Diplomarbeit

Treatment of pilon tibial fractures with Ilizarov Fixateur
a retrospective patient analysis

eingereicht von

Savio Hausberger

zur Erlangung des akademischen Grades

Doktor der gesamten Heilkunde

(Dr. med. univ.)

an der

Medizinischen Universität Graz

ausgeführt an der

Universitätsklinik für Orthopädie und Traumatologie

unter der Anleitung von

Ao.Univ.-Prof. Mag.phil. Dr. med. univ. Franz Seibert

Dr.med. Dr.scient.med. Patrick Reinbacher, MA

Graz, 13.11.2024

Eidesstattliche Erklärung

Ich erkläre ehrenwörtlich, dass ich die vorliegende Arbeit selbstständig und ohne fremde Hilfe verfasst habe, andere als die angegebenen Quellen nicht verwendet habe und die den benutzten Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Des Weiteren erkläre ich hiermit, dass, sofern bei der Erstellung dieser Arbeit Künstliche Intelligenz (KI) Werkzeuge zur Generierung und/oder Korrektur bestimmter Textpassagen verwendet wurden, dieser Einsatz unter Einhaltung ethischer Grundsätze, akademischer Integrität und den Vorgaben meiner Universität erfolgte, sowie in Folge dies transparent gemacht und in angemessener Weise gekennzeichnet wurde.

Graz, am 13.11.2024 Savio Hausberger eh.

Acknowledgements

I would like to express my sincere gratitude to my thesis supervisors, Ao.Univ.-Prof. Mag.phil. Dr.med.univ. Franz Seibert, Univ. FA Dr.med.univ. Patrick Reinbacher, MA and FOA Dr.med.univ. Philipp Walter Lanz. Their invaluable guidance and unwavering support were instrumental in the successful completion of this work.

I would also like to extend my thanks to Dr.med.univ. Andrzej Stanislaw Hecker MSc for his significant contributions during the data analysis stage.

Finally, I am deeply grateful to my family and friends for their unwavering support throughout my entire academic journey.

Zusammenfassung

Einleitung

Seit seiner Entwicklung durch Dr. Gavril Abramovich Ilizarov im Jahr 1951 hat der Ilizarov-Ringfixateur die externe Fixierung revolutioniert. Seine einzigartige modulare Bauweise und die Möglichkeit zur dreidimensionalen Korrektur von Deformitäten machen ihn zu einem vielseitigen Instrument in der Orthopädie und Traumatologie. Insbesondere bei komplexen Frakturen wie der Pilon tibial Fraktur bietet der Ilizarov-Fixateur eine minimalinvasive und anpassungsfähige Behandlungsmöglichkeit. Diese Studie untersucht die Effektivität des Ilizarov-Systems bei der Behandlung von Pilon tibial Frakturen und setzt seine Ergebnisse in Relation zur aktuellen Forschungslage.

Methoden

In diese retrospektive Studie wurden PatientInnen eingeschlossen, die zwischen 2005 und 2020 an der Universitätsklinik Graz aufgrund einer Pilon tibial Fraktur mit einem Ilizarov-Ringfixateur versorgt wurden. Nach telefonischer Kontaktaufnahme und Erteilung der Einverständniserklärung wurden die PatientInnen einer ausführlichen klinischen Untersuchung unterzogen. Die Datenanalyse stützte sich primär auf deskriptive statistische Verfahren, wobei die Wahl der statistischen Kennwerte (Mittelwert/Standardabweichung oder Median/Interquartilbereich) von der Verteilung der erhobenen Daten abhing.

Ergebnisse

In dieser Studie wurden 23 PatientInnen mit einer durchschnittlichen Nachbeobachtungszeit von 8,2 Jahren (von 5 bis 12 Jahren) untersucht. Die Studie schloss erwachsene PatientInnen (≥18 Jahre) mit Pilon tibial Frakturen nach AO 43 Typ C ein, bei denen eine Ilizarov-Fixation als Behandlungsmethode gewählt wurde. Das Durchschnittsalter betrug 64,8 Jahre (von 29 bis 85 Jahren), wobei Frauen etwas älter waren als Männer. Bei einigen Teilnehmern lagen Komorbiditäten wie Diabetes Mellitus und Rauchen vor.

Die Schmerzbewertung ergab, dass alle PatientInnen im Ruhezustand schmerzfrei waren, unter Belastung jedoch individuelle Unterschiede bestanden. Während die Hälfte der PatientInnen keine belastungsabhängigen Schmerzen angab, beeinträchtigten bei der anderen Hälfte leichte bis moderate Schmerzen die täglichen Aktivitäten.

Die funktionelle Beurteilung zeigte signifikante Einschränkungen der Beweglichkeit im behandelten Sprunggelenk im Vergleich zur gesunden Seite, insbesondere in Plantar- und

Dorsalflexion. Die AOFAS-Rückfuß-Scores zeigten eine große Streuung der Ergebnisse: Fast die Hälfte der PatientInnen (45,5 %) erzielte ein ausgezeichnetes Ergebnis, während etwa ein Drittel (32 %) mit einem schlechten Ergebnis abschloss.

Die Analyse der SF-36-Scores ergab unterschiedliche Durchschnittswerte in den Unterkategorien, die von 62,7 (Vitalität) bis 90,9 (Einschränkungen durch emotionale Probleme) reichten. Es ist jedoch zu beachten, dass einige dieser Werte durch vorbestehende Krankheiten (Komorbiditäten) beeinflusst sein könnten, die häufig mit dem Altern einhergehen.

Diskussion

Die vorliegende Studie hat die langfristigen funktionellen Ergebnisse nach einer Ilizarov-Fixation von Pilon tibial Frakturen untersucht und mit den Befunden bestehender Literatur verglichen. Während sich unsere Ergebnisse im Großen und Ganzen mit den in der Literatur beschriebenen übereinstimmen, konnten insbesondere bei der Betrachtung spezifischer Ergebnisparameter Unterschiede festgestellt werden. Diese Diskrepanzen könnten auf Unterschiede in der Patientenkollektivzusammensetzung (Alter, Geschlecht, Begleiterkrankungen) zurückzuführen sein.

Es ist zu beachten, dass die begrenzte Fallzahl in unserer Studie sowie möglicherweise auch in den Vergleichsstudien die Verallgemeinerbarkeit der Ergebnisse einschränkt. Daher sind die Schlussfolgerungen mit Vorsicht zu interpretieren. Um ein umfassenderes Bild der langfristigen Wirksamkeit der Ilizarov-Fixation bei Pilon tibial Frakturen zu erhalten, sind weitere prospektive Studien mit größeren Patientenkollektiven erforderlich.

Abstract

Introduction

Since its invention in 1951 by Dr. Gavril Abramovich Ilizarov, the Ilizarov ring fixator has revolutionized external fixation. This versatile device offers a minimally invasive alternative to traditional osteosynthesis methods for bone fractures. Unlike other external fixators, the Ilizarov system allows for gradual three-dimensional deformity correction and modular frame adjustments, even in outpatient settings. This study investigates the effectiveness of the Ilizarov fixator specifically for pilon fractures, comparing its long-term outcomes with existing literature. (Solomin 2008)

Methods

This study recruited patients treated with Ilizarov fixation for pilon fractures at the University Hospital Graz between 2005 and 2020. Patients attending follow-up appointments were contacted by phone and invited to participate. After informed consent, a team of specialists conducted a comprehensive clinical examination followed by a discussion to ensure clear communication about the post-operative plan. Data analysis primarily employed descriptive statistics (mean/standard deviation or median/interquartile range) based on data distribution.

Results

The study examined 23 patients with an average follow-up time of 8.2 years (from 5 to 12 years). The study included adult patients (≥18 years) with AO 43 Type C pilon fractures who underwent Ilizarov fixation as the chosen treatment method. The average age was 64.8 years (from 29 years to 85 years), with females slightly older than males. Comorbidities like diabetes and smoking were present in some participants.

Assessment of pain revealed that while all participants reported no pain at rest, pain on exertion varied considerably. Exactly half (n=11) of the patients experienced no pain on exertion, while the remaining half reported mild to moderate pain impacting daily activities. Maximum pain scores also showed heterogeneity.

Range of motion measurements showed significant limitations in the ankle joint treated with the Ilizarov fixator compared to the healthy ankle. Plantar flexion and dorsiflexion were particularly restricted. AOFAS hindfoot scores indicated a diverse range of outcomes, with

nearly half (45,5%) achieving excellent results and about a third (32%) experiencing poor outcomes.

Analysis of the SF-36 scores revealed a variation in average values across the subcategories, ranging from 62.7 (vitality) to 90.9 (limitations due to emotional problems). It's important to acknowledge, however, that some of these scores might be influenced by pre-existing medical conditions (comorbidities) often associated with aging, potentially underestimating the true impact of the surgery on patients' health-related quality of life (HRQoL).

Discussion

This analysis compared long-term functional outcomes following Ilizarov fixation for pilon tibial fractures with existing literature. While our findings and those of previous studies showed generally similar trends, some variations were observed, particularly when considering specific outcome categories. These discrepancies may be due to differences in patient demographics (age, gender). It's important to acknowledge that the relatively small sample size in our study, and potentially in the comparison studies as well, limits the generalizability of these findings. Therefore, cautious interpretation is necessary. Further research with larger and more diverse populations is warranted to solidify our understanding of the long-term effectiveness of Ilizarov fixation for pilon tibial fractures.

Table of contents

Acknowledgements III

Zusammenfassung IV

Einleitung IV

Methoden IV

Ergebnisse IV

Diskussion V

Abstract VI

Introduction VI

Methods VI

Results VI

Discussion VII

Glossary and Abbreviations XII

List of figures XIII

List of tables XV

1 Introduction 1

1.1 Anatomy of the talocrural joint 1

1.1.1 Osseous structures 1

1.1.2 Joint capsule 1

1.1.3 Ligament system 2

1.1.4 Mechanics 3

1.2 Anatomy of the talotarsal joint 4

1.2.1 Osseous structures 4

1.2.2 Ligament system 4

1.2.3 Mechanics 5

1.3 Fracture theory 5

1.3.1 Fracture mechanisms 5

1.3.2 Types of fractures 6
1.3.3 AO classification of fractures 8
1.4 Bone fracture healing 8
1.4.1 Fracture phase 8
1.4.2 Inflammation phase 8
1.4.3 Granulation phase 9
1.4.4 Callus hardening phase 9
1.4.5 Modeling- and remodeling phase 10
1.4.6 Primary bone healing 10
1.5 Pilon tibial fracture 10
1.5.1 Definition 10
1.5.2 Classification 11
1.6 Ilizarov Device 12
1.6.1 Advantages and Disadvantages of the Ilizarov Fixation 12
1.6.2 Biomechanical Principles 13
1.6.3 Osteosynthesis of the Tibia and Fibula using the Circular External Fixator (CEF) System 16
1.6.4 Ilizarov External Fixation for Distal Tibia and Fibula Fractures 18
1.7 Study question 23
2 Material and Methods 24
2.1 Study design and procedure 24
2.2 Patients 25
2.2.1 Inclusion criteria 25
2.2.2 Exclusion criteria 25
2.3 Examinations 25
2.3.1 Short Form Health 36 Questions (SF-36) 26
2.3.2 AOFAS Score 27

2.3.3 Numeric rating scale.....27
2.3.4 Range of Motion.....28
2.4 Statistic Methods.....31
3 Results.....32
3.1 Study population.....32
3.2 Demography.....33
3.3 Numeric Rating Scale Results.....34
3.4 Range of motion differences between affected and healthy ankle joint.....35
3.5 AOFAS Score Results.....38
3.5.1 AOFAS Score Hindfoot Results.....38
3.5.2 AOFAS Score Midfoot Results.....40
SF-36 Score Results.....42
3.5.3 Physical functioning (Figure 18).....42
3.5.4 Limitations due to physical health (Figure 19).....43
3.5.5 Limitations due to emotional problems.....43
3.5.6 Vitality (energy) (Figure 20).....44
3.5.7 Mental health (emotional well-being) (Figure 21).....45
3.5.8 Social Functioning (Figure 22).....45
3.5.9 Bodily pain (Figure 23).....46
3.5.10 General health perception (Figure 24).....47
4 Discussion.....48
4.1 Comparative Analysis with the study of S. Vidyadhara and Sharath K. Rao (2006) 48
4.1.1 Comparing Range of Motion (Vidyadhara und Rao 2006).....49
4.1.2 Comparing AOFAS hindfoot Score Results (Vidyadhara und Rao 2006).....50
4.2 Comparative Analysis with the study of Walid Osman et al. (2017).....52
4.2.1 Comparing AOFAS hindfoot Score Results (Osman et al. 2017).....52

4.3 Comparison with two studies that used the Open Reduction Internal Fixation technique (Viberg et al. 2016) (Rubio-Suarez et al. 2018) 54

4.3.1 Comparing AOFAS hindfoot Score Results (Viberg et al. 2016) 54

Comparing AOFAS hindfoot Score Results (Rubio-Suarez et al. 2018) 54

4.4 Limitations 55

5 Conclusion 56

List of references 58

Adnex 60

Adex I (SF-36 Score) 60

Adnex II (AOFAS Hindfoot Score) 66

Adnex III (AOFAS Midfoot Score) 67

Adnex IV (Numeric Rating Scale) 68

Glossary and Abbreviations

AO .... *Association of Osteosynthesis*
AOFAS .... *The American Orthopaedic Foot and Ankle Society*
ASIF .... *Association of the Study of Internal Fixation*
BMI .... *Body Mass Index*
BMU .... *basic multicellular unit*
CEF .... *circular external fixator*
COVID-19 .... *coronavirus disease 2019*
DF .... *dorsiflexion*
Dr. .... *Doctor*
e.g. .... *"exempli gratia" for example*
f *female*
HRQoL .... *health related quality of life*
i.e. .... *"id est" that is*
ID .... *Identity document*
KAGES .... *Styrian Hospital Association*
lig. .... *ligament*
Ligg. .... *ligaments*
m *male*
m. .... *musculus*
MEDocs .... *Styrian medical and nursing documentation and communication network*
n *number of patients*
NRS .... *Numeric Rating Scale*
PF .... *plantar flexion*
PRO .... *patient-reported outcome*
PROM .... *patient-reported outcome measure*
ROM .... *range of motion*
SARS-CoV-2 .... *severe acute respiratory syndrome coronavirus type 2*
SF-36 .... *Short Form-36*
std. dev. .... *standard deviation*
SVNR .... *Social insurance number*

List of figures

Figure 1 Osseous structures of the talocrural joint (from Prometheus LernAtlas. Thieme, 4. Aufl.)....................1
Figure 2 Ligament system of the talocrural joint and the talotarsal joint (from Prometheus LernAtlas. Thieme, 4. Aufl.)....................3
Figure 3AO classification of region 43 Distal lower leg (from Frakturen Müller-Mai 2010) .12
Figure 4: (a-b) external fixation device for reduction and fixation of fractures of the lateral malleolus (from The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices, Solomin 2012, Second Edition) 19
Figure 5: (a-b) Ilizarov external fixation device for the fixation of pronation fracture-dislocations of the ankle (from The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices, Solomin 2012, Second Edition) 20
Figure 6: (a-b) External fixation device for the reduction and fixation of the posteroinferior tibia (from The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices, Solomin 2012, Second Edition) 20
Figure 7: (a-c) Combined external devices for the fixation of fractures of the ankle (from The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices, Solomin 2012, Second Edition) 21
Figure 8: (a-b) External fixation for the fixation of chronic injuries to the ankle joint (from The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices, Solomin 2012, Second Edition) 23
Figure 9: Dorsal extension and plantar flexion movement test in the upper ankle joint (from Klinische Tests und Untersuchungen in Orthoopädie und Unfallchirurgie; Konrads, Rudert, Springer Verlag, 2018) 29
Figure 10: Supination (a,c) and pronation (b,d) movement test in the lower ankle joint (from Klinische Tests und Untersuchungen in Orthoopädie und Unfallchirurgie; Konrads, Rudert, Springer Verlag, 2018) 30
Figure 11: Presentation of the patient collective with indication of gender ratios....................32
Figure 12:Histogram showing the distribution of the results of the Numeric Rating Scale under stress 34
Figure 13: Histogram showing the distribution of the results of the Numeric Rating Scale for the maximum pain experienced in the affected extremity 35
Figure 14: Presentation of the results of the AOFAS hindfoot score as a boxplot diagram.....38

Figure 15: The AOFAS hindfoot score distribution is presented graphically using a pie chart. 39
Figure 16: Presentation of the results of the AOFAS midfoot score as a boxplot diagram 40
Figure 17:The AOFAS midfoot score distribution is presented graphically using a pie chart. 41
Figure 18:Boxplot diagram representation of the “physical functioning” sub-area.................42
Figure 19: Boxplot diagram representation of the “limitations due to physical health” sub-area 43
Figure 20: Boxplot diagram representation of the “vitality” sub-area"...................................44
Figure 21: Boxplot diagram representation of the “mental health” sub-area".........................45
Figure 22: Boxplot diagram representation of the “social functioning” sub-area"..................45
Figure 23: Boxplot diagram representation of the “bodily pain” sub-area" 46
Figure 24: Boxplot diagram representation of the “general health perception” sub-area".......47

List of tables

Table 1: List of the eight dimensions of the SF-36 score. Source: Own design based on Ware, JR and Gandek B. 1998 27
Table 2: Presentation of the demographic data of the study participants with regard to BMI and age with details of gender ratios 33
Table 3: Presentation of the demographic data of the study participants regarding diabetes mellitus, peripheral arterial disease and smoking, divided into male and female 33
Table 4: Comparison between average plantar flexion at the affected ankle joint and the unaffected ankle joint 36
Table 5:Comparison between average dorsiflexion at the affected ankle joint and the unaffected ankle joint 36
Table 6:Comparison between average pronation at the affected ankle joint and the unaffected ankle joint 36
Table 7: Comparison between average supination at the affected ankle joint and the unaffected ankle joint 37
Table 8: Presentation of the average difference in plantar flexion between affected and unaffected ankle joints and indication of significance (p) 37
Table 9: Presentation of the average difference in dorsiflexion between affected and unaffected ankle joints and indication of significance (p) 37
Table 10:Presentation of the average difference in pronation between affected and unaffected ankle joints and indication of significance (p) 37
Table 11: Presentation of the average difference in supination between affected and unaffected ankle joints and indication of significance (p) 37
Table 12: Statistical presentation of the results of the AOFAS hindfoot score 38
Tabelle 13: Statistical presentation of the results of the AOFAS midfoot score 40
Table 14: Statistical result of all eight sections of the SF-36 score, showing arithmetic mean, median, minimum, maximum and standard deviation 42
Table 15:Comparison between male and female study population considering the AOFAS hindfoot score and the AOFAS midfoot score 49

1 Introduction

1.1 Anatomy of the talocrural joint

1.1.1 Osseous structures

It articulates the roller roof of the shin (tibia), facies articularis inferior, with the roller sheath of the trochlea tali, facies superior. The roll cheeks of the talus are bordered medially and laterally by the ankle cheeks. The facies articularis malleoli medialis of the tibia articulates with the facies malleolaris medialis of the talus. On the inner side of the fibular malleolus the facies articularis malleoli lateralis is located. It is in articular contact with the facies malleolaris lateralis of the talus. (Anderhuber et al. 2012)

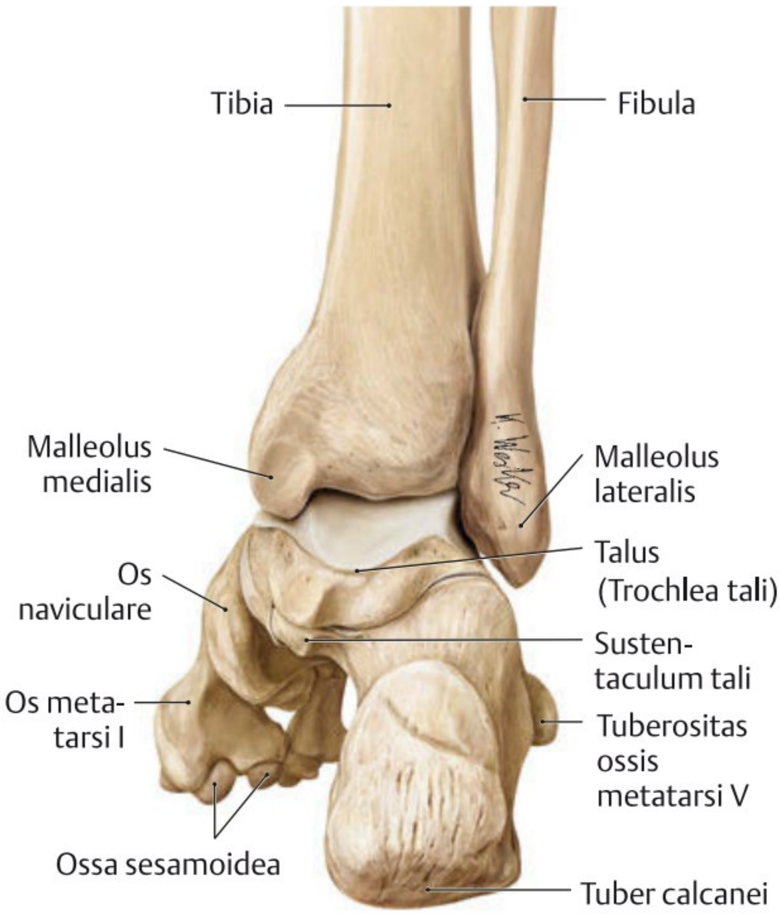

Figure 1 Osseous structures of the talocrural joint (from Prometheus LernAtlas. Thieme, 4. Aufl.)

1.1.2 Joint capsule

The joint capsule is attached to the edges of the cartilaginous surfaces. The malleoli are exposed. It is thin on the anterior and posterior sides and thus more easily injured. Anteriorly, it is fused to the tendon sheaths of the musculi extensores digitorum and hallucis. This prevents entrapment during dorsal extension. On the posterior surface of the collum tali and also in the area of the processus posterior tali, synovial fat bodies are found that exert a shock-absorbing function in the end positions of dorsiflexion and plantar flexion. (Anderhuber et al. 2012)

1.1.3 Ligament system

The medial and lateral collateral ligaments, together with the syndesmosis ligaments, play a crucial role in stabilizing and guiding the upper ankle joint, since ligamentous components are tense in every joint position and thus in all movements. (Schünke et al. 2014)

- **Ligamentum collaterale mediale (deltoideum)**
  The fan-shaped subsections of the medial collateral ligament, with superficial long and short deep ligamentous branches, extend between the medial malleolus, talus, calcaneus, and navicular bone: The superficial layer contains the pars tibiocalcanea, pars tibionavicularis and pars tibiotalaris posterior, while the deep layer is formed by the pars tibiotalaris anterior. This is covered by the pars tibionavicularis. (Anderhuber et al. 2012)
- **Ligamentum collaterale laterale**
  It represents an apparatus of several ligaments and runs from the lateral malleolus to the talus and calcaneus. Almost horizontally, the ligamentum talofibulare anterius runs from the anterior edge of the lateral malleolus to the collum tali. It is of great importance for stabilization in the upper ankle joint. The strong ligamentum talofibulare posterius originates on the inner side of the processus posterior tali. A portion of the cranial fibers of this ligament ascends to the inferior transverse (tibiofibular) ligament. The two talofibular ligaments are located intraarticularly. Also, from the anterior margin of the lateral malleolus, the calcaneofibular ligament detaches and extends obliquely posteriorly to the lateral calcaneal surface, covered by tendon sheaths of the musculi peronei. This ligament, unlike the two aforementioned ligaments, is superficial and outside the capsula fibrosa. (Anderhuber et al. 2012)

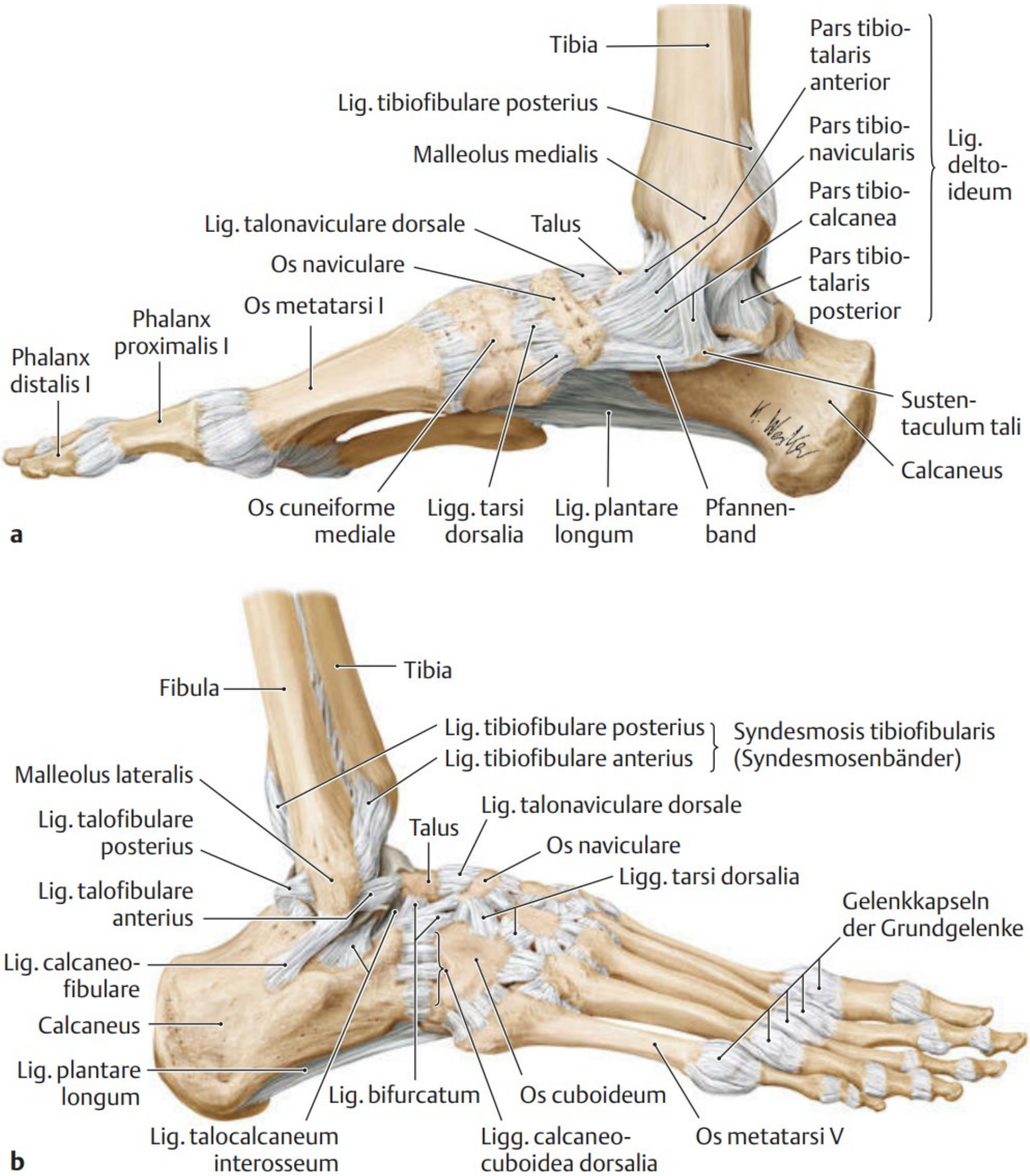

Figure 2 Ligament system of the talocrural joint and the talotarsal joint (from Prometheus LernAtlas. Thieme, 4. Aufl.)

1.1.4 Mechanics

According to the shape of the joint bodies, the articulatio talocruralis is a hinge joint with a secure bone and ligament guidance. The foot can be extended dorsally by 20-30 degrees and flexed plantarly by 40-50 degrees relative to the lower leg. In dorsal extension, the malleolus fork is forced apart by the trochlea tali, which widens anteriorly; this results in a "springy" external rotation of the fibula by a few degrees. During the gait phases, this corresponds to the heel strike. The foot is firmly braced. Since the superior facies of the trochlea tali is narrower at the back, the guidance becomes looser when rolling into plantar flexion and the fibula is automatically returned to the starting position by means of internal rotation. The talus's ability to laterally displace and rotate is facilitated by adaptation to the ground. The axis of motion in the upper ankle joint is transverse. It connects the tips of the two malleoli. Since the lateral malleolus extends further distally, it is inclined laterally by 82 degrees relative to the tibial axis. (Anderhuber et al. 2012)

1.2 Anatomy of the talotarsal joint

1.2.1 Osseous structures

The proximal articular body is the talus, on the underside of which is a larger, caudally concave articular facet for articulation with the calcaneus in the articulatio subtalaris. Ventrally of this, two smaller articular surfaces articulate with the calcaneus in the articulatio talocalcaneonavicularis, as does the head of the talus, the Os naviculare and the cartilaginous Ligamentum calcaneonaviculare plantare. (Aumüller et al. 2020)

The distal articular body consists of the calcaneus with its three cranial articular facets and the os naviculare. Between the ventral end of the sustentaculum tali of the calcaneus and the os naviculare, there is a gap under the head of the talus. This is closed by the calcaneonavicular plantar ligament, which has cartilaginous tissue at its surface. The lig. calcaneonaviculare plantare clasps the os naviculare and calcaneus, which themselves have no direct contact, to the distal joint body of the lower ankle joint on the inner side. (Aumüller et al. 2020)

1.2.2 Ligament system

Ligg. calcaneonaviculare plantare and calcaneonaviculare of the bifurcatum are not inhibitory or stabilizing ligaments of the lower ankle joint because they do not cross the axis of motion to connect the two joint bodies but are themselves part of the distal joint body. (Aumüller et al. 2020)

Some of the ligaments of the upper ankle also extend across the lower ankle:

- **Ligamentum deltoidem**
  The pars tibiocalcanea and the pars tibionavicularis brake pronation, i.e., the lifting of the lateral edge of the foot. The calcaneofibulare ligament limits supination, i.e., the lifting of the medial edge of the foot. (Aumüller et al. 2020)

The following ligaments are exclusively acting on the lower ankle:

- **Ligamentum talocalcaneum interosseum**
  Located within the sinus tarsi, the ligament separates the two joint cavities of the lower ankle joint. It connects the calcaneus and talus with short, robust fibers. Its medial fibers brake pronation, the lateral ones supination.

- **Ligamentum talocalcaneum laterale**
  This ligament, which is located laterally, also inhibits supination. (Aumüller et al. 2020)

1.2.3 Mechanics

The lower ankle joint is a compound joint. The talus can rotate about an oblique axis relative to the calcaneus and the os naviculare. This runs from the lateral part of the dorsum of the calcaneus medially, slightly ascending through the neck and head of the talus to the os naviculare. At the talonavicular joint the hindfoot can be turned inward by about 30 degrees, which is called supination. In contrast, the opposite turning movement of the foot, pronation, is only about 15 degrees. The isolated pro- and supination takes place on the standing leg exclusively in the lower ankle joint. On the free leg, movements in other ankles also occur, resulting in the more complex movements of eversion and inversion. Inversion is defined as simultaneous supination and adduction, while eversion is defined as joint pronation and abduction. (Anderhuber et al. 2012)

1.3 Fracture theory

When the continuity of a bone is completely interrupted by a load that exceeds its elastic limit, this is called a fracture. A fissure, on the other hand, is a gap formation without a complete interruption of continuity. (Niethard, Fritz, U. et al. 2009)

1.3.1 Fracture mechanisms

Direct fractures

Direct fractures are caused by external force acting on the bone, which breaks directly in the area of the force. Typical example: tibial plateau fracture in a lateral collision between a pedestrian and a car. (Niethard, Fritz, U. et al. 2009)

Indirect fractures

Indirect fractures result from internal leverage forces by means of rotation, bending, compression, or avulsion; the bone fractures away from the primary site of force application. Typical example: supination trauma of the upper ankle joint with shear fracture of the medial malleolus. (Niethard, Fritz, U. et al. 2009)

Pathological fractures

Pathological fractures occur in pathologically altered bone with relatively little external force, i.e. without adequate trauma. The cause may be generalized bone diseases (e.g. osteoporosis or osteogenesis imperfecta) as well as local bone tumors or metastases. Tumors that metastasize to bone preferentially include thyroid, breast, prostate, bronchial, and renal cell carcinoma. (Niethard, Fritz, U. et al. 2009)

Fatigue fractures (stress fractures)

If a bone is persistently subjected to a mechanical overload, a fatigue fracture of the affected bone may occur. A typical example is a fatigue fracture caused by prolonged walking load (also known from the roman soldiers). (Niethard, Fritz, U. et al. 2009)

1.3.2 Types of fractures

1.3.2.1 Related to dislocation

Dislocatio ad axim: axial buckling

Dislocatio ad latus: lateral fragment displacement

Dislocatio ad peripheriam: rotational displacement due to rotation of the fragments

Dislocatio ad longitudinem: "cum contractione" indicates a shortening, "cum distractione" indicates a lengthening (Müller et al. 2020)

1.3.2.2 Related to the mechanism of formation

Bending fractures are caused by a force exceeding the bending moment of the bone. On the side of the acting force (concave side), a bending wedge is blown out by compressive stress. On the convex side, the bone cracks transversely due to tensile stress. Typical examples: Lateral impact of a car bumper on the shaft area of the tibia. (Niethard, Fritz, U. et al. 2009)

Rotational or torsional fractures occur indirectly when two opposing forces act on the bone. The fracture line is spiral. Weak torque results in a long-drawn fracture line, while strong torque results in a short rotational fracture. An additional bending or compression torque is responsible for the formation of a rotational wedge. Typical example: tibial shaft fracture in the context of a skiing accident, in which the foot remains fixed in the rigid ski boot, but the proximal portion of the tibia is twisted. (Niethard, Fritz, U. et al. 2009)

Avulsion fractures result from tensile forces transmitted to the bone through a tendon or ligamentous attachment. The insertion zone is torn out, with the fracture line running transverse to the direction of traction. Typical example: a fracture at the base of the Os metatarsale V, which is torn off by the tendon of the m. peronaeus brevis. (Niethard, Fritz, U. et al. 2009)

Shear fractures: Here, thrust and shear power act in addition to tensile forces; in this case, the fracture gap runs parallel to the shear force. Typical examples: Shear fracture of the acetabulum at the posterior wall or shear fracture of the glenoid (scapula). A special form is the flake fracture, in which a cartilage-bearing bone fragment is sheared off in the region of joints. (Niethard, Fritz, U. et al. 2009)

Compression fractures usually occur in the cancellous bone of epiphyses and metaphyses, vertebral bodies or wrist and tarsal bones. Compression of the bone usually results in irreversible loss of volume. Typical example: compression fractures of vertebral bodies height in osteoporosis (often already after trivial traumas). (Niethard, Fritz, U. et al. 2009)

Comminuted fractures are usually the result of considerable force (high impact trauma). The interaction of different mechanisms can lead to bursting, splintering and total destruction of the bone, by definition more than 6 fragments are counted. In addition to defect formation, there is a high risk of concomitant soft tissue injuries. Typical example: Gunshot fracture with fragments sometimes widely dispersed in the soft tissues. (Niethard, Fritz, U. et al. 2009)

Incomplete fractures: These are fissures, infractions (collapses) or avulsions that have not resulted in a complete break in the continuity of the bone. The periosteal tube is usually preserved on one side. In childhood, these fractures are called "greenstick fractures", and the forearm is a typical location. (Niethard, Fritz, U. et al. 2009)

Luxation fractures result from a fracture of cartilage-bearing parts of the joint with simultaneous luxation of the bones involved. The prognosis is significantly determined by concomitant capsular, ligamentous, and meniscal damage. Typical examples: Humeral head or ankle dislocation fracture. (Niethard, Fritz, U. et al. 2009)

1.3.3 AO classification of fractures

For better comparability of different types of fractures, the AO (Arbeitsgemeinschaft für Osteosynthese) classification of the Working Group on Osteosynthesis was introduced, which is intended to describe fractures as clearly as possible using a four-digit number/letter code. Each body region is assigned a specific number (1-9), long tubular bones are additionally divided into 3 segments (1-3, special case tibia/fibula: 4 = malleolar). According to the morphological complexity of the fracture, the degree of difficulty of its treatment as well as its prognosis, 3 degrees of severity (type A-C) with 3 groups each (1-3) and again 3 subgroups each (1-3) are further broken down. (Niethard, Fritz, U. et al. 2009; Müller et al 2020)

1.4 Bone fracture healing

The healing of a bone fracture is also accompanied in adults by the phenomenon, unique in nature, that at the end of this process no scar tissue replaces the injured structures, but normal bone tissue has been rebuilt. In a strict sense, therefore, the process corresponds to "bone regeneration" and not to "scarring healing". (Rüter et al. 1995)

Natural fracture healing (secondary bone healing) proceeds in five, partially overlapping phases. Fracture-, inflammation-, granulation-, callus hardening- and modeling-remodeling phase (Rüter et al. 1995)

1.4.1 Fracture phase

This lasts from the onset of the force until the moment when the entire force is destroyed by the bone breaking in the process and the surrounding tissue. The process injures the cortical bone, bone marrow, periosteum and, to varying degrees, adjacent soft tissues and results in a hematoma in the fracture area. (Rüter et al. 1995)

1.4.2 Inflammation phase

Immediately after the onset of the fracture, excessive capillary sprouting and cell proliferation of predominantly polymorphonuclear neutrophil granulocytes, macrophages and mast cells begins. (Rüter et al. 1995)

The increased vascularization not only leads to a better supply of the existing cells, but also brings large amounts of new cells, whereby these not only originate from the flowing blood, but also from the vascular endothelium itself. The increased blood flow takes place under a so-called "flow reversal" While normally the blood flow is predominantly centrifugal, i.e. about ¾ of the cortical blood is supplied by the medullary vessels, the periosteal vessels now become the main suppliers. The increased blood flow reaches its peak in the second week after the trauma, where it reaches values around 6 times the normal. (Rüter et al. 1995)

1.4.3 Granulation phase

After 2-3 days, the inflammatory phase has subsided. The hematoma, in which a light network of fibrin and collagen fibrils can already be detected, is rapidly replaced by granulation tissue with fibroblasts, newly formed collagen and numerous capillaries. Even in the early stages, mineral deposits are found in the collagen fibrils near the fibroblasts. The granulation tissue leads to the first formation of bridges between the fragments, the so-called soft callus. This phase also starts the degradation of dead fragment ends by osteoclasts. The first chondroblasts appear and the first subperiosteal new bone formation by osteoblasts is seen. (Rüter et al. 1995)

At the same time, a blastema migrates from the medullary cavity into the hematoma and fills the fracture gaps as a so-called medullary callus. At the end of this phase, after approx. 3-4 weeks, the fragments are softly connected partly by connective tissue and partly by cartilage. (Rüter et al. 1995)

1.4.4 Callus hardening phase

Increasing mineralization of the ground substance leads to hardening of the callus. The calcium required for this comes from the mitochondria of hypertrophied chondrocytes. Enchondral ossification results in the formation of a woven bone, which is not oriented according to its mechanical stress, but spreads along the capillaries. The ossification process occurs more or less simultaneously throughout the so-called osteogenic blastema. (Rüter et al. 1995)

A basic multicellular unit (BMU) is responsible for the degradation of necrotic bone and the conversion of mineralized cartilage into bone during this phase. (Rüter et al. 1995)

This consists of cells, intercellular substance and capillaries with time-dependent different activities and capabilities. First osteoclasts are formed, which remove all hard tissue, then osteoblasts, which replace this with bone in an almost stereotypical manner. Here it is remarkable that mineralized cartilage is always replaced only by woven bone, but mineralized bone, and thus also the woven bone just created, is replaced exclusively by lamellar bone. (Rüter et al. 1995)

1.4.5 Modeling- and remodeling phase

Towards the end of callus formation, a large woven bone is found, which is now converted back into lamellar bone according to its later mechanical stress with the help of the BMU mentioned above. This part is called modeling. (Rüter et al. 1995)

The at least partial restoration of a normal bone contour as well as of the medullary cavity, called remodeling, completes fracture healing. (Rüter et al. 1995)

1.4.6 Primary bone healing

In so-called primary fracture healing, the union of the fragments does not occur via an external callus cuff. Rather, Haversian canals grow in a peg-like manner from one fragment to the other. If the fragments touch, this bridging occurs immediately. (Rüter et al. 1995)

The prerequisite is stable and anatomic fixation of both fragments and good blood supply so that the osteons can migrate directly through the fracture and induce sufficient fracture healing. (Niethard, Fritz, U. et al. 2009)

If minimal bone gaps remain between the stable fixed fragments, these are filled by means of callus (gap healing, "indirect/secondary bone healing"). The definitive remodeling process after primary bone healing until "restitutio ad integrum" takes between 1.5 and 2 years. (Niethard, Fritz, U. et al. 2009)

Primary fracture healing is only observed under stable fracture conditions, i.e. after osteosyntheses. It skips, so to speak, the inflammation and granulation phase as well as the phase of callus hardening, but thereby forgoes the physiological stability to be gained in the course of these phases. (Rüter et al. 1995)

1.5 Pilon tibial fracture

1.5.1 Definition

This is a distal tibial fracture with involvement or tipping of the articular surface. The cause is an axial force pressing the structures of the upper ankle joint from below against the articular surface of the tibia. Less frequently, also due to traction on the Achilles tendon. (Niethard, Fritz, U. et al. 2009)

The high energy of the trauma often results in additional soft tissue damage; vascular nerve damage is rare.

Most often axial compression trauma is involved. The classic mechanism of injury is from an high impact trauma or a fall from a great height. The bony harder talus is rammed into the softer tibial joint surface. Depending on foot position, shear fractures with edge fragments occur.

Another cause of indirect twisting trauma occurs due to rotational force over the foot/upper ankle joint, i.e. pilon involvement with ankle fracture. (Harrasser et al. 2016)

1.5.2 Classification

Here, 3 fracture types are distinguished in segment 43 (metaphyseal square), which can be divided into 3 groups of 3 subgroups each. (Manegold und Schaser 2014)

According to the AO classification, the distal lower leg is classified as follows. The actual pilon fractures involve the fractures of severity grade B and especially C. Severity grade A is rare and is more likely to result from indirect force application. (Harrasser et al. 2016)

Extraarticular fractures: (Manegold und Schaser 2014)

A1: simple metaphyseal fracture,

A2: fracture with metaphyseal wedge,

A3: complex metaphyseal fracture.

Partial articular fractures: (Manegold und Schaser 2014)

B1: pure split fractures in the coronal or sagittal plane,

B2: in addition to the split fracture, there is an impression of the tibia plafond,

B3: multi-fragmentary impression fractures with partial dissociation of the articular surface.

Complete articular fractures: (Manegold und Schaser 2014)

C1: articular simple, articular metaphyseal simple fracture,

C2: simple-articular joint fracture, complex-metaphyseal joint fracture,

C3: complex-articular joint fracture, complex-metaphyseal joint fracture. (Manegold und Schaser 2014)

In all fractures, the involvement of the fibula must be mentioned separately (Harrasser et al. 2016)

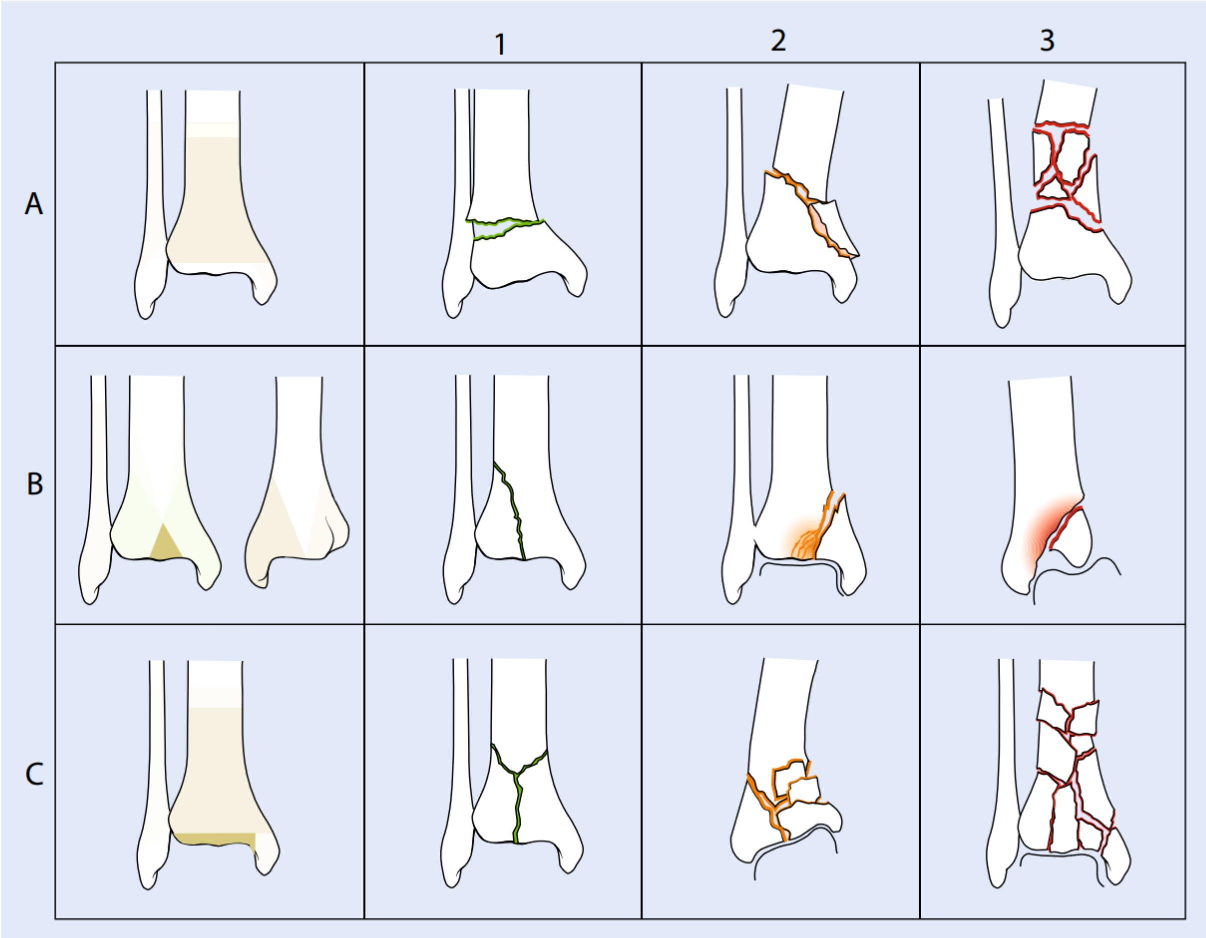

Figure 3AO classification of region 43 Distal lower leg (from Frakturen Müller-Mai 2010)

1.6 Ilizarov Device

1.6.1 Advantages and Disadvantages of the Ilizarov Fixation

1.6.1.1 Advantages (Solomin 2008)

- In the region of trauma, the device does only minimally interfere the soft tissues and the blood supply is still preserved. The local vascularity is necessary for the healing of the bone.
- It provides a stable fixation outside the zone of injury.
- Closed reduction and repositioning of bone fragments is possible in all three planes simultaneously
- Promotes a quicker return of limb function in the affected limb.
- The device finds a wide range of applications in traumatology and orthopedics, particularly for treating a variety of injuries and deformities.
- It is possible to make individual adjustments to the device, depending on the clinical and radiological progress of the patient. (Solomin 2008)

1.6.1.2 **Disadvantages** (Solomin 2008)

- Continuous monitoring of the device due to the possible occurrence of pin infection or loosening or hardware failure.
- Chance of stiffness of transfixed joints
- The large size of the Ilizarov device can be aesthetically disruptive to the patient and may require a special form of clothing.
- The required compliance of the patient can be a major problem in some cases and can significantly complicate continuous treatment.
- Anatomic reconstruction is possible concerning axes but not automatically for the articular surface if there is severe displacement
- The relatively complex use of the device, especially Type IV- VI (Solomin 2008)

1.6.2 Biomechanical Principles

1.6.2.1 Transosseous Elements and the Surrounding Tissues

The Ilizarov external fixation system relies on transosseous elements (wires and half-pins) for bone fixation. This section highlights key biomechanical considerations for their placement: (Solomin 2012)

- **Bone-Metal Interface:** Specific wire shapes (feather, single-facet, drill cutting) and insertion techniques (interrupted drilling, cooling) minimize thermal damage and enhance bone-wire stability.
- **Half-Pin Insertion:** Placement considers cortical and cancellous bone structure. Canals are pre-drilled in the diaphysis to match half-pin size, with adjustments for bone density (reduced diameter in osteoporosis). Proper insertion necessitates penetration of both cortical plates.
- **Biocompatible Surface Coatings:** Advancements include metal-ceramic and calcium phosphate coatings to improve implant stability within the bone, particularly in osteoporotic patients.
- **Minimizing Soft Tissue Complications:** Transosseous elements can restrict joint movement and contribute to inflammation. Strategic placement techniques are employed:
    - **Soft Tissue Reserve:** Creating a "reserve" by inserting wires/half-pins through flexor and extensor surfaces of the limb segment.

  - **Minimizing Disruption:** Inserting elements where soft tissue displacement during movement is minimal. (Solomin 2012)

1.6.2.2 Control of Bone Fragment Position

External fixators offer precise control over bone fragment position during healing. This control is achieved through two main methods: (Solomin 2012)

- **Moving the external supports:**
  - Angled pins or wires can cause simultaneous fragment displacement and distraction.
  - Specialized reduction nodes (Ilizarov hinges) enable controlled movement on multiple axes.
- **Moving the transosseous elements:**
  - These pins, wires, or screws are manipulated while the external supports remain static. (Solomin 2012)

These methods often work together for precise control. Additionally, computer-assisted navigation systems are emerging to help surgeons design optimal fixator configurations and guide fragment manipulation: (Solomin 2012)

1. **Passive Navigation:** Software generates recommendations based on images and measurements especially for correction of the deformities.
2. **Active Navigation:** Advanced systems (future focus) can automatically manipulate fragments under computer control. (Solomin 2012)

1.6.2.3 Control of Bone Fragment Rigidity

External fixators offer precise control over bone fragment rigidity during healing. Several factors influence this rigidity: (Solomin 2012)

Material: Stiffer materials like titanium allow enhance rigidity compared to stainless steel. (Solomin 2012)

Transosseous Elements:

- **Number:** More elements increase rigidity but also tissue trauma and joint stiffness risk.

- **Diameter & Type:** Larger diameter elements provide more rigidity but may damage tissues. Angled threads offer better rigidity (Taylor Spatial Frame fixation).
- **Tension:** Insufficient wire tension reduces rigidity. (Solomin 2012)

Levels of Insertion:

- Greater distance between insertion points of different types of transosseous elements increases rigidity.
- Four-hole posts offer more support for stabilizing half-pins. (Solomin 2012)

Transosseous Element Orientation:

- "Neutral" crossing angle for wires in the support is 60 degrees. Wider angles weaken, narrower ones pull.
- Half-pins inserted at an angle to displacing forces can increase rigidity. (Solomin 2012)

Distance to Bone: Shorter distance provides greater rigidity but try to avoid soft tissue compression. (Solomin 2012)

External Support Geometry:

- Devices covering more bone segment at insertion points offer higher rigidity (Type I vs. Type V).
- Closed supports allow for optimal wire tension and wider insertion angle range. (Solomin 2012)

Number of Connecting Rods:

- Three rods connect closed supports and intermediate/basic supports.
- A fourth rod may increase rigidity only with specific open support configurations. (Solomin 2012)

Balancing Requirements:

- Sometimes trade-offs are needed between rigidity and other factors like pin placement and soft tissue considerations. Priorities should be set based on specific osteosynthesis tasks. (Solomin 2012)

Testing and Optimization:

- Stand tests on models can provide insights but lack standardization and often use artificial materials.
- Mathematical modeling and finite element analysis offer additional avenues for optimization.
- Research on defining optimal rigidity throughout healing and objectively measuring durability of bone restoration is ongoing. (Solomin 2012)

1.6.3 Osteosynthesis of the Tibia and Fibula using the Circular External Fixator (CEF) System

This section describes the surgical technique for osteosynthesis of the tibia and fibula using the CEF system. This minimally invasive approach offers several advantages over traditional methods, including the ability to adjust bone alignment after initial fixation. (Solomin 2008)

1.6.3.1 Implant Selection

The CEF system utilizes various implants to achieve stable fixation: (Solomin 2008)

- **Wires:** These thin wires (1.8-2.0 mm diameter) are suitable for most applications.
- **Half-pins:** Larger diameter half-pins (5 or 6 mm) offer increased stability and are often used in conjunction with wires.
- **Console wires with stops:** These specialized wires (2.0 mm diameter) come in various lengths (5, 10, 15, 20 mm) for precise bone insertion and incorporate a stop mechanism to control reduction force – used as push-wires. (Solomin 2008)

1.6.3.2 External Fixation Components

The CEF system utilizes standardized external supports for most leg circumferences. However, in cases with significant differences between the upper and lower leg, two different sized supports can be combined for optimal fit. To allow for knee flexion during healing, open rings (two-thirds or three-quarter circles) are used at the first three levels (0, I, II) of the tibia and fibula. For juxtaarticular and intraarticular fractures (classified as 41, 43, or 44 according to the AO/ASIF classification system), radiolucent external supports are recommended to allow for clear radiographic visualization of the fracture site. (Solomin 2008)

1.6.3.3 Transosseous Element Insertion

Careful positioning of the leg is crucial for proper transosseous element (wire or half-pin) insertion. Conversely, wires inserted through the posterior tibia require a neutral knee position. To minimize pin-induced stiffness at the ankle, plantar flexion of the foot at 40 degrees is recommended during wire and half-pin insertion through the anterior distal tibia. In contrast, transosseous elements inserted through the posterior distal tibia require maximum dorsiflexion of the foot. In situations where achieving the ideal joint position is not possible due to injury severity, manual skin displacement techniques or a thin hook can be used to temporarily reposition the skin relative to the underlying bone. (Solomin 2008)

1.6.3.4 Fixation and Reduction Techniques

Once the transosseous elements are inserted, proper fixation to the external support is essential. The external supports should be aligned with the anatomical axis of the bone fragment and the soft tissue envelope. Ideally, the supports should be perpendicular to the bone fragment's anatomical axis, particularly in the diaphyseal region. The CEF device itself is assembled such that the junctions between the intermediate reduction supports and the distal basic support lie in the frontal plane. This facilitates modularity during the fixation process, allowing for the removal of posterior half-rings if needed. (Solomin 2008)

Wires and half-pins are secured to the external supports using posts and/or spacing washers. Half-pins used for purposes other than basic or reduction fixation are only stabilized after achieving the desired bone fragment alignment. L-shaped clips can be used for additional half-pin fixation to the support or post. (Solomin 2008)

The CEF system allows for various reduction techniques to achieve optimal bone alignment. Wires can be used for relocation with the help of a stop and controlled bending. Half-pins primarily achieve reduction through pushing or pulling maneuvers. Console wires with stops are limited to pushing movements due to their design. Notably, these reduction techniques can be combined with adjustments of the external supports for more complex fracture patterns. Large bone fragments (splinters) are typically reduced and fixed using wires with stops or console wires with stops. In cases where a bone fragment is lodged between the tibia and fibula, a specialized fork device or a raspatorium can be employed for reduction. (Solomin 2008)

1.6.4 Ilizarov External Fixation for Distal Tibia and Fibula Fractures

This section describes the application of the Ilizarov external fixation system for fractures of the distal tibia and fibula, classified according to the AO/ASIF system. The Ilizarov technique offers minimally invasive fracture management with the advantage of allowing for post-operative adjustments to achieve optimal bone alignment. (Solomin 2008)

1.6.4.1 Fractures of the Distal Tibia and Fibula (Group 43 According to AO/ASIF Classification)

Management of these fractures typically begins with inserting two crossed wires proximally at the level of the tibiofibular joint. One wire perforates both bones. A perpendicular basic ring is then installed on the proximal tibia, oriented relative to the soft tissues and the tensioned wires. This ring serves as the foundation for the fixation device. A reduction and fixation ring is mounted at a distal level on the lower leg and connected to the base support by three telescopic rods, forming a proximal transosseous module. (Solomin 2008)

The management of extraarticular fractures (43-A) and those involving the epiphysis or osteoepiphysis (growth plate) is similar to the technique used for fractures of the distal third of the tibial shaft. After assembling the proximal transosseous module at the level of the distal fragment's epiphysis, two crossed wires are inserted. The distal support is then connected with three or four rods to the base, with the nuts on the reduction and fixation support left loose to allow for controlled movement within the holes of the ring. The distal basic ring is oriented relative to the soft tissues such that the connecting rods are parallel to the anatomical axis of the distal fragment. Once positioned, the distal basic wires are tensioned and secured to the ring, followed by tightening the nuts on the reduction and fixation support for stabilization. (Solomin 2008)

A distraction force may then be applied to create a gap of 4-5 mm between the fragments to allow fracture reduction. Radiographic imaging is performed to confirm proper reduction. Any residual displacement of the proximal fragment can be addressed by inserting a wire with a stop at a specific location. In the case of a small, displaced distal fragment, a wire may be inserted for increased rigidity, while larger displaced fragments are often managed through manipulation of the external supports themselves. (Solomin 2008)

In pilon fractures it will not be sufficient to fixate only the lower leg and the temporary fixation of the ankle joint will be necessary. This involves inserting two wires through the heel bone, tensioned in an elongated support and connected to the device's distal base for added stability. The wire-based device can be later converted to a hybrid wire-pin device for a less bulky design. After insertion and fixation of a half-pin to the reduction and fixation support, the proximal component can be dismantled. In cases where the initial assembly positions the half-rings within the frontal plane, the posterior half-ring of the wire-pin support is usually removed within a 2-3 week timeframe. (Solomin 2008)

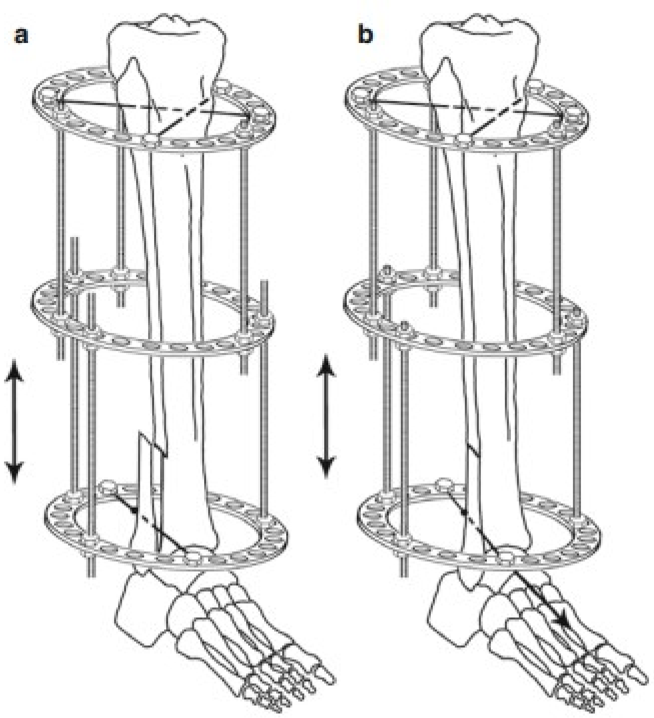

Figure 4: (a-b) external fixation device for reduction and fixation of fractures of the lateral malleolus (from The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices, Solomin 2012, Second Edition)

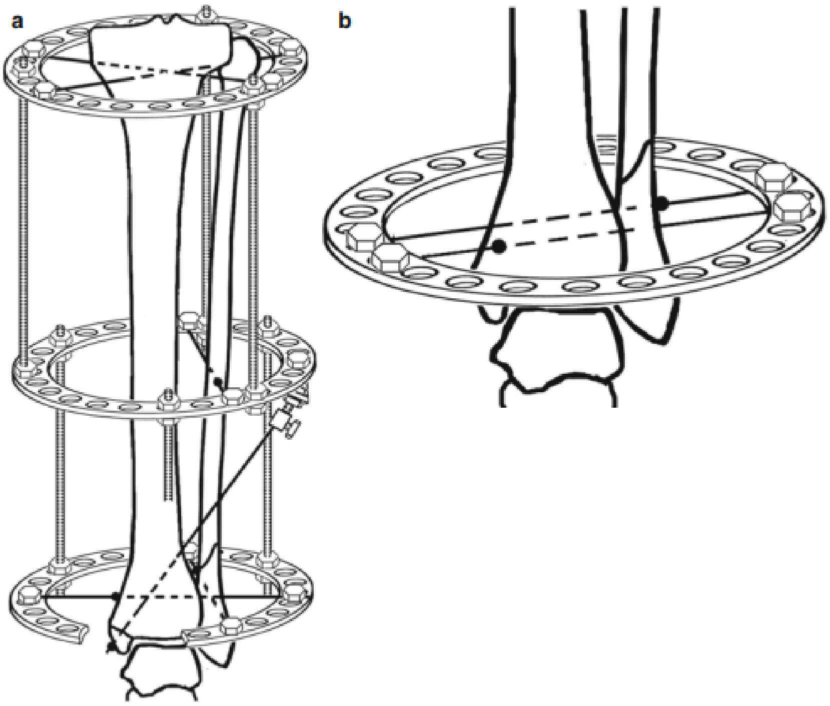

Figure 5: (a-b) Ilizarov external fixation device for the fixation of pronation fracture-dislocations of the ankle (from The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices, Solomin 2012, Second Edition)

