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**MICROVASCULAR  
RECONSTRUCTION OF  
TRAUMATIC COMPOUND BONE  
AND SOFT TISSUE DEFECTS OF  
THE TIBIA AND ANKLE**

LONG-TERM PATIENT-REPORTED OUTCOMES

**Jussi Repo**

ACADEMIC DISSERTATION

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*To Meri and Kevin*





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## **LIST OF ORIGINAL PUBLICATIONS**

This thesis is based on the following original articles referred to in the text by their Roman numerals:

- I Repo JP, Tukiainen E, Roine RP, Ilves O, Järvenpää S, Häkkinen A. *Reliability and validity of the Finnish version of the Lower Extremity Functional Scale (LEFS)*. Disabil Rehabil. 2016: In press.
- II Junnila J, Repo JP, Mustonen A, Tukiainen E. *Treatment of compound tibial fracture with free osteomuscular latissimus dorsi scapula flap*. J Reconstr Microsurg. 2015;31(3):217-224.
- III Repo JP, Barner-Rasmussen I, Roine RP, Sintonen H, Tukiainen E. *Treatment of compound tibia fracture with a microvascular latissimus dorsi flap and the Ilizarov technique: a cross-sectional study of long-term outcomes*. J Plast Reconstr Aesthet Surg. 2016;69(4):524-532.
- IV Repo JP, Barner-Rasmussen I, Roine RP, Sintonen H, Tukiainen E. *Role of free iliac crest flap in foot and ankle reconstruction*. J Reconstr Microsurg. 2016;32(5):386-394.

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## ABBREVIATIONS

ALT	anterolateral thigh flap
AO	Arbeitsgemeinschaft für Osteosynthesefragen
AOFAS	American Orthopaedic Foot & Ankle Society
ASES	American Shoulder and Elbow Surgeons
BMP	bone morphogenic protein
CI	confidence interval
DASH	Disabilities of the Arm, Shoulder, and Hand
EQ-5D	EuroQol 5-Dimensions instrument
FIT	Frequency Intensity Time
HRQoL	health-related quality of life
ICC	intraclass correlation coefficient
ICD	International Classification of Diseases
LD	latissimus dorsi
LEFS	Lower Extremity Functional Scale
MCID	minimal clinically important difference
MRSA	methicillin-resistant <i>Staphylococcus aureus</i>
mSv	millisievert
N/A	not available
NPWT	negative-pressure wound therapy
ODI	Oswestry Disability Index
ORIF	open reduction internal fixation
PRO	patient-reported outcome
SD	standard deviation
SEM	standard error of measurement
SF-36	Short Form – 36 Health Survey
THL	National Institute for Health and Welfare
VAS	Visual Analog Scale
VAS-FA	Visual Analog Scale Foot and Ankle
15D	15-dimension HRQoL instrument

## ABSTRACT

### **Background**

Treatment of extensive compound fractures with bone and soft tissue defects, and sequelae of prolonged complications are challenging for the reconstructive surgeon. The treatment aims to achieve optimal function and elevate the health-related quality of life (HRQoL). Different microvascular reconstructive techniques may have a significant impact on the functional outcomes and HRQoL. However, the literature has a paucity of data on the long-term patient-reported outcomes after vascularized bone flaps and free muscle flaps together with distraction osteogenesis are used in compound tissue reconstruction in the tibia and ankle regions.

The objective of this study was to assess the reliability and validity of the new Finnish version of the Lower Extremity Functional Scale (LEFS) among foot and ankle patients. The reliability and long-term outcomes of free osteomuscular latissimus dorsi scapula flap in reconstruction of compound tibial fractures were evaluated. Also examined were the reliability and long-term outcomes of the combined method of free latissimus dorsi flap and the Ilizarov technique in the treatment of extensive compound tibial fractures. Finally, the reliability and outcomes of the free iliac crest flap in foot and ankle reconstruction were investigated.

### **Methods**

The LEFS underwent translation and cross-cultural adaptation into Finnish and was thereafter validated and psychometrically tested among 165 patients who had undergone surgical management of various musculoskeletal pathologies of the foot and ankle. The Finnish version of the LEFS was used in Study III. The main study population consisted of various patient groups who had undergone foot and ankle or tibial reconstruction using microvascular techniques due to extensive compound bone defects at Helsinki University Hospital, a level I trauma and academic referral center. Consecutive patients were recorded prospectively before the hospital electronic database was established. A database search was conducted using procedure codes. The study design included a retrospective review of patient records and a cross-sectional assessment using patient-reported outcomes, as well as clinical and radiological assessments. HRQoL was compared to the age- and gender-standardized Finnish general population in Studies III and IV.

### **Results**

The Finnish version of the LEFS was confirmed to be a reliable instrument (internal consistency, 0.93; intraclass correlation coefficient, 0.96; standard error of measurement, 4.1). The LEFS had good validity (correlation with the 15D Mobility dimension,  $r=0.74$ ) to assess foot and ankle function.

The free osteomuscular latissimus dorsi scapula flap was successful in 25 of the 26 patients in treatment of compound tibial fracture or late complications. One flap loss led to transtibial amputation. Full weight bearing and clinical fracture site stability were achieved in a median of five months. The median time to complete radiographic bone union was seven months. Results of 14 patients from the cross-sectional evaluation using patient-reported outcomes together with radiological and

clinical assessments of 12 patients showed perfect to significantly impaired ankle function. Good shoulder function was found in most patients after harvesting a free osteomuscular latissimus dorsi scapula flap.

Three of the 16 patients required reoperation for minor flap complication and one patient needed late soft tissue reconstruction for partial flap necrosis when the microvascular latissimus dorsi flap was used in reconstruction of a compound tibial fracture. Ilizarov bone transport and tibia lengthening did not compromise the free muscle flap. Complete radiological bone union was achieved after a median of 23 months. The mean amount of distracted bone was 3.8 cm. The cross-sectional assessment of 11 patients showed adequate decent lower limb function and good shoulder function.

The free iliac crest flap is a reliable option in foot and ankle reconstruction. Full weight bearing and clinical stability of the reconstructed site were achieved in a median of five months. The median time to radiological bone union was 22 months. One pseudarthrosis was encountered. Transtibial amputation was required in one patient due to chronic pain. One patient required pedicled flap reconstruction in treatment of a late donor-site defect. Seven of the 13 patients participated in the cross-sectional assessment using patient-reported outcomes. The results showed functional outcomes of the reconstructed extremity and the donor site ranging from none to significant.

Patients' HRQoL was comparable with that of the general population using the free latissimus dorsi flap combined with the Ilizarov method in tibial reconstruction and in most patients using the free iliac crest flap in foot and ankle reconstruction.

### **Conclusions**

The Finnish version of the LEFS instrument is reliable and valid for assessing ankle function. The free latissimus dorsi scapula flap is a reliable technique in reconstruction of compound tibial defects of bone and soft tissue loss. The combined method of microvascular latissimus dorsi flap and the Ilizarov distraction osteogenesis is reliable in treating absolute bone loss with a massive soft tissue defect or infected non-union. The Ilizarov method is also reliable in correcting limb length discrepancy after microvascular reconstruction. Free iliac crest flap proved to be a reliable option in foot and ankle reconstruction. The overall long-term outcomes for the microvascular techniques studied here support their use in reconstruction of extensive compound defects in the tibia and ankle regions. The function of the reconstructed limb is usually good or acceptable considering the complexity and severity of these uncommon traumatic compound defects. Donor site morbidity is acceptable.

**Keywords:** bone lengthening, distraction osteogenesis, free flaps, free tissue flaps, latissimus dorsi, LEFS, limb salvage, lower extremity, Lower Extremity Functional Scale, Ilizarov technique, microsurgery, microsurgical free flaps, orthopedics, plastic surgery, quality of life, reconstructive microsurgery, reconstructive surgical procedures, scapula

## SUOMENKIELINEN TIIVISTELMÄ

### **Tausta**

Mikrokirurgisten hoitomenetelmien tavoitteena on paras mahdollinen toimintakyky sekä terveyteen liittyvä elämänlaatu laajojen avomurtumien sekä murtuman jälkeisten pitkittyneiden komplikaatioiden hoidossa. Kirjallisuudessa on niukasti tietoa siitä, miten potilas itse on kokenut pitkäaikaistuloksen mikrovaskulaaristen luu-lihassirteiden, pehmytkudossiirteiden sekä distraktio-osteogeneesin käytöstä säären ja nilkan alueen luu-pehmytkudosvaurioiden korjauksessa.

Tutkimuksen tavoitteena oli selvittää Lower Extremity Functional Scale (LEFS) -alaraajan toimintakykymittarin suomenkielisen käännöksen luotettavuutta ja validiteettia jalkaterän ja nilkan leikkausten jälkeisessä arvioissa. Tavoitteena oli myös arvioida mikrovaskulaarisen latissimus dorsi scapula -luu-lihaskielekkeen toimivuutta sääriluun avomurtumien ja niiden myöhäiskomplikaatioiden hoidossa. Lisäksi tutkimuksessa pyrittiin arvioimaan mikrovaskulaarisen latissimus dorsi (LD) -lihaskielekkeen ja Ilizarovin luunvenytystekniikan luotettavuutta ja pitkäaikaistuloksia laajan sääriluun avomurtuman hoidossa sekä luunpidennystä raajan pituseron korjauksessa. Viimeisenä tavoitteena oli tarkastella mikrovaskulaarisen suoliluunharjan etuosan luu-ihokielekkeen toimivuutta jalkaterän ja nilkan luu-pehmytkudosvaurioiden korjauksessa.

### **Menetelmät**

Ensimmäisessä osiossa LEFS-mittari käännettiin suomen kielelle kansainvälisten ohjeiden mukaisesti. Mittarin luotettavuus ja validiteetti testattiin 165 potilaalla, joille oli suoritettu jalkaterän tai nilkan leikkaus. Osatöiden II-IV otanta koostui kolmesta erilaisesta potilasryhmästä, joille oli suoritettu sääriluun, jalkaterän tai nilkan rekonstruktio laajan luu-pehmytkudosvaurion hoitona mikrokirurgisilla menetelmillä. Potilaat merkittiin ylös prospektiivisesti. Potilata etsittiin myös Helsingin yliopistollisen keskussairaalaan potilastietojärjestelmästä diagnoosi- ja toimenpidekoodeilla. Tutkimus sisälsi takautuvan potilastietokatsauksen, poikkileikkaustutkimuksen siitä miten potilas itse kokee sen hetkisen tilanteensa sekä kliinisiä ja radiologisia arviointoja. Terveyteen liittyvää elämänlaatua verrattiin osatöissä III ja IV ikä- ja sukupuolivakioituun suomalaisen verrokkiväestöön.

### **Tulokset**

Tulokset osoittivat, että suomenkielinen LEFS -alaraajan toimintakