelier etc.

In patients with comorbidities (osteoporosis in elderly people, alcoholics, diabetics, patients with metabolic disorders etc.), injuries were caused as a rule by a much less trauma energy than in healthy and young individuals. Such a **low-energy trauma** resulted for instance from incautious jump on a hard surface or a jump from a minimal height.

High-energy trauma (Table 2) included patients with typical signs of a severe injury, i.e., patients with polytrauma or with other severe concomitant injuries (spinal fractures, femoral fractures, fractures of the proximal tibia or the tibial pilon). High-energy traumas included also isolated comminuted calcaneal fractures without any associated injury.

Three cases were **suicidal falls**, either jump off a balcony or from a window of a tall building with landing on the heels with the lower limbs in extension. According to the reports, the patients jumped from 4th - 6th floor, i.e. about 10–15m. All these injuries were sustained by young people at the age of 20–30 years, within polytrauma, with comminuted fractures of both calcanei. **Extreme fall height** was recorded in the above mentioned paraglider. According to his estimate he fell from the height of about 50m. He sustained multiple injuries, including bilateral open comminuted calcaneal fractures, fracture-dislocations of both talar bodies, fractures of both distal lower legs and a fracture of the lumbar spine.

Table 2: Patients with high-energy trauma

High-energy trauma	Number	%
Extreme height	1	0.8
More than 10m	3	2.5
5 – 10m	17	13.9
Road traffic injury	3	2.5
TOTAL	**24**	**19.7**