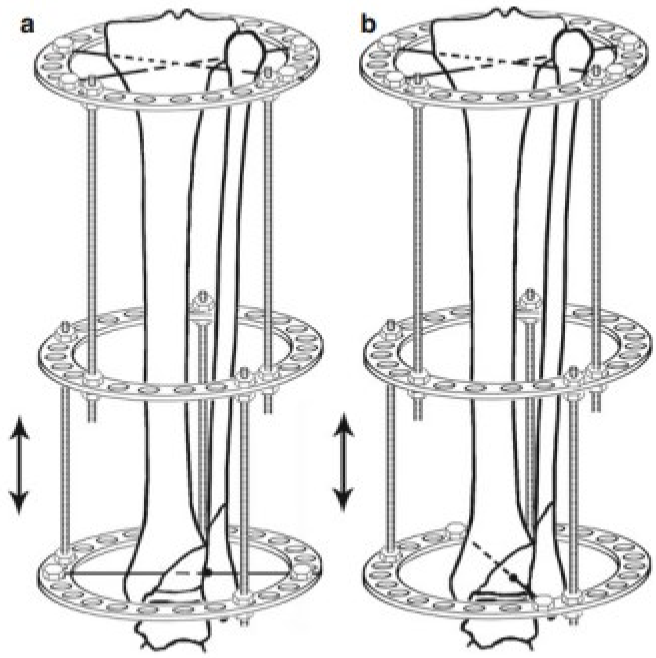

Figure 6: (a-b) External fixation device for the reduction and fixation of the posteroinferior tibia (from The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices, Solomin 2012, Second Edition)

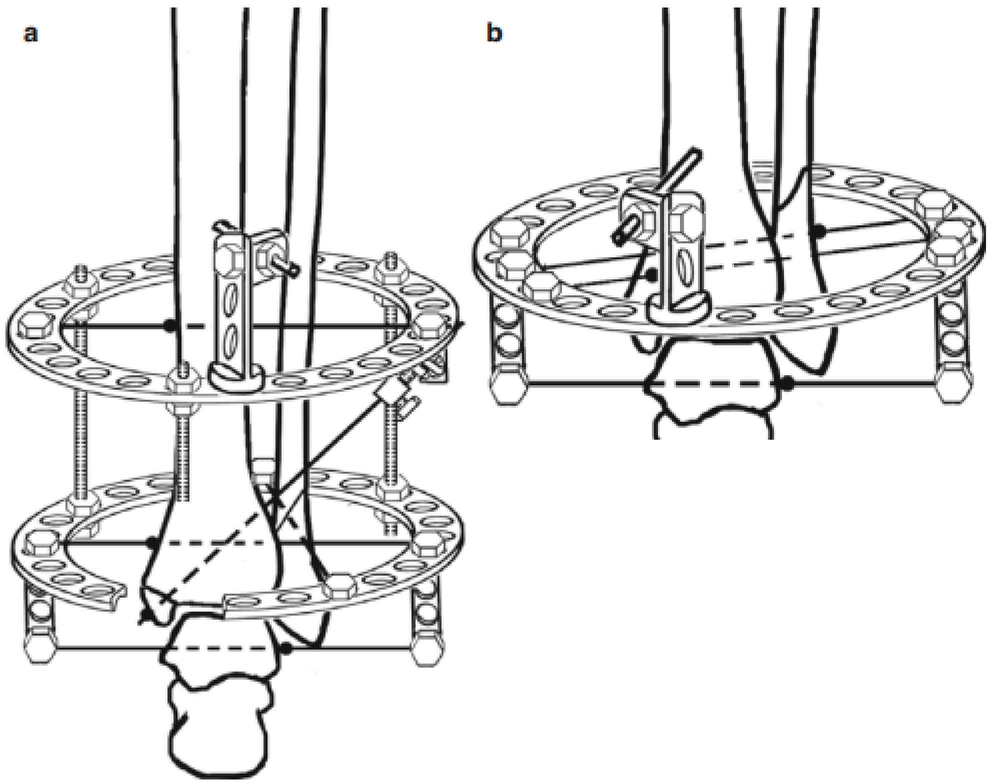

Figure 7: (a-c) Combined external devices for the fixation of fractures of the ankle (from The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices, Solomin 2012, Second Edition)

1.6.4.2 Ilizarov External Fixation for Intraarticular Fractures

Management of intraarticular fractures of the distal tibia and fibula (specifically pilon or plafond fractures, classified as 43-B or 43-C according to AO/ASIF) also begins with the assembly of a basic module consisting of two supports – a proximal basic support and a reduction and fixation support. A radiolucent ring support is then secured to this module at a specific level on the lower leg. Finally, a foot support is mounted to complete the initial fixation. (Solomin 2008)

Manual reduction of bone fragments is attempted followed by application of a distraction force via the device and connection to comparison radiographs or an image intensifier for confirmation. (illustrated in Figure 4) A wire with a stop is then inserted at the level of the reduction and fixation ring to aid in correcting and stabilizing the proximal fragment's position. (illustrated in Figure 5) (Solomin 2008)

In situations where ligamentotaxis (utilizing ligaments for reduction) fails to achieve adequate reduction, a thin awl is used as a lever under image intensifier or arthroscopic guidance to manipulate the displaced fragments together. (Figure 6 illustrate examples) Arthroscopy offers the additional benefit of allowing for joint space cleansing to remove small bone and cartilage fragments, which helps to prevent post-traumatic arthritis. (Solomin 2008)

In cases where closed techniques are unable to restore joint congruity, open reduction surgery may be required. A significant advantage of external fixation in these cases is the ability to minimize surgical intervention and joint surface unloading, thereby reducing the risk of fragment devitalization and additional soft tissue injury. Prior to the initial incision, the ring support at a specific level is elevated to the level of the reduction and fixation support, and any connecting rods that hinder manipulation are removed. If necessary, the distraction force can be temporarily reduced to improve surgical access through the soft tissues. (Solomin 2008)

Standard pairs of wires are then used for fixation after open reduction using established techniques. (Solomin 2008)

1.6.4.3 Chronic ankle injuries

The Ilizarov system can also be a valuable tool for addressing chronic ankle instability and malunion. For chronic instability, an osteotomy is performed at the level of the ankle deformity, followed by realignment and fixation using the external frame. In cases of chronic incomplete dislocation of the foot outwards, the frame is specifically adjusted to account for the displacement. A gradual distraction force is then applied to increase the joint space, allowing for manipulation and correction of the dislocation. As shown in Figure 8, wires are inserted through various locations, including the talus, heel bone and tibia, to provide stability and maintain the correction. (Solomin 2008)

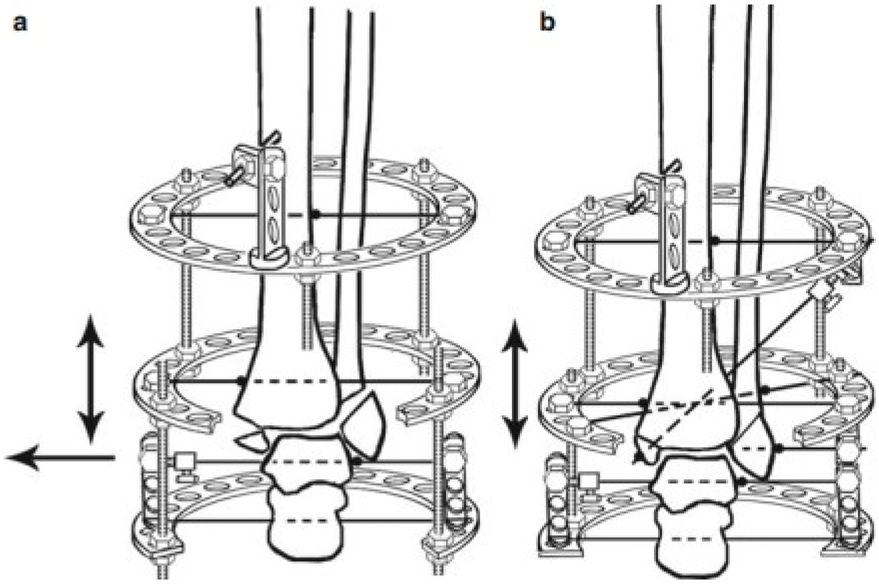

Figure 8: (a-b) External fixation for the fixation of chronic injuries to the ankle joint (from The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices, Solomin 2012, Second Edition)

1.7 Study question

This retrospective study investigates the long-term functional outcomes of Ilizarov fixator treatment for pilon tibial injuries type C (with mostly type C3 fractures). Focusing on patients treated at the Department of Traumatology and Orthopedics of the Medical University of Graz between 2005 and 2020, the study will analyze patient data and results from follow-up appointments. Patient identification was done over the clinical information system (keywords: pilon fracture, Ilizarov) and from the surgeons list (P.W. L.). The core question is: What are the long-term functional outcomes in patients treated with Ilizarov fixators for ankle injuries at the Medical University of Graz? This study centers on the effectiveness of Ilizarov fixation for pilon tibial fractures. Our primary focus is to assess long-term functional outcomes and health-related quality of life (HRQoL) in patients who underwent this procedure. We'll be evaluating their ability to perform daily activities and overall well-being several years after surgery. Additionally, we'll be analyzing pain levels specifically in the affected ankle joint to understand its impact on patients' lives. Functional outcomes will be evaluated using patient-reported scores like the SF-36, AOFAS, and Numeric Rating Score. Furthermore, the study will compare these findings to existing literature on Ilizarov fixators for ankle injuries. This comparison will assess the effectiveness of this treatment modality within the context of this specific patient population. By addressing these questions, the study aims to provide valuable insights into the long-term benefits and potential limitations of Ilizarov fixators for ankle injuries in our institution.

2 Material and Methods

2.1 Study design and procedure

This study is a retrospective collection of data with follow-up of the respective patients in the Department of Orthopedics and Traumatology of the Medical University of Graz.

All patients who were treated with an Ilizarov fixator due to a pilon fracture type C at the University Hospital Graz between 2005 and 2020 and who attended the follow-up in the course of the study were included. If the inclusion criteria were not met or the exclusion criteria were met, these patients were excluded from the data collection.

The collection and processing of data was performed by qualified and authorized personnel in the presence of patient informed consent.

The ethics application with the number 34-142 ex 21/22 was approved on 06.05.2022.

Due to the reluctance of many patients to go to the hospital's outpatient clinic (because of the COVID-19 situation at the time), most examinations were carried out outside the hospital and X-rays could only be taken of 5 patients. Therefore, the radiological data could not be compared.

A planned component of this study was an MRI examination for seven patients with non-reconstructible injuries. This examination was intended to assess cartilage quality using a 3T MRI at the Department of Radiology of the Medical University. However, due to the COVID-19 pandemic, this part of the study was not feasible and will be addressed in a future investigation.

The required data were collected via the MEDocs program of KAGES. The collected data were pseudonymized and assigned to a patient ID. Only the study director can assign patient data using a secure electronic keycode.

The patients were contacted by telephone and, after consultation, asked to attend a follow-up appointment at the orthopedic trauma surgery outpatient clinic. Unfortunately, most of the patients refused this visit (due to COVID-19), necessitating off-site examinations and interviews.

Upon arrival at the facility, a team of specialized medical personnel conducts a thorough clinical examination of the patient. This examination is followed by a comprehensive discussion regarding the patient's postoperative management plan. This discussion ensures clear communication and understanding between the patient and the healthcare team.

2.2 Patients

Patients were informed in writing that their data would be analyzed in indirect personal form.

Informed consent was prepared for the patients.

Patients who consented to take part in the study were called to the Department of Trauma Surgery for an appointment. The examination of the corresponding parameters is equivalent to an indicated follow-up control in the context of the aftercare.

All patients were included who were treated at the Department of Orthopaedics and Traumatology Graz due to a pilon fracture AO Classification type 43 C with an Ilizarov fixator and are relevant according to defined inclusion criteria.

Patients who did not agree or who were not suitable for participation in the study due to the defined exclusion criteria were excluded.

2.2.1 Inclusion criteria

- Patients with a minimum age of 18 years.
- Pilon fracture (AO 43) Type C
- Surgical treatment with Ilizarov ring fixator because this method was considered more suitable than ORIF
- Subjects consent to the study in writing

2.2.2 Exclusion criteria

- Limited capacity to consent (known psychiatric illness, dementia).
- Parallel study representing biopsychosocial interference.
- Resolution of consent

2.3 Examinations

Study-specific data collection was performed only by those conducting the studies. Medical data were also required as part of the study. Both names, date of birth, SVNR, telephone numbers, addresses, medical histories, and other personal data were accessed. Patient data were routinely collected and were obtained from the MEDocs system of KAGES.

Patients were assessed by SF-36 score, AOFAS score, and Numeric Rating Scale.

Patients were weighted and their height was measured, and the resulting body mass index was calculated. In the clinical examination, the degrees of freedom of both ankle joints in the different joint positions were measured using a gonometer - this included plantar flexion, dorsiflexion, pronation and supination.

Furthermore, the patients were questioned regarding diabetes, occlusive diseases and smoking behavior.

2.3.1 Short Form Health 36 Questions (SF-36) (Adnex I)

The SF-36 is a widely used patient-reported outcome (PRO) measure for assessing health-related quality of life (HRQoL). This short-form health survey, consisting of 36 questions categorized into eight subscales, offers a valuable tool for understanding a patient's physical and mental well-being. (McHorney et al. 1993)

The SF-36 Health Survey offers a valuable tool for understanding a patient's overall well-being. This generic questionnaire applies to a broad population and various health conditions, capturing HRQoL through 36 questions categorized into eight subscales. These subscales assess physical functioning, limitations due to physical health problems, bodily pain, general health perceptions, mental health (including limitations due to emotional problems and mental well-being), social functioning, and vitality. Each subscale is scored on a 0-100 scale, with higher scores indicating better health-related quality of life. This scoring process involves transforming raw responses into a standardized score based on population norms. (Ware, JR und Gandek B. 1998)

This established scoring method allows researchers and clinicians to track changes in a patient's HRQoL over time and evaluate the impact of interventions or disease burden. However, it's important to acknowledge that the SF-36, like any self-reported measure, relies on the participants accurate reporting of their health status. (McHorney et al. 1993)

In conclusion, the SF-36 health survey offers a well-established and versatile tool for measuring HRQoL. While interpreting SF-36 scores requires careful consideration of both the strengths and limitations of this instrument, it remains a valuable tool in understanding patient well-being. (Ware, JR und Gandek B. 1998)

Table 1: List of the eight dimensions of the SF-36 score. Source: Own design based on Ware, JR and Gandek B. 1998

General health perception	**5 questions**
Physical functioning	**10 questions**
Limitations due to physical health	**4 questions**
Bodily pain	**2 questions**
Vitality	**4 questions**
Mental health	**5 questions**
Limitations due to emotional problems	**3 questions**
Social functioning	**2 questions**

2.3.2 AOFAS Score (Adnex II and Adnex III)

The American Orthopaedic Foot and Ankle Society (AOFAS) scoring system is a common tool used to assess patient outcomes after foot and ankle surgery. It combines subjective and objective elements into a single score that reflects a patient's foot and ankle function. Patients report their pain levels, functional abilities, and limitations in daily activities. Surgeons assess factors like range of motion, swelling, and alignment during a clinical examination. Each component is scored and combined into a final score, typically ranging from 0 (worst) to 100 (best), with higher scores indicating better function. (Ibrahim et al. 2007)

The AOFAS score's validity, especially the subjective component, has been questioned. Studies have investigated this by comparing the AOFAS score with other measures of foot function. While the score captures some aspects of function, limitations exist. Patient-reported information can be influenced by factors like pain tolerance. Further research is needed for a more comprehensive assessment. (Ibrahim et al. 2007)

Despite these limitations, the AOFAS score remains valuable. Studies offer some reassurance about its ability to capture patient-reported function. However, acknowledging these limitations and potentially using the score alongside other outcome measures is important, especially in research settings. (Ibrahim et al. 2007)

2.3.3 Numeric rating scale (Adnex IV)

The Numeric Rating Scale (NRS) is a valuable tool for measuring pain intensity in research, including studies on foot and ankle conditions. This simple and reliable patient-reported outcome measure (PROM) uses a horizontal line typically ranging from 0 (no pain) to 10 (worst pain imaginable). Patients simply choose the number that best reflects their current pain level. (Hartrick et al. 2003)

The NRS offers several advantages for research. It's easy for both patients and researchers to understand and administer, making it suitable for various research settings. This user-friendliness contributes to the NRS's widespread use in clinical research and clinical use especially for pain medication. (Hartrick et al. 2003)

It's important to acknowledge that the NRS, like many self-reported measures, has limitations. Pain perception can be subjective and influenced by factors like pain tolerance and cultural background. (Hartrick et al. 2003)

2.3.4 Range of Motion

Dorsal extension is tested with the knee joint extended and flexed.

If there is a significant increase in dorsiflexion when the knee joint is flexed, there is a shortening of the gastrocnemius tendon because this is a two-joint muscle. In this case, one speaks of a positive transmission phenomenon. (Konrads und Rudert 2018)

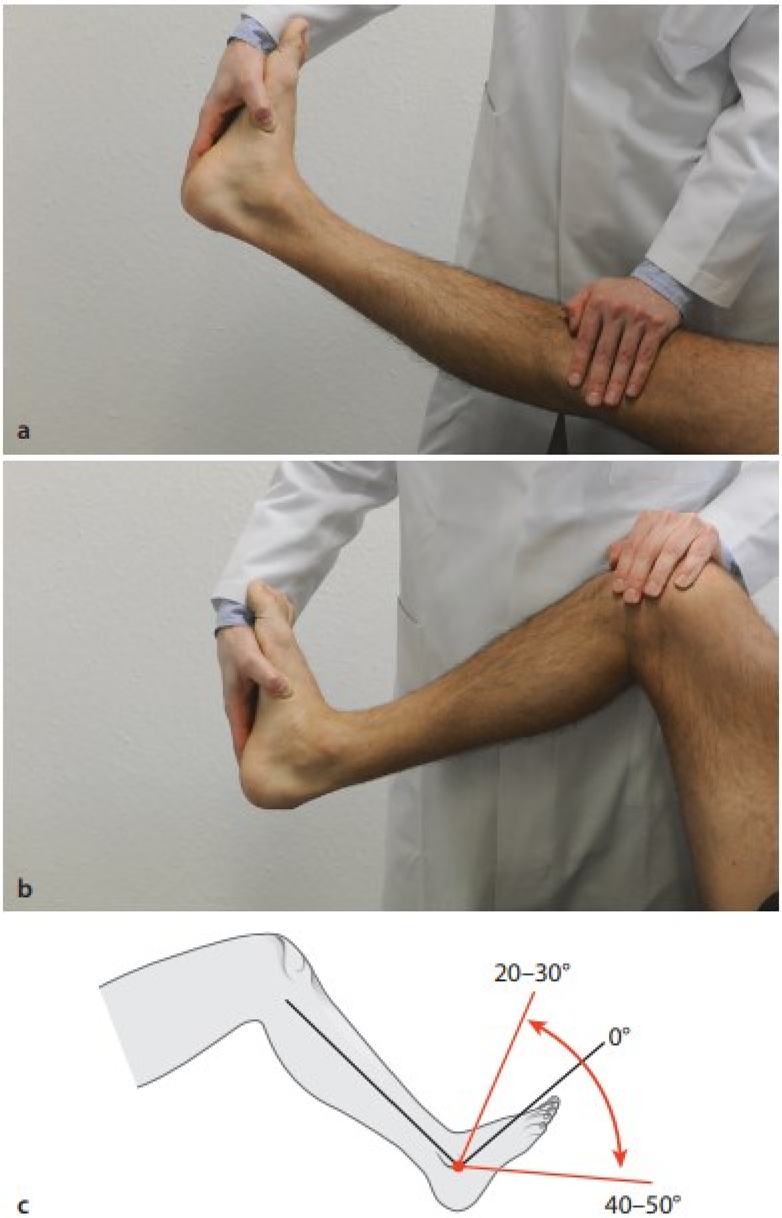

Figure 9: Dorsal extension and plantar flexion movement test in the upper ankle joint (from Klinische Tests und Untersuchungen in Orthoopädie und Unfallchirurgie; Konrads, Rudert, Springer Verlag, 2018)

Supination and pronation are examined as shown in Figure 10.

The range of motion is documented either in fifths of the normal range of motion or in degrees of possible mobility. (Konrads und Rudert 2018)

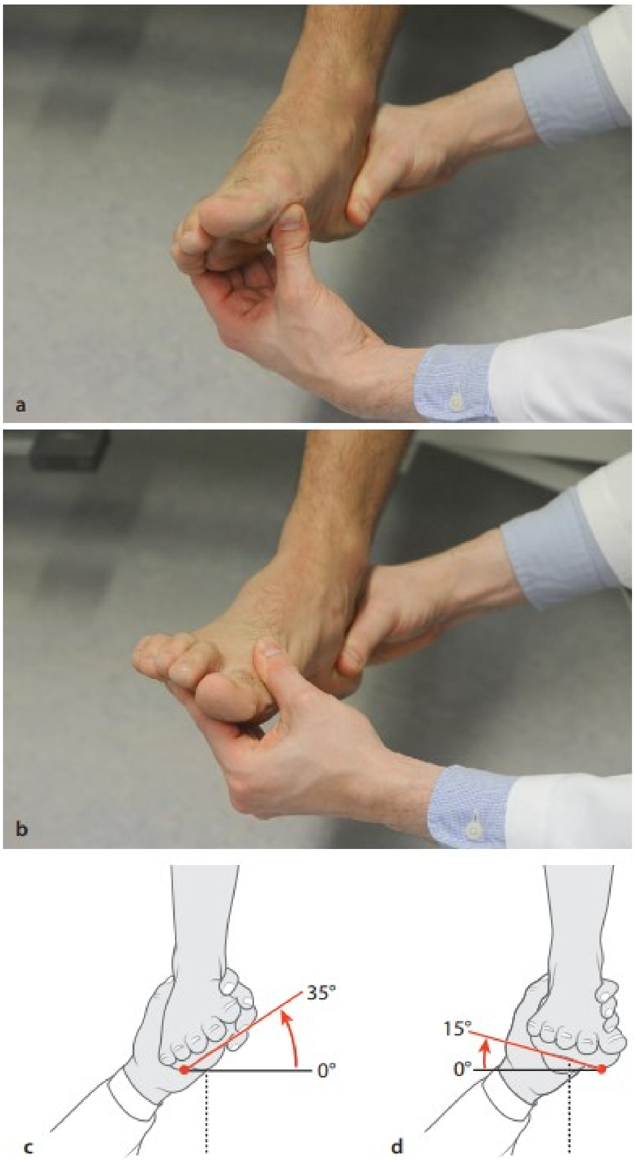

Figure 10: Supination (a,c) and pronation (b,d) movement test in the lower ankle joint (from Klinische Tests und Untersuchungen in Orthoopädie und Unfallchirurgie; Konrads, Rudert, Springer Verlag, 2018)

2.4 Statistic Methods

This study employed descriptive statistics to summarize and characterize the features of our data set comprehensively. Unlike inferential statistics, which aim to draw conclusions about a larger population based on a sample, descriptive statistics are primarily concerned with understanding the distribution and central tendencies within the data itself. This methodological approach enabled us to meticulously analyze the collected information, such as patient ages, pain scores, and functional outcomes, and present these findings in a clear and concise manner.

Descriptive statistics utilize various measures, including mean, median, and standard deviation, to depict the central tendencies and variability within the data. These measures provide a detailed understanding of the average values and the spread of data points. Additionally, frequency distributions and percentages are employed to visualize the prevalence of different outcomes within the patient population studied, offering a more nuanced view of the data.

By employing descriptive statistics, we gained valuable insights into the characteristics of our sample. This approach facilitated the identification of potential patterns or trends within the data, enhancing our overall understanding of the studied phenomena. Consequently, descriptive statistics served as a crucial tool in presenting our findings in a manner that is both informative and accessible, laying a robust foundation for further analysis and interpretation.

3 Results

3.1 Study population

Our target population originally consisted of 38 patients whose pilon fractures were treated with an Ilizarov fixator at the Department of Orthopaedics and Traumatology of the Medical University of Graz between 2005 and 2020 and who consented in writing to the perioperative short-term follow-up. This collective initially consisted of 15 men and 23 women. Five persons (4 women and 1 man) have died in the meantime. Eleven patients (6 women and 5 men) declined our telephone request to participate in the current follow-up study or could not be reached despite repeated attempts. (shown in Figure 11) Reasons for refusal were mainly the need for care, immobility and fear of infection with SARS-CoV-2. The gender difference of those who refused to participate was not significant.

The average follow-up time (time of surgery to time of examination) of the patients was 8.2 years (from 5 to 12 years).

Controls were complicated by the COVID-19 period. Of the 22 people included, thirteen were willing to undergo a ten-year check-up in person at the orthopaedic outpatient clinic. Due to the circumstances surrounding the COVID-19 pandemic, only five of the patients agreed to be examined in the trauma surgery outpatient clinic, so the rest of the patients were examined outside the hospital (on the hospital grounds, in the park or at the patient's home).

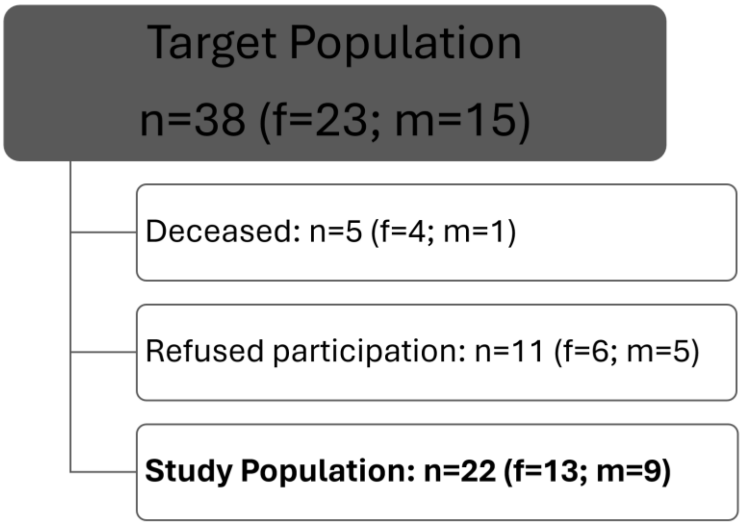

Figure 11: Presentation of the patient collective with indication of gender ratios

3.2 Demography

Table 2: Presentation of the demographic data of the study participants with regard to BMI and age with details of gender ratios

		Sex				
		Mean	Median	Minimum	Maximum	Standard Deviation
Age	male	60,8	63,0	29,0	78,0	15,7
	female	67,5	65,0	44,0	85,0	13,0
BMI	male	28,8	29,1	18,5	35,1	5,6
	female	29,8	29,3	23,8	35,4	3,7

Analyzing data from a study with participants undergoing Ilizarov fixator surgery for ankle injuries, we see some sex-based differences (as shown in Table 2). While both male (n=9) and female (n=13) patients have average BMIs in the overweight category (28.8 and 29.8 respectively), the wider standard deviation for males (5.6) suggests a greater spread of BMI values compared to females (3.7). This indicates a more homogenous BMI distribution among females.

Age reveals following trends. Females (67.5 years) are older on average than males (60.8 years) in this study. However, the lower standard deviation for female age (13.0) compared to males (15.7) suggests their ages are more tightly clustered. In other words, the female patient group exhibits a narrower range of ages compared to the wider distribution seen in males.

Table 3: Presentation of the demographic data of the study participants regarding diabetes mellitus, peripheral arterial disease and smoking, divided into male and female

		Sex	
		male Count	female Count
Diabetes	no Diabetes	8	12
	Diabetes	1	1
PAD	no PAD	8	10
	PAD	1	3
Smoking	Non-Smoker	5	8
	Smoker	4	5

The presence of diabetes mellitus, peripheral arterial occlusive disease and smoking (as shown in Table 3) were asked about factors favoring wound healing disorders. One male and one female study participant each suffered from diabetes. One male and three female patients had peripheral arterial occlusive disease. Four men and three women stated that they smoked cigarettes regularly.

3.3 Numeric Rating Scale (Adnex IV) Results

All 22 patients stated in their medical history that they felt no pain in the affected extremity at rest.

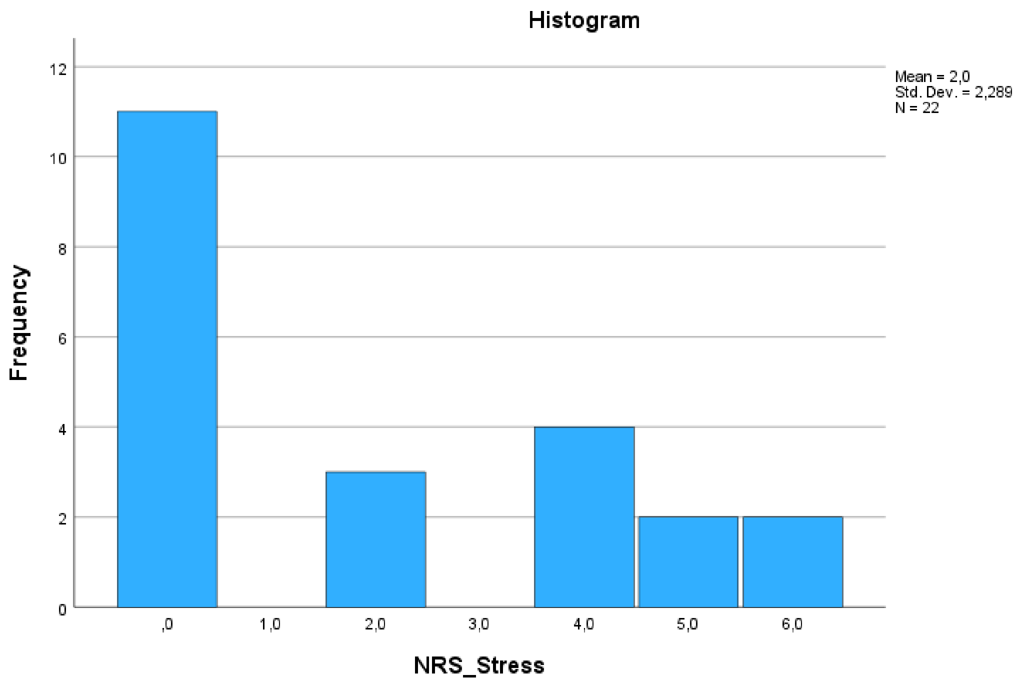

Figure 12:Histogram showing the distribution of the results of the Numeric Rating Scale under stress

On exertion, 11 patients stated that they felt no pain, which means that the surgical procedure was successful in 50% of patients in view of the pain. Three patients report pain on exertion as a 2 out of 10, which they say does not bother them much in everyday life but prevents them from doing certain activities. Four patients rated the pain on exertion as a 4 out of 10, which already noticeably impairs them in everyday life. Two study participants each rated the pain on exertion as 5 out of 10 and 6 out of 10, which has a major impact on coping with everyday life and makes many activities that were previously performed no longer possible. (shown in Figure 12)

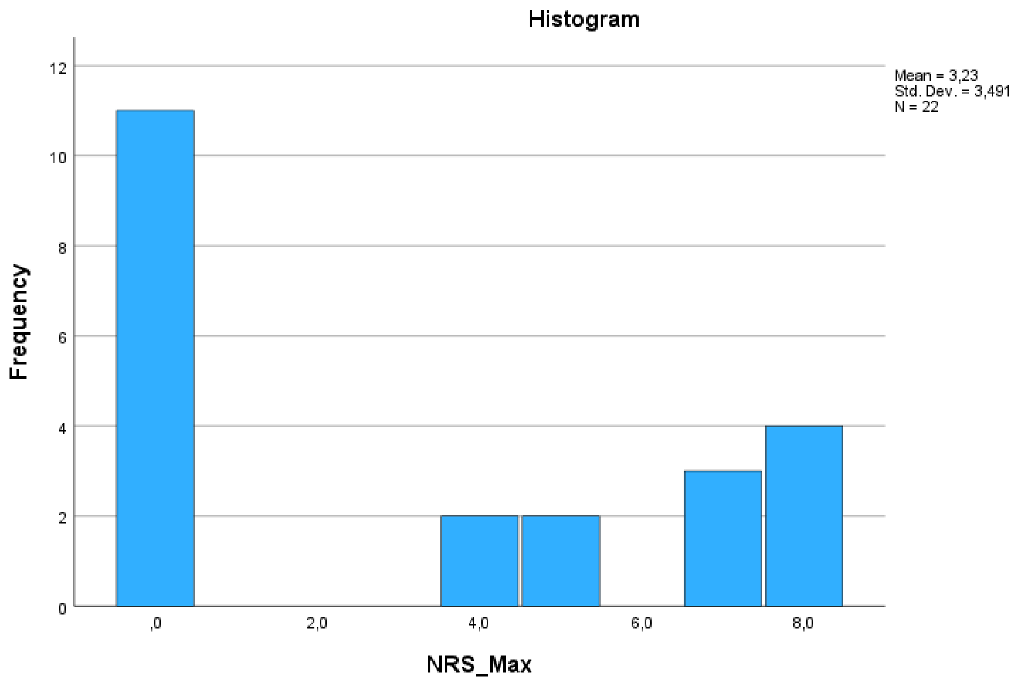

Figure 13: Histogram showing the distribution of the results of the Numeric Rating Scale for the maximum pain experienced in the affected extremity

Analysis of the maximum pain scores revealed a notable level of heterogeneity among the participants (n=11) who reported no pain during exercise. Interestingly, all eleven patients who did not experience pain during exercise also reported a maximum pain score of 0 out of 10 in the affected extremity. This suggests a potential association between pain-free movement and complete pain resolution. However, the maximum pain scores varied for other participants, with two individuals reporting a maximum of 4 out of 10 and 5 out of 10, respectively. Additionally, three participants experienced a maximum pain level of 7 out of 10, and four reported a maximum of 8 out of 10. The occurrence and frequency of this maximum pain experienced after treatment with the Ilizarov fixator varied significantly among the patients. (shown in Figure 13)

3.4 Range of motion differences between affected and healthy ankle joint

In the range of motion examination of the ankle joints, the impacted joint was compared in its full range of motion with the joint that was not treated with an Ilizarov fixator.

For plantar flexion, there was an average difference of around 15 degrees (as shown in Table 4 and Table 8), which represents a significant restriction of movement in the affected ankle joint. The average value for plantar flexion in the affected ankle joint is approximately 21 degrees, while the unaffected ankle joint can be plantar flexed by an average of approximately 37 degrees.

The mean values for dorsiflexion differ by a difference of around 7 degrees (as shown in Table 5 and Table 9), which in turn shows a clear restriction of movement in the operated ankle joint.

While the average value for the impacted ankle joint was 10 degrees, the not impacted ankle joint could be dorsiflexed by an average of around 18 degrees.

The mean difference for pronation was approximately 3.5 degrees (as shown in Table 6 and Table 10) , although it should also be mentioned that 11 patients (50% of the test subjects) had a pronation of 0 degrees, which completely limits the range of motion in this respect. The mean value for pronation on the operated foot is 2.5 degrees, while the non-operated foot can be pronated by an average of around 6 degrees.

The values for supination also differ significantly between the affected and unaffected ankle joint, with an average difference of around 8 degrees (as shown in Table 7 and Table 11). While the ankle joint treated with an Ilizarov fixator can be supinated by an average of 12.5 degrees, this contrasts with a value of around 20.5 degrees of supination on the unaffected side.

Table 4: Comparison between average plantar flexion at the affected ankle joint and the unaffected ankle joint

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PF_impact_rom	20,909	22	11,5095	2,4538
	PF_not_impact_rom	36,591	22	8,6446	1,8430

Table 5:Comparison between average dorsiflexion at the affected ankle joint and the unaffected ankle joint

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	DF_impact_rom	10,000	22	8,0178	1,7094
	DF_not_impact_rom	17,727	22	5,5048	1,1736

Table 6:Comparison between average pronation at the affected ankle joint and the unaffected ankle joint

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pronation_impact_rom	2,500	22	2,5588	,5455
	Pronation_not_impact_rom	5,909	22	1,9739	,4208

Table 7: Comparison between average supination at the affected ankle joint and the unaffected ankle joint

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Supination_impact_rom	12,500	22	7,8300	1,6694
	Supination_not_impact_rom	20,455	22	4,6057	,9819

Table 8: Presentation of the average difference in plantar flexion between affected and unaffected ankle joints and indication of significance (p)

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	PF_impact_rom - PF_not_impact_rom	-15,6818	15,2983	3,2616	-22,4647	-8,8989	-4,808	21	<,001	<,001

Table 9: Presentation of the average difference in dorsiflexion between affected and unaffected ankle joints and indication of significance (p)

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	DF_impact_rom - DF_not_impact_rom	-7,7273	8,5534	1,8236	-11,5196	-3,9349	-4,237	21	<,001	<,001

Table 10:Presentation of the average difference in pronation between affected and unaffected ankle joints and indication of significance (p)

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	Pronation_impact_rom - Pronation_not_impact_rom	-3,4091	3,8994	,8314	-5,1380	-1,6802	-4,101	21	<,001	<,001

Table 11: Presentation of the average difference in supination between affected and unaffected ankle joints and indication of significance (p)

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	Supination_impact_rom - Supination_not_impact_rom	-7,9545	9,9593	2,1233	-12,3703	-3,5388	-3,746	21	<,001	,001

3.5 AOFAS Score Results

3.5.1 AOFAS Score Hindfoot (Adnex II) Results

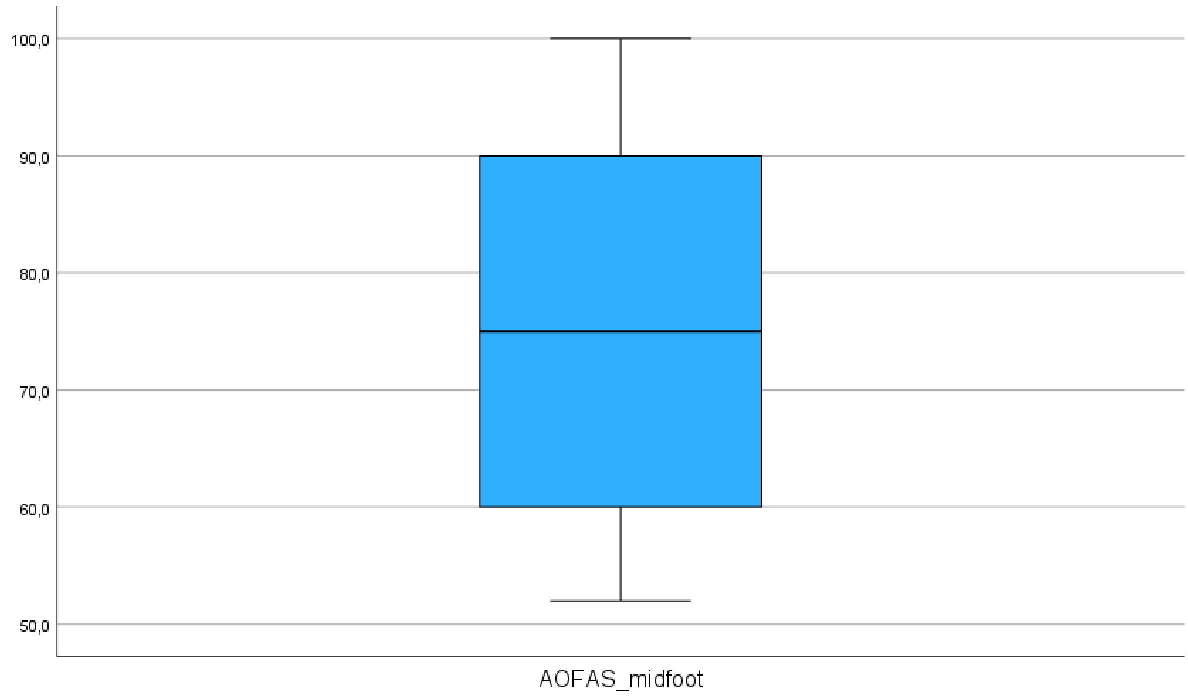

Figure 14: Presentation of the results of the AOFAS hindfoot score as a boxplot diagram

Table 12: Statistical presentation of the results of the AOFAS hindfoot score

	Mean	Median	Minimum	Maximum	Standard Deviation
AOFAS_hindfoot	77,2	79,0	47,0	100,0	19,3

The AOFAS hindfoot score showed a very heterogeneous distribution, as illustrated in Figure 14 and presented in Table 12. While two of the study participants achieved the full score of 100 points, two of the participants only received 47 points. The arithmetic mean of the scores is 77.2 and the median is 79, with a standard deviation of 19.3.

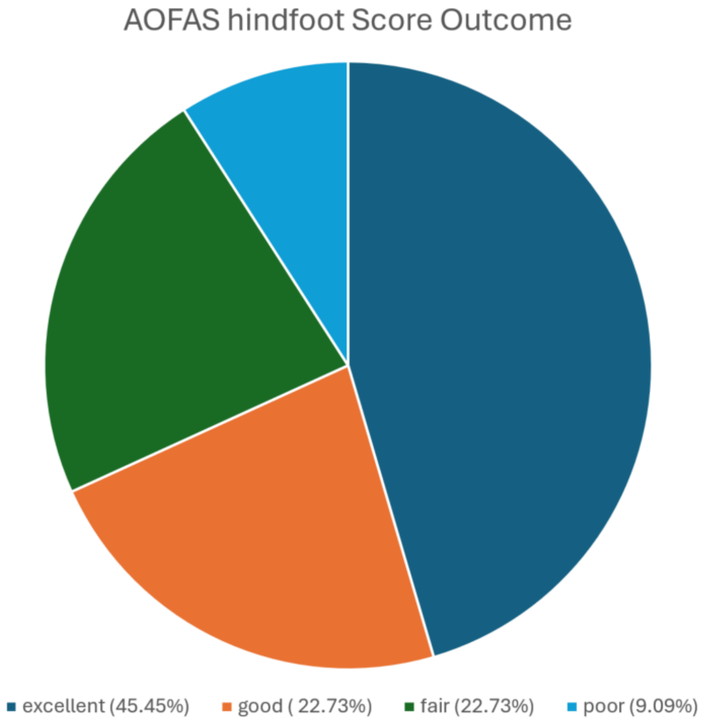

Figure 15: The AOFAS hindfoot score distribution is presented graphically using a pie chart.

Analysis of the AOFAS hindfoot scores revealed a promising distribution of functional outcomes (as shown in Figure 15). The majority of patients (45.45%, n=10) achieved 'excellent' results, indicating minimal functional impairment. An additional noteworthy group (22.73%, n=5) achieved 'good' outcomes**.** A comparable group (22.73%, n=5) fell into the 'fair' category, and a minimal number (9.1%, n=2) exhibited 'poor' functional outcomes based on the AOFAS scoring system.

3.5.2 AOFAS Score Midfoot (Adnex III) Results

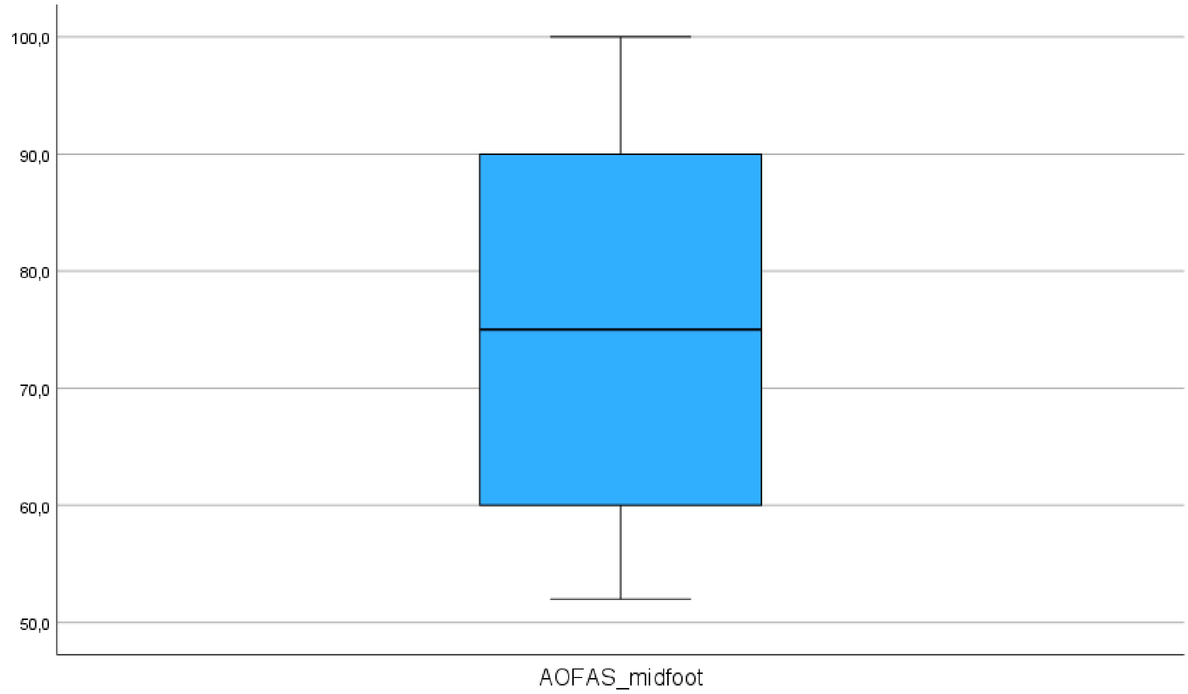

Figure 16: Presentation of the results of the AOFAS midfoot score as a boxplot diagram

Tabelle 13: Statistical presentation of the results of the AOFAS midfoot score

	Mean	Median	Minimum	Maximum	Standard Deviation
AOFAS_midfoot	75,8	75,0	52,0	100,0	16,7

The AOFAS midfoot score showed a similar distribution of points (illustrated in Figure 16 and presented in Table 13). While two of the study participants achieved the full score of 100 points, three of the participants only received 52 points. The arithmetic mean of the scores is 75.8 and the median is 75, with a standard deviation of 16.7.

The results in the AOFAS score are very different. While some patients lost points due to pain and reported no functional restrictions in everyday movements, some patients lost points due to a significant restriction in movement and function with no pain at all.

The most common reason for a loss of points in the AOFAS score is the sub-item “walking on uneven surfaces”.

It should be mentioned at this point that some sub-items (such as maximum walking distance) are limited due to the advanced age of some patients, regardless of the ankle injury that has occurred.

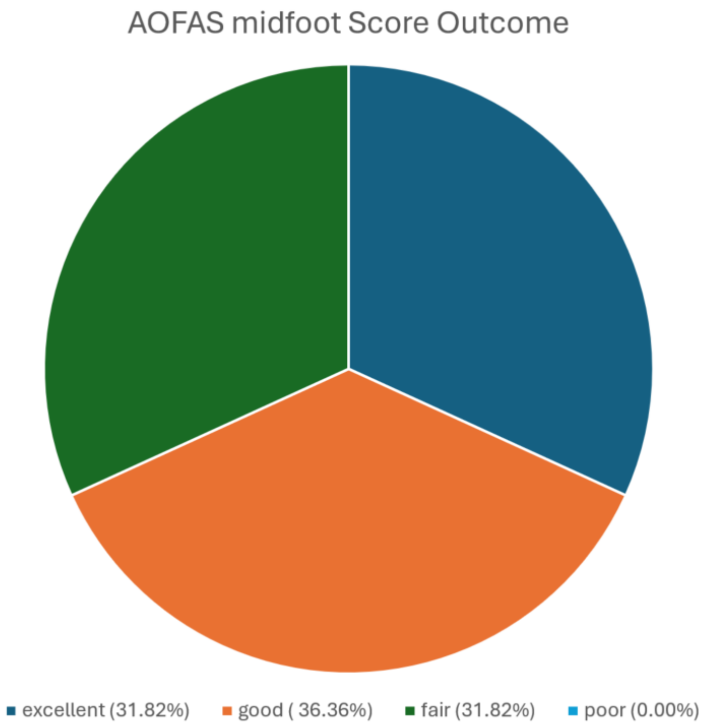

Figure 17:The AOFAS midfoot score distribution is presented graphically using a pie chart.

Analysis of the AOFAS midfoot scores reveals a varied distribution of patient outcomes (as shown in Figure 17). Notably, 31.82% (n=7) achieved excellent results, indicating minimal pain, full function, and good alignment in their midfoot. A similarly substantial portion (36.36%, n=8) achieved good outcomes, suggesting mild pain but overall good function. Fair outcomes, characterized by moderate pain and limitations, were observed in another 31.82% (n=7) of patients. Importantly, no patients fell into the 'poor outcome' category, which means there was no undetected foot compartment.

SF-36 Score (Adnex I) Results

Table 14: Statistical result of all eight sections of the SF-36 score, showing arithmetic mean, median, minimum, maximum and standard deviation

	Mean	Median	Minimum	Maximum	Standard Deviation
SF36_physica_function	66,6	70,0	30,0	95,0	19,8
SF36_physica_health	70,5	100,0	,0	100,0	39,1
SF36_emotions	90,9	100,0	,0	100,0	29,4
SF36_energy	62,7	70,0	25,0	95,0	20,6
SF36_wellbeeing	76,8	84,0	20,0	100,0	21,6
SF36_social	89,2	100,0	50,0	100,0	16,9
SF36_pain	71,4	72,5	32,5	100,0	22,7
SF36_general_health	65,2	65,0	20,0	90,0	20,6

Table 14 provides a comprehensive overview of the results across all sub-areas of the SF-36 health-related quality of life (HRQoL) assessment. This table summarizes the average scores achieved by patients in each domain, offering a quick visual representation of their overall well-being in various aspects of life. We will dive deeper into each individual sub-area of the SF-36 score in the following sections, providing a more detailed analysis of the specific aspects of HRQoL impacted by Ilizarov fixation for pilon tibial fractures.

3.5.3 **Physical functioning** (Figure 18)

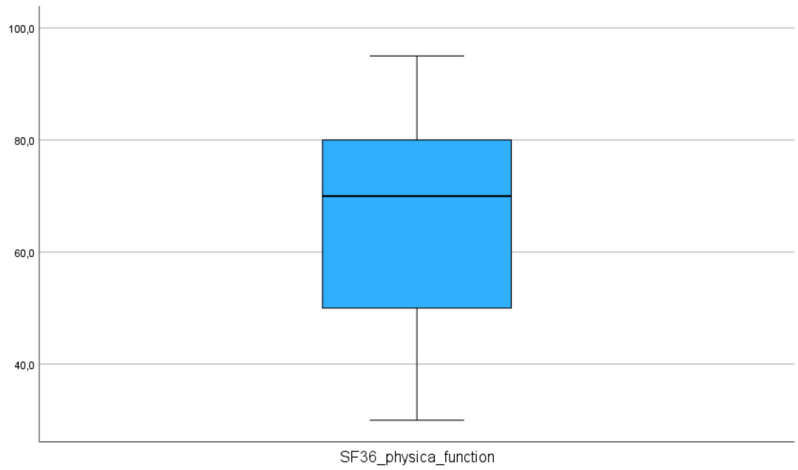

Figure 18:Boxplot diagram representation of the "physical functioning" sub-area

The physical functioning scale consists of 10 questions that inquire about limitations in physical activities due to health problems.

The most frequent deduction of points among the 10 questions of physical functioning was found in the question regarding strenuous activities. Here, all patients stated that they were restricted in some way. However, it should again be noted that the mean age of the female participants was 67.5 years and that of the male participants was 60.8 years and that many study participants are no longer able to perform strenuous activities even without the ankle injury.

Points were also lost when kneeling, bending and stooping, as well as when climbing stairs, which in turn could often be attributed to comorbidities such as hip or knee arthrosis in the medical history.

Participants received the most points for the question about walking across one or more streets.

3.5.4 Limitations due to physical health (Figure 19)

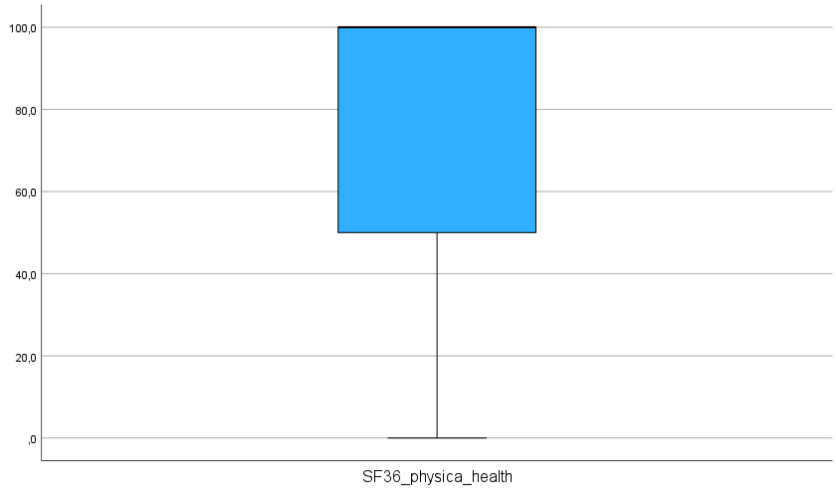

Figure 19: Boxplot diagram representation of the "limitations due to physical health" sub-area

The part of the SF-36 score that deals with limitations due to physical health consists of four questions.

Regarding the limitations due to physical health, the majority of study participants completed the study with the full number of points. Twelve of the twenty-two participants achieved 100 points. This suggests that twelve of the patients are coping well in everyday life, either by being completely free of symptoms or by adapting their everyday life to their health situation. Two of the participants scored 75 points and four of the participants scored 50 points. However, four of the patients also scored zero points, which means that four participants were unable to cope with everyday activities at home or at work in any way.

3.5.5 Limitations due to emotional problems

The SF-36 score contains three questions regarding limitations due to emotional problems.

Twenty of the twenty-two study participants did not indicate the presence of emotional problems and their influence on everyday life in their medical history and received the full 100 points for this sub-item. Two of the patients stated in all three questions that the emotional problems had a significant influence on coping with everyday life. They received zero points for this sub-item.

3.5.6 **Vitality (energy)** (Figure 20)

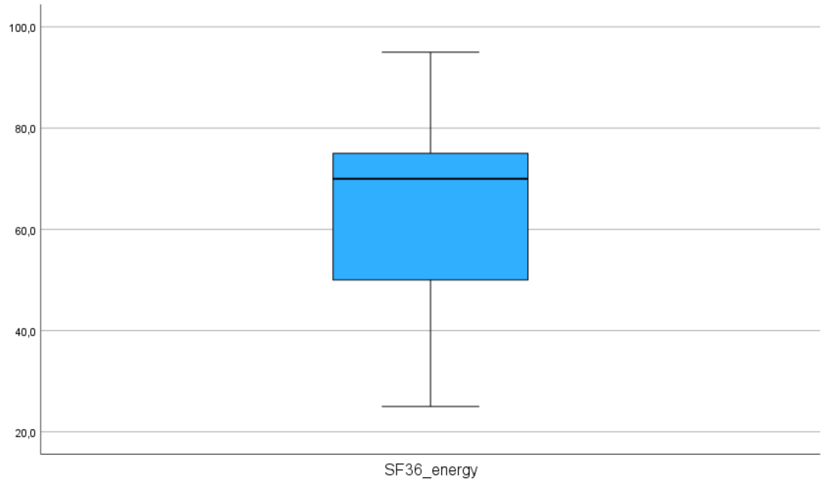

Figure 20: Boxplot diagram representation of the "vitality" sub-area"

The Vitality Scale consists of 4 questions that directly assess a person's level of energy and fatigue during the past four weeks.

None of the study participants achieved the full number of points (100 points). The maximum is 95 points and was achieved by two participants. Three of the patients only received 25 points for answering the questions, marking the minimum statistical result for this sub-item. The mean value is 62.7 points. The composition of the respective points varied greatly in this part of the SF-36 score and hardly allows any indication of a statistical anomaly.

In this sub-item in particular, the average age of the patient population must be emphasized again.

3.5.7 **Mental health (emotional well-being)** (Figure 21)

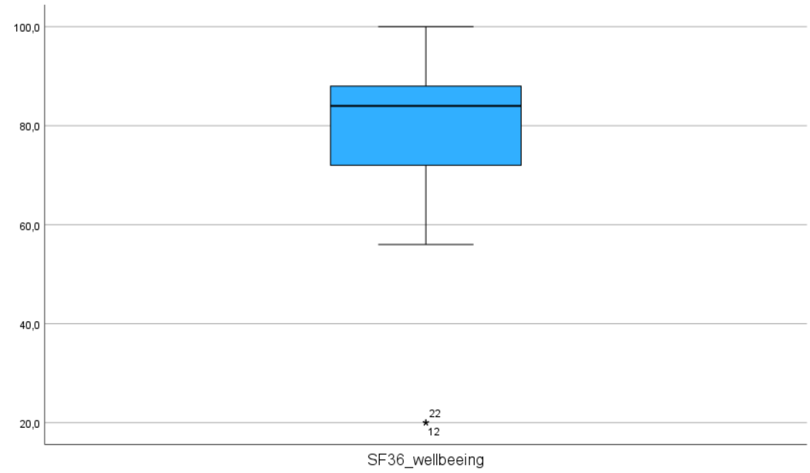

Figure 21: Boxplot diagram representation of the "mental health" sub-area"

The mental health scale consists of 5 questions that assess a person's emotional well-being and psychological distress during the past four weeks.

The average score is 76.8 points. Two of the study participants received the full 100 points for their answers. On the other hand, two of the patients gave their mental health a score of 20 points. As can be seen in the boxplot diagram and in the arithmetic mean, the majority of patients reported relatively good mental health.

Here, too, the allocation of points varies greatly depending on the question, so that the composition of points is very individual and does not reveal any statistical anomalies.

3.5.8 **Social Functioning** (Figure 22)

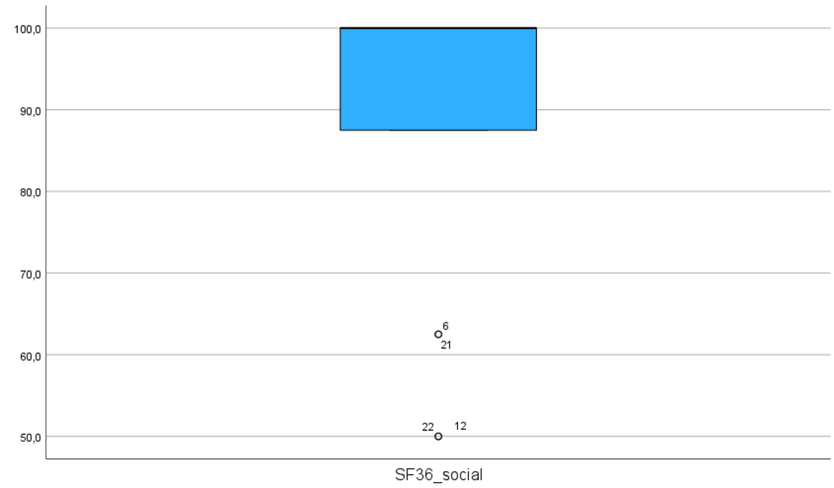

Figure 22: Boxplot diagram representation of the "social functioning" sub-area"

The Social Functioning scale, which consists of only 2 questions targets the limitations a person experiences in their social life due to their health.

Thirteen of the twenty-two study participants received the full 100 points for answering these two questions.

The minimum of 50 points was achieved by two of the patients. There is also a connection here with the “mental health” sub-category, as these are the same patients who also received the minimum score there. As can be seen in the boxplot and underpinned by the arithmetic mean of 89.2 points, the majority of patients performed well in terms of social functioning.

3.5.9 **Bodily pain** (Figure 23)

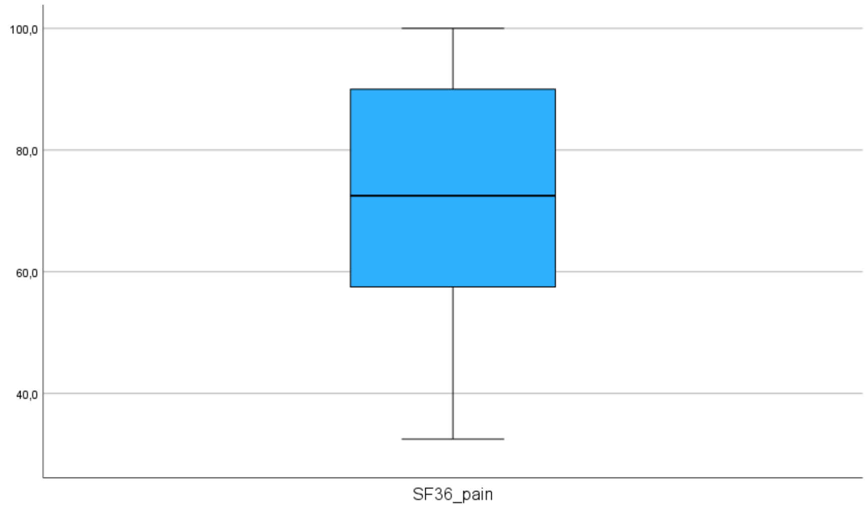

Figure 23: Boxplot diagram representation of the “bodily pain” sub-area"

The two questions the patients were asked regarding physical pain include the general presence of possible pain (none, very mild, mild, moderate, severe or very severe) and the extent to which possible pain interferes with everyday life (not at all, a little, moderately, fairly or very much).

Five of the study participants received the maximum score of 100 points each and therefore reported no pain at all. Two of the patients received the minimum score of 32.5 points on the Bodily Pain Scale. It was noticeable in the elaboration of the questions that as soon as study participants reported pain in the medical history, they were also at least “a little” hindered by it in their work and/or profession.

The average score in this sub-area was 71.4 points. The boxplot diagram clearly shows that the pain characteristics reported varied considerably among the participants.

It should also be mentioned here that the SF-36 score with the category "bodily pain" asks the patient about pain in general and not the localized pain symptoms at the affected ankle joint as queried in this study using the Numeric Rating Scale. For this reason, the results differ between SF-36 "bodily pain" and NRS (rest, stress, max).

3.5.10 **General health perception** (Figure 24)

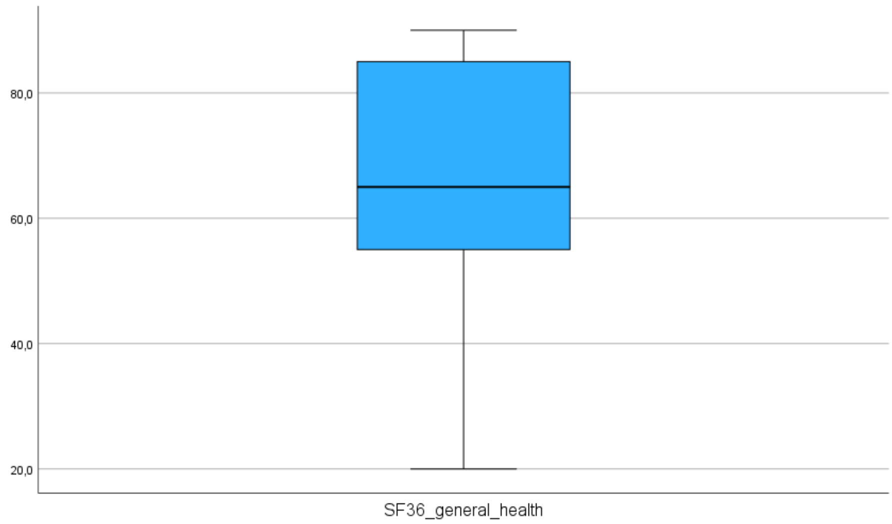

Figure 24: Boxplot diagram representation of the "general health perception" sub-area"

The General Health scale consists of 5 questions that assess a person's overall perception of their health and physical well-being.

None of the study participants were able to achieve the full 100 points in terms of general physical health. Among other things, this could most likely be due to the increased age of the study group.

Four of the patients received the maximum score of 90 points. One of the participants achieved the minimum statistical result with 20 points. The arithmetic mean of the points achieved with regard to general health is 65.2 points. According to data collection and individual medical history, this phenomenon can be attributed to the postoperative course of the affected extremity in the case of local pain symptoms or functional impairment but is also dependent on numerous comorbidities of the patient.

4 Discussion

This study aims to evaluate the long-term functional outcomes of patients with complex pilon tibial fractures treated using the Ilizarov external fixator at the Department of Traumatology and Orthopaedics of the Medical University of Graz. Pilon tibial fractures, known for their inherent complexity and potential for significant functional impairment, often necessitate specialized treatment strategies. The Ilizarov fixator has emerged as a viable option for managing these complex fractures, offering advantages such as minimal soft tissue disruption and the ability to achieve fracture reduction and stabilization. (Solomin 2008)

This investigation seeks to assess the long-term effectiveness of the Ilizarov fixator in this patient population. By analyzing functional outcomes through validated scoring systems, the study aims to contribute valuable data to the existing body of literature regarding the long-term efficacy of this treatment modality for pilon tibial fractures. Furthermore, the study will compare the findings with existing literature on similar interventions, fostering a deeper understanding of the Ilizarov fixator's role in managing these challenging injuries.

4.1 Comparative Analysis with the study of S. Vidyadhara and Sharath K. Rao (2006)

A crucial component of this investigation involves a comprehensive comparison of its findings with relevant research within the existing body of literature. The study by S. Vidyadhara and Shrath K. Rao titled "Ilizarov Treatment of Complex Tibial Pilon Fractures" presents a particularly valuable point of reference due to its comparable sample size. Both studies involved a similar number of participants (21 in Vidyadhara and Rao's study, and 22 in the present study). This similarity in sample size allows for a more direct comparison of treatment outcomes.

However, a noteworthy distinction exists between the demographic characteristics of the two study populations. The age of participants in Vidyadhara and Rao's study is reported as 34±5.6 years (range 28-52 years), indicating a considerably younger population compared to the current study. In contrast, the present study demonstrates a significantly higher average age of 64.8±14.2 years (range 29-85 years) in its participant pool. This age disparity is a factor that may potentially influence treatment outcomes. As the analysis of results progresses, we will explore this potential influence and its impact on the comparative findings between the two studies.

Beyond the disparity in age, another noteworthy difference exists between the demographic characteristics of the two study populations. The current investigation included 13 female and 9 male participants, resulting in a more balanced gender distribution. In stark contrast, the study by S. Vidyadhara and Sharath K. Rao (2006) exhibited a significant gender imbalance, with 20 out of 21 participants being male and only one participant being female. The observed gender and age disparities in the study population are likely attributable to the higher prevalence of high-energy trauma among young men in countries like India. In Western countries like Austria, such disparities are less pronounced, potentially due to differences in lifestyle, occupational hazards, and healthcare systems. This substantial difference in gender composition warrants further exploration in the context of potential influences on treatment outcomes.

As illustrated in Table 15, a trend emerged within the present study, suggesting that female participants achieved lower average scores, particularly on the AOFAS hindfoot assessment compared to their male counterparts. However, the relatively small sample size in our study precludes definitive conclusions regarding the statistical significance of this observation. The observed trend could very well be attributable to chance alone. Nevertheless, it is important to acknowledge this potential influence, particularly considering the markedly skewed gender composition within the study by Vidyadhara and Rao (2006). The significant difference in gender ratios between the two studies may contribute to the observed discrepancies in treatment outcomes.

Table 15:Comparison between male and female study population considering the AOFAS hindfoot score and the AOFAS mid-foot score

	Sex									
	male					female				
	Mean	Median	Minimum	Maximum	Standard Deviation	Mean	Median	Minimum	Maximum	Standard Deviation
AOFAS_hindfoot	81,2	90,0	47,0	100,0	21,3	74,5	79,0	50,0	100,0	18,2
AOFAS_midfoot	76,4	80,0	52,0	100,0	17,7	75,3	75,0	52,0	100,0	16,6

4.1.1 Comparing Range of Motion (Vidyadhara und Rao 2006)

A critical limitation arises when attempting to directly compare the findings related to plantarflexion and dorsiflexion range of motion with the study by Vidyadhara and Rao (2006). Their investigation provides a range of motion data for these aspects, with plantarflexion reported as ranging from 5 degrees to 35 degrees and dorsiflexion ranging from 5 degrees to 15 degrees. In contrast, our study demonstrates a wider range of motion, with plantarflexion values spanning from 0 degrees to 45 degrees and dorsiflexion values ranging from 0 degrees to 25 degrees. However, it's crucial to acknowledge that the presence of extreme values (0 degrees in both plantarflexion and dorsiflexion) in our study population influences the overall range reported. With only one participant exhibiting zero degrees of plantarflexion and two participants demonstrating zero degrees of dorsiflexion, these values may be considered outliers within the data set.

Given the limitations of solely comparing range extremes, a more insightful approach would involve analyzing the average values for plantarflexion and dorsiflexion range of motion in both studies. Focusing solely on the reported ranges in Vidyadhara and Rao's study overlooks the central tendency of their data, potentially leading to misinterpretations. Therefore, the current comparison primarily highlights outliers within each data set, precluding definitive conclusions regarding the overall range of motion across the respective study populations.

Our study demonstrates an average range of motion of 20.9 degrees (SD = 11.5 degrees) in plantarflexion and 10 degrees (SD = 8 degrees) in dorsiflexion. To facilitate a more robust comparison, the average values and standard deviations from Vidyadhara and Rao's study (if available) should be incorporated into the analysis. This would allow for a more comprehensive evaluation of potential differences in plantarflexion and dorsiflexion range of motion outcomes between the two studies.

Unfortunately, the values for pronation and supination are not given for Vidyadhara and Rao (2006), so it is not possible to compare the data in that axis of movement.

4.1.2 Comparing AOFAS hindfoot Score Results (Vidyadhara und Rao 2006)

A closer look at the AOFAS hindfoot score distribution reveals some intriguing trends. Notably, both studies demonstrate a substantial portion of patients achieving "excellent" outcomes (defined as a score of 90-100 points). While our study observed 45.5% of patients in this category, Vidyadhara and Rao's study reported a slightly higher percentage (52.4%).

The distribution in the "good" outcome category (defined as a score of 70-89 points) shows interesting trends. While Vidyadhara and Rao's study has a slight edge (23.8% compared to 22.7% in our study), both studies demonstrate a notable presence of patients in this category.

The distribution in the "fair" category (defined as a score of 50-69 points) is also relatively close between the two studies (22.73% in our study and 19.0% in Vidyadhara and Rao's study).

However, a disparity emerges in the "poor" outcome category (defined as less than 50 points). Our study observed a considerably higher percentage of patients with "poor" outcomes compared to Vidyadhara and Rao's study (9.1% versus 4.8%).

While the AOFAS hindfoot scores in our study indicate a positive outcome for a substantial portion of patients (45.5% achieving "excellent," 22.7% achieving "good," and 22.7% achieving "fair"), a comparison with the findings of Vidyadhara and Rao (2006) reveals some noteworthy differences in outcome distribution. Their study reported a seemingly more favorable outcome spread, with over half of their patients (52.4%) achieving "excellent" scores, compared to 45.5% in our study. Additionally, a higher percentage of patients in their study achieved "good" scores (23.8%) compared to our study (22.7%). Conversely, a lower proportion of patients in their study fell into the "poor" outcome category (4.8%) compared to our study (9.1%).

Although demographic differences between the two studies (age and gender) might be contributing factors, a more plausible explanation for the observed discrepancies likely lies in the relatively small sample sizes of both investigations. This is particularly evident in the "poor" outcome category, where a single participant from one study significantly impacts the overall percentage. Smaller sample sizes can lead to wider confidence intervals, making it more difficult to detect statistically significant differences between groups.

Despite these limitations, it's worth noting that the age of our patients might be a contributing factor to the slightly less favorable outcomes observed in our study. As age increases, the body's natural healing processes tend to slow down, and patients are more likely to have pre-existing medical conditions (comorbidities) that can further complicate recovery.

It's important to acknowledge that limitations in our own study design or data collection procedures could have also influenced the AOFAS hindfoot score distribution. Future research efforts with larger and more diverse patient populations are necessary to provide a more definitive understanding of the factors influencing AOFAS hindfoot scores following treatment with the Ilizarov fixator for complex pilon tibial fractures.

4.2 Comparative Analysis with the study of Walid Osman et al. (2017)

The Osman et al. (2017) study included a larger sample size (30 participants) compared to the current study. While a larger sample can enhance the generalizability of findings, in this case, the 36% increase might not translate into a significantly more representative depiction of the overall pilon fracture population.

The average age of patients in the Osman et al. (2017) study (47 years, range 20-73 years) falls closer to the average age in our current study (64.8 years, range 29-85 years) compared to the demographics reported by Vidyadhara and Rao (2006). However, a notable age disparity remains between our study and both Osman et al. (2017) and Vidyadhara and Rao (2006). This difference in age distribution could be a contributing factor to the observed variations in functional ankle outcomes between the studies.

The gender distribution in the Osman et al. (2017) study is significantly skewed, with 26 men and only 4 women among the 30 participants. This contrasts with the current study, which included a more balanced representation with 9 men and 13 women. As highlighted in the study by Vidyadhara and Rao (2006), high-energy trauma occurrences in some regions might be more prevalent among males due to occupational hazards. This factor could potentially influence the observed gender distribution discrepancies between the studies and might contribute, at least partially, to the functional outcome disparity.

Table 15 demonstrates that women in this study performed worse in the AOFAS hindfoot score, with an average value of 74.5 compared to 81.2 for the male participants. However, due to the small sample size, it is crucial to exercise caution when interpreting this finding. While a definitive conclusion regarding a gender-based difference in surgical outcomes cannot be drawn from this data alone, the demographic disparity between the studies warrants consideration alongside patient age, where a potential correlation with functional outcomes might exist.

4.2.1 Comparing AOFAS hindfoot Score Results (Osman et al. 2017)

In the Osman et al. (2017) study, 16 patients achieved an excellent outcome (defined as a score of 90-100 points), 6 patients achieved a good outcome (70-89 points), 6 patients achieved a fair outcome (50-69 points), and 2 patients achieved a poor outcome (less than 50 points). In comparison, the current study observed 10 patients with excellent outcomes, 5 patients with good outcomes, 5 patients with fair outcomes, and 2 patients with poor outcomes.

Converted to percentages, these findings reveal some interesting trends in functional outcomes between the two studies. While both studies demonstrate a positive outcome for a substantial portion of patients, the Osman et al. (2017) study showed a slightly higher percentage achieving excellent outcomes (53.3%) compared to the current study (45.5%). Interestingly, the distribution in the "good" outcome category is relatively close. The Osman et al. (2017) study observed a good outcome rate of 20.0%, while our study showed 22.7%. The distribution in the "fair" category is also relatively close (20.0% in Osman et al. (2017) and 22.73% in the current study). However, a key difference emerges in the "poor" outcome category. Our study observed a similar percentage of patients with poor outcomes (9.1%) compared to Osman et al. (2017) (6.6%).

The most likely explanation for the observed variations in functional outcomes between the two studies lies in the relatively small sample sizes of both investigations. Smaller sample sizes can lead to wider confidence intervals, making it more difficult to detect statistically significant differences between groups. This limitation makes it challenging to definitively conclude whether the observed discrepancies are due to true underlying differences in treatment efficacy or simply random chance.

While demographic differences between the study populations (e.g., age, gender) could also be contributing factors, their influence is difficult to determine with certainty due to the small sample sizes. The Osman et al. (2017) study included a younger patient population (average age 47 years) compared to the current study. Age is known to influence healing rates and functional recovery after musculoskeletal injuries. Younger patients often experience faster and more complete recovery compared to older individuals. Additionally, the Osman et al. (2017) study have included a different gender distribution, potentially influencing the overall outcome spread.

4.3 Comparison with two studies that used the Open Reduction Internal Fixation technique (Viberg et al. 2016) (Rubio-Suarez et al. 2018)

4.3.1 Comparing AOFAS hindfoot Score Results (Viberg et al. 2016)

A comparative analysis with the study by Viberg et al. (2016) reveals some interesting trends in functional outcomes following pilon fracture treatment. Viberg et al. reported a median AOFAS Ankle-Hindfoot score of 73 (IQR 59-87) in their study, which utilized open reduction and internal fixation (ORIF) with low-profile locking plates.

In contrast, our study achieved a median AOFAS Ankle-Hindfoot score of 79 (IQR 60-90). This suggests a potential advantage for Ilizarov fixation, although caution is warranted due to the relatively small sample size in both studies. Further research with larger patient populations is necessary to draw definitive conclusions regarding the comparative effectiveness of these treatment modalities.

The observed difference in AOFAS scores might partially be attributed to the minimally invasive nature of the Ilizarov fixator. This technique is associated with a lower complication rate and reduced soft tissue damage compared to traditional ORIF procedures. However, the small sample sizes in both studies limit the ability to definitively establish a causal relationship between the surgical technique and the observed outcome differences.

Future studies with larger participant pools can analyze this aspect in more detail, shedding light on the potential benefits of Ilizarov fixation in achieving improved functional outcomes following pilon fractures.

Comparing AOFAS hindfoot Score Results (Rubio-Suarez et al. 2018)

The study by Rubio-Suarez et al. examines the functional outcomes of pilon fractures treated with open reduction and internal fixation (ORIF) using the locking compression plate-less invasive stabilizing system (LCP-LISS).

The Colombian research found that 30.5% of patients achieved excellent outcomes, 46.7% had good outcomes, 13.1% experienced fair outcomes, and 9.7% had poor outcomes, as measured by the AOFAS ankle-hindfoot scale.

In contrast, our study reported that 45.45% of patients treated with the Ilizarov technique achieved excellent outcomes, but only 22.73% fell into the good outcome category. Additionally, 22.73% of Ilizarov patients had fair outcomes, which is notably higher than the 13.1%

observed in the ORIF group. The percentage of patients with poor outcomes was similar, with 9.1% of Ilizarov patients compared to 9.7% of ORIF patients.

Given the small sample size of our study—compared to Rubio-Suarez et al.'s 137 participants—it's challenging to draw definitive conclusions. However, one observation is that poor outcomes appear comparable across both surgical techniques, while the Ilizarov method tends to achieve more excellent results.

Overall, comparing these two techniques is complex, as the choice of surgical method often depends on the specific injury pattern and the surgeon's proficiency with each technique. This variability is particularly pronounced in different geographical contexts, such as Colombia and Austria.

4.4 Limitations

A critical factor limiting the generalizability and informative value of this study is the relatively small sample size. This challenge is not unique to our investigation, as other studies exploring this specific surgical technique within the western medical field have similarly encountered difficulties in recruiting large patient populations. While the observed outcomes in our study exhibit promising trends when compared to existing literature, the statistical significance of these findings may be limited due to the small number of participants (n=22) across all comparative studies, including our own. Notably, none of the referenced studies on Ilizarov fixation exceeded 30 participants.

This limitation is particularly relevant when considering the "poor" outcome category in our study, where a single patient significantly impacted the overall percentage. Had this patient achieved a "fair" outcome instead, the distribution of results would have shifted considerably. This highlights the sensitivity of findings in such small studies, where individual data points can exert a substantial influence on overall results, particularly when relying on self-reported patient assessments.

The relatively small sample size in our study can be partially attributed to the ongoing COVID-19 pandemic. Many potential participants expressed apprehension about participating in follow-up assessments due to concerns regarding potential infection. This apprehension is further amplified by the increased vulnerability of our study population, given the higher risk factors associated with severe COVID-19 complications in older age groups.

Furthermore, the retrospective nature of this study introduces the potential for bias due to memory limitations and participant selection. Patients may struggle to accurately recall details of their experiences, particularly several years after surgery. This can lead to overestimation or underestimation of pain levels, functional abilities, and overall well-being, potentially introducing inaccuracies in the collected data, especially regarding pre-surgical function. Additionally, selection bias is a concern, as our patient pool is limited to those who attended follow-up appointments. Patients with particularly positive or negative experiences may be more likely to attend, potentially skewing the overall distribution of outcomes observed in the study. For instance, those with significant ongoing pain might be more motivated to seek solutions, while those with excellent outcomes might be less inclined to return.

5 Conclusion

Drawing upon the results of this study and comparisons with existing literature, no statistically significant deviations from expected outcomes were observed in the data. This is particularly noteworthy considering the relatively high average age of the patient population. Based on these findings, we cannot advise against the continued use of the Ilizarov fixation technique for the currently established indications. However, the data does not presently support a recommendation for expanding the range of suitable applications. It is important to emphasize that these conclusions pertain specifically to the application of Ilizarov fixation at the Department of Orthopedics and Traumatology, Medical University of Graz, between the years 2005 and 2020.

To formulate a more definitive recommendation regarding the broader use of Ilizarov fixation, future studies with a larger patient population are warranted. Critically, such studies should incorporate a significantly younger average age group to enable more robust comparisons with existing literature. By addressing these limitations in future research endeavors, we can strive towards a more comprehensive understanding of the long-term efficacy and potential applications of Ilizarov fixation for pilon tibial fractures.

While our study did not yield groundbreaking insights into the surgical technique of Ilizarov fixation for pilon tibial fractures, it did provide valuable confirmation of findings established in existing research. Although slight variations exist between our results and prior studies, such discrepancies are to be expected in investigations with relatively small sample sizes, as these can be unduly influenced by individual outlier data points.

Looking towards the future, this study, with its comprehensive data collection and scoring methods, offers a strong foundation for comparative analysis in further research on Ilizarov fixation for pilon tibial fractures. In particular, the detailed reporting of range of motion across various statistical values provides a valuable benchmark for future studies. Additionally, our utilization of the AOFAS score, SF-36 score, and Numeric Rating Scale reinforces the generalizability of our findings. These established scoring systems offer a standardized approach for future investigations, facilitating robust comparisons across different studies conducted worldwide.

List of references

Anderhuber, Friedrich; Pera, Franz; Streicher, Johannes (Hg.) (2012): WALDEYER ANATOMIE DES MENSCHEN. Lehrbuch und Atlas in einem Band. 19. Aufl. Berlin, Boston: Walter de Gruyter GmbH & Co. KG.

Aumüller, Gerhard; Aust, Gabriela; Engele, Jürgen; Kirsch, Joachim; Mario, Giovanni; Mayerhofer, Artur et al. (Hg.) (2020): Duale Reihe Anatomie. 5. Aufl. Rüdigerstraße 14, Stuttgart: Georg Thieme Verlag.

Harrasser, Norbert; Eisenhart-Rothe, Rüdiger von; Biberthaler, Peter (Hg.) (2016): Facharztwissen Orthopädie Unfallchirurgie. Berlin, Heidelberg: Springer-Verlag.

Hartrick, Craig T.; Kovan, Juliann P.; Shapiro, Sharon (2003): The Numeric Rating Scale for Clinical Pain Measurement: A Ratio Measure? In: *Pain Practice* (4), S. 310–316.

Ibrahim, Talal; Beiri, Almoghera; Azzabi, Mohamed; Best, Alistair J.; Taylor, Grahame J.; Menon, Dipen K. (2007): Reliability and Validity of the Subjective Component of the American Orthopaedic Foot and Ankle Society Clinical Rating Scales. In: *The Journal of foot and ankle surgery* (2), S. 65–74.

Konrads, Christian; Rudert, Maximilian (Hg.) (2018): Klinische Tests und Untersuchung in Orthopädie und Unfallchirurgie. Heidelberger Platz 3, 14197 Berlin, Germany: Springer-Verlag.

Manegold, Sebastian; Schaser, Klaus-Dieter (2014): Pilon-tibial-Fraktur–operatives Vorgehen. In: *OP-JOURNAL 30* (2), S. 82–91.

McHorney, C. A.; Ware, J. E., JR; Raczek, A. E. (1993): The MOS 36-Item Short-Form Health Survey (SF-36): II. Psychometric and clinical tests of validity in measuring physical and mental health constructs. In: *Medical Care* (31), S. 247–263.

Müller, Markus; et al (Hg.) (2020): CHIRURGIE. für Studium und Praxis. 15. Aufl. Neutorplatz 4, Breisach/Rh: Medizinische Verlags- und Informationsdienste.

Niethard, Fritz, U.; Pfeil, Joachim; Biberthaler, Peter (Hg.) (2009): Duale Reihe Orthopädie und Unfallchirurgie. 6. Aufl. Rüdigerstraße 14, Stuttgart: Georg Thieme Verlag.

Osman, Walid; Laya, Zeineb; Kaziz, Hamdi; Hassini, Lassad; Braiki, Meriem; Naouar, Nader; Ayeche, Mohamed Laaziz Ben (2017): Treatment of high-energy pilon fractures using the ILIZAROV treatment. In: *The Pan African Medical Journal* (27), Article number 199.

Rubio-Suarez, Juan C.; Carbonell-Escobar, Rafael; Rodriguez-Merchan, E. Carlos; Ibarzabal-Gil, Aitor; Gil-Garay, Enrique (2018): Fractures of the tibial pilon treated by open reduction and internal fixation (locking compression plate-less invasive stabilising system): Complications and sequelae. In: *Injury* (49), S. 60–64.

Rüter, A.; Trentz, O.; Wagner, M. (Hg.) (1995): Unfallchirurgie. München, Wien, Baltimore: Urban & Schwarzenberg.

Schünke, Michael; Schulte, Erik; Schumacher, Udo (Hg.) (2014): PROMETHEUS. Allgemeine Anatomie und Bewegungssystem. 4. Aufl. Rüdigerstraße 14, Stuttgart: Georg Thieme Verlag.

Solomin, Leonid (2008): The Basic Principles of External Fixation Using the Ilizarov Device. Italia, Milan: Springer-Verlag.

Solomin, Leonid (2012): The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices. 2. Aufl. Italia, Milan: Springer-Verlag.

Viberg, Bjarke; Kleven, Silje; Hamborg-Petersen, Ellen; Skov, Ole (2016): Complications and functional outcome after fixation of distal tibia fractures with locking plate - A multicentre study. In: *Injury* (47), S. 1514–1518.

Vidyadhara, S.; Rao, Sharath K. (2006): Ilizarov treatment of complex tibial pilon fractures. In: *International Orthopaedics* (2), S. 113–117.

Ware, J. E., JR; Gandek B. (1998): Overview of the SF-36 Health Survey and the International Quality of Life Assessment (IQOLA) Project. In: *Journal of Clinical Epidemiology* (51), S. 903–912.

Adnex

Adex I (SF-36 Score)

Universitätsklinikum Hamburg-Eppendorf

Fragebogen zum Gesundheitszustand (SF-36)

In diesem Fragebogen geht es um Ihre Beurteilung Ihres Gesundheitszustandes. Der Bogen ermöglicht es, im Zeitverlauf nachzuvollziehen, wie Sie sich fühlen und wie Sie im Alltag zurechtkommen.

Bitte beantworten Sie jede der folgenden Fragen, indem Sie bei den Antwortmöglichkeiten die Zahl ankreuzen, die am besten auf Sie zutrifft.

1. Wie würden Sie Ihren Gesundheitszustand im Allgemeinen beschreiben ?

(Bitte kreuzen Sie nur eine Zahl an)

Ausgezeichnet.. 1

Sehr gut... 2

Gut.. 3

Weniger gut... 4

Schlecht... 5

2. Im Vergleich zum vergangenen Jahr, wie würden Sie Ihren derzeitigen Gesundheitszustand beschreiben ?

(Bitte kreuzen Sie nur eine Zahl an)

Derzeit viel besser als vor einem Jahr............................ 1

Derzeit etwas besser als vor einem Jahr.........................2

Etwa so wie vor einem Jahr.. 3

Derzeit etwas schlechter als vor einem Jahr.................. 4

Derzeit viel schlechter als vor einem Jahr...................... 5

3. Im folgenden sind einige Tätigkeiten beschrieben, die Sie vielleicht an einem normalen Tag ausüben. Sind Sie durch Ihren derzeitigen Gesundheitszustand bei diesen Tätigkeiten eingeschränkt ? Wenn ja, wie stark ?

(Bitte kreuzen Sie in jeder Zeile nur eine Zahl an)

TÄTIGKEITEN	Ja, stark eingeschränkt	Ja, etwas eingeschränkt	Nein , überhaupt nicht eingeschränkt
a. anstrengende Tätigkeiten, z.B. schnell laufen, schwere Gegenstände heben, anstrengenden Sport treiben	1	2	3
b. mittelschwere Tätigkeiten, z.B. einen Tisch verschieben, staubsaugen, kegeln, Golf spielen	1	2	3
c. Einkaufstaschen heben oder tragen	1	2	3
d. mehrere Treppenabsätze steigen	1	2	3
e. einen Treppenabsatz steigen	1	2	3
f. sich beugen, knien, bücken	1	2	3
g. mehr als 1 Kilometer zu Fuß gehen	1	2	3
h. mehrere Straßenkreuzungen weit zu Fuß gehen	1	2	3
i. eine Straßenkreuzung weit zu Fuß gehen	1	2	3
j. sich baden oder anziehen	1	2	3

4. Hatten Sie in den vergangenen 4 Wochen aufgrund Ihrer körperlichen Gesundheit irgendwelche Schwierigkeiten bei der Arbeit oder anderen alltäglichen Tätigkeiten im Beruf bzw. zu Hause ?

(Bitte kreuzen Sie in jeder Zeile nur eine Zahl an)

SCHWIERIGKEITEN	JA	NEIN
a. Ich konnte nicht so lange wie üblich tätig sein	1	2
b. Ich habe weniger geschafft als ich wollte	1	2
c. Ich konnte nur bestimmte Dinge tun	1	2
d. Ich hatte Schwierigkeiten bei der Ausführung (z.B. ich mußte mich besonders anstrengen)	1	2

5. Hatten Sie in den vergangenen 4 Wochen aufgrund seelischer Probleme irgendwelche Schwierigkeiten bei der Arbeit oder anderen alltäglichen Tätigkeiten im Beruf bzw. zu Hause (z.B. weil Sie sich niedergeschlagen oder ängstlich fühlten) ?

(Bitte kreuzen Sie in jeder Zeile nur eine Zahl an)

SCHWIERIGKEITEN	JA	NEIN
a. Ich konnte nicht so lange wie üblich tätig sein	1	2
b. Ich habe weniger geschafft als ich wollte	1	2
c. Ich konnte nicht so sorgfältig wie üblich arbeiten	1	2

6. Wie sehr haben Ihre körperliche Gesundheit oder seelischen Probleme <u>in den vergangenen 4 Wochen</u> Ihre normalen Kontakte zu Familienangehörigen, Freunden, Nachbarn oder zum Bekanntenkreis beeinträchtigt?

(Bitte kreuzen Sie nur eine Zahl an)

Überhaupt nicht.. 1

Etwas.. 2

Mäßig... 3

Ziemlich... 4

Sehr.. 5

7. Wie stark waren Ihre Schmerzen <u>in den vergangenen 4 Wochen</u> ?

(Bitte kreuzen Sie nur eine Zahl an)

Ich hatte keine Schmerzen.. 1

Sehr leicht 2

Leicht.. 3

Mäßig... 4

Stark... 5

Sehr stark.. 6

8. Inwieweit haben die Schmerzen Sie in den vergangenen 4 Wochen bei der Ausübung Ihrer Alltagstätigkeiten zu Hause und im Beruf behindert ?

(Bitte kreuzen Sie nur eine Zahl an)

Überhaupt nicht.. 1

Ein bißchen.. 2

Mäßig... 3

Ziemlich.. 4

Sehr.. 5

9. In diesen Fragen geht es darum, wie Sie sich fühlen und wie es Ihnen in den vergangenen 4 Wochen gegangen ist. (Bitte kreuzen Sie in jeder Zeile die Zahl an, die Ihrem Befinden am ehesten entspricht). Wie oft waren Sie in den vergangenen 4 Wochen...

(Bitte kreuzen Sie in jeder Zeile nur eine Zahl an)

BEFINDEN	Immer	Meistens	Ziemlich oft	Manch-Mal	Selten	Nie
a. ...voller Schwung	1	2	3	4	5	6
b. ...sehr nervös	1	2	3	4	5	6
c. ...so niedergeschlagen, daß Sie nichts aufheitern konnte ?	1	2	3	4	5	6
d. ...ruhig und gelassen	1	2	3	4	5	6
e. ...voller Energie?	1	2	3	4	5	6
f. ...entmutigt und traurig	1	2	3	4	5	6
g. ...erschöpft	1	2	3	4	5	6
h. ... glücklich	1	2	3	4	5	6
i. ...müde	1	2	3	4	5	6

9. Wie häufig haben Ihre körperliche Gesundheit oder seelischen Probleme in den vergangenen 4 Wochen Ihre Kontakte zu anderen Menschen (Besuche bei Freunden, Verwandten usw.) beeinträchtigt?

(Bitte kreuzen Sie nur eine Zahl an)

Immer.. 1

Meistens.. 2

Manchmal.. 3

Selten.. 4

Nie.. 5

10. Inwieweit trifft jede der folgenden Aussagen auf Sie zu ?

(Bitte kreuzen Sie in jeder Zeile nur eine Zahl an)

AUSSAGEN	Trifft ganz zu	Trifft weit-gehend zu	Weiß nicht	Trifft weitgehend nicht zu	Trifft überhaupt nicht zu
a. Ich scheine etwas leichter als andere krank zu werden	1	2	3	4	5
b. Ich bin genauso gesund wie alle anderen, die ich kenne	1	2	3	4	5
c. Ich erwarte, daß meine Gesundheit nachläßt	1	2	3	4	5
d. Ich erfreue mich ausgezeichneter Gesundheit	1	2	3	4	5

11. Wie würden Sie Ihren derzeitigen Gesundheitszustand beschreiben ?

sehr gut o gut o mittelmäßig o schlecht o sehr schlecht o

12. Im Folgenden finden Sie eine Reihe von Aussagen. Bitte Kreuzen (X) Sie in jeder Reihe an, ob diese für Sie zutrifft oder nicht.

	JA	NEIN
Ich bin andauernd müde	0	0
Ich habe nachts Schmerzen	0	0
Ich fühle mich niedergeschlagen	0	0
Ich habe unerträgliche Schmerzen	0	0
Ich nehme Tabletten, um schlafen zu können	0	0
Ich habe vergessen, wie es ist Freude zu empfinden	0	0
Ich fühle mich gereizt	0	0
Ich finde es schmerzhaft, meine Körperposition zu verändern	0	0
Ich fühle mich einsam	0	0
Ich kann mich nur innerhalb des Hauses bewegen	0	0
Es fällt mir schwer mich zu bücken	0	0
Alles strengt mich an	0	0
Ich wache in den frühen Morgenstunden auf	0	0
Ich kann überhaupt nicht gehen	0	0
Es fällt mir schwer, zu anderen Menschen Kontakt aufzunehmen	0	0
Die Tage ziehen sich	0	0
Ich habe Schwierigkeiten Treppen hinauf- und hinunterzugehen	0	0
Es fällt mir schwer nach Gegenständen zu greifen	0	0
Ich habe Schmerzen beim Gehen	0	0
Mir reißt derzeit oft der Geduldsfaden	0	0
Ich fühle, daß ich niemanden nahestehe	0	0
Ich liege nachts die meiste Zeit wach	0	0
Ich habe das Gefühl, die Kontrolle zu verlieren	0	0
Ich habe Schmerzen, wenn ich stehe	0	0
Es fällt mir schwer mich selbst anzuziehen	0	0
Meine Energie läßt schnell nach	0	0
Es fällt mir schwer lange zu stehen (z.B. am Spülbecken, an der Bushaltestelle)	0	0
Ich habe andauernd Schmerzen	0	0
Ich brauche lange zum Einschlafen	0	0
Ich habe das Gefühl für andere Menschen eine Last zu sein	0	0
Sorgen halten mich nachts wach	0	0
Ich fühle, daß das Leben nicht lebenswert ist	0	0
Ich schlafe nachts schlecht	0	0
Es fällt mir schwer mit anderen Menschen auszukommen	0	0
Ich brauche Hilfe, wenn ich mich außer Haus bewegen will (Stock oder jemand, der mich stützt)	0	0
Ich habe Schmerzen, wenn ich Treppen hinauf- und hinuntergehe	0	0
Ich wache deprimiert auf	0	0
Ich habe Schmerzen, wenn ich sitze	0	0

Adnex II (AOFAS Hindfoot Score)

Klinik für Fuß- und Sprunggelenkchirurgie Rummelsberg / Nürnberg

American Orthopaedic Foot and Ankle Society (AOFAS) Score

Rückfuß Sektion / Hindfoot Section

(Validierte deutsche Version, max. 100 Punkte)

Schmerz:	1: kein	☐	40 Pkt.
	2: leicht, gelegentlich	☐	30 Pkt.
	3: mittelmäßig, täglich	☐	20 Pkt.
	4: heftig, fast immer	☐	00 Pkt.
Funktion:	1: keine Einschränkung, keine Stütze/ Hilfe	☐	10 Pkt.
	2: keine Einschränkung bei den täglichen Aktivitäten Einschränkung bei Freizeitaktivitäten, keine Hilfen	☐	07 Pkt.
	3: Einschränkungen bei den tägl. Aktivitäten, Freizeitaktivitäten, Stock	☐	04 Pkt.
	4: Starke Einschränkungen bei tägl. Aktivitäten, Gehstütze, Krücke, Rollstuhl, Korsett	☐	00 Pkt.
Gehstrecke (in Blocks):	1: mehr als 6	☐	05 Pkt.
	2: 4 bis 6	☐	04 Pkt.
	3: 1 bis 3	☐	02 Pkt.
	4: weniger als 1	☐	00 Pkt.
Gehen auf Oberfläche:	1: keine Schwierigkeiten auf sämtlichen Oberflächen	☐	05 Pkt.
	2: geringe Schwierigkeiten auf unebenem Terrain, Treppen, Neigung, Leiter	☐	03 Pkt.
	3: große Schwierigkeiten auf unebenem Terrain, Treppen, Neigungen, Leiter	☐	00 Pkt.
Gangabnormalität:	1: keine, leichte	☐	08 Pkt.
	2: augenscheinlich	☐	04 Pkt.
	3: erhebliche	☐	00 Pkt.
Saggitale Bewegung:	1: normal, leichte Einschränkung. (30° oder mehr)	☐	08 Pkt.
	2: mäßige Einschränkung (15°-29°)	☐	04 Pkt.
	3: starke Einschränkung (weniger als 15°)	☐	00 Pkt.
Hinterfußbewegung (Inversion/ Eversion):	1: normal, oder leichte Einschränkungen (75%-100% von normal)	☐	06 Pkt.
	2: mäßige Einschränkungen (25%-74%)	☐	03 Pkt.
	3: massive Einschränkungen (weniger als 25%)	☐	00 Pkt.
Gelenk-Hinterfuß-Stabilität (ap, varus/valgus)	1: stabil	☐	08 Pkt.
	2: definitiv instabil	☐	00 Pkt.
Achse:	1: gut plantigrader Fuß, Gelenk-Hinterfußachse norm.	☐	10 Pkt.
	2: ausreichend plantigrader Fuß, um einige Grad der Gelenk-Hinterfußachse abweichend o. Symptome	☐	05 Pkt.
	3: nicht plantigrader Fuß, erhebliche Abweichung der Gelenk-Hinterfußachse mit Symptomen	☐	00 Pkt.

Adnex III (AOFAS Midfoot Score)

Zentrum für Fuß- und Sprunggelenkschirurgie Rummelsberg / Nürnberg

American Orthopaedic Foot and Ankle Society (AOFAS) Score

Mittelfuß Sektion / Midfoot Section
(Validierte deutsche Version, max. 100 Punkte)

Schmerz:	1: kein	☐	40 Pkt.
	2: leicht, gelegentlich	☐	30 Pkt.
	3: mittelmäßig, täglich	☐	20 Pkt.
	4: heftig, fast immer	☐	00 Pkt.
Funktion:	1: keine Einschränkungen, keine Stütze/ Hilfe	☐	10 Pkt.
	2: keine Einschr. bei den tägl.Aktivitäten, Einschr. bei Freizeitakt., keine Hilfen	☐	07 Pkt.
	3: Einschr. bei den tägl. Aktivitäten/ Freizeitakt, Stock	☐	04 Pkt.
	4: starke Einschr. bei den tägl. Aktivitäten, Freizeitaktivitäten, Gehstütze, Krücke, Rollstuhl	☐	00 Pkt.
Schuhwerk:	1: modische Konfektionsschuhe ohne Einlagen	☐	05 Pkt.
	2: Konfektionsschuhe mit Einlagen	☐	03 Pkt.
	3: orthopädische Schuhe	☐	00 Pkt.
Gehstrecke (in Blocks):	1: mehr als 6	☐	10 Pkt.
	2: 4 bis 6	☐	07 Pkt
	3: 1 bis 3	☐	04 Pkt.
	4: weniger als 3	☐	00 Pkt.
Oberfläche:	1: keine Schwierigkeiten auf sämtlichen Oberflächen	☐	10 Pkt.
	2: geringe Schwierigkeiten auf unebenem Terrain, Treppen, Neigung, Leiter	☐	05 Pkt.
	3: große Schwierigkeiten auf unebenem Terrain, Treppen, Neigungen, Leiter	☐	00 Pkt
Gangabnorm:	1: keine, leichte	☐	10 Pkt.
	2: augenscheinlich	☐	05 Pkt.
	3: erhebliche	☐	00 Pkt
Achse:	1: gut plantigrader Fuß, Mittelfußachse ausgerichtet	☐	15 Pkt
	2: ausreichend plantigrader Fuß um einige Grad in der Mittelfußachse abweichend, keine Symptome	☐	08 Pkt.
	3: schlecht, non plantigrader Fuß, erhebliche Abweichung der Mittelfußachse, Symptome	☐	00 Pkt.

2

Adnex IV (Numeric Rating Scale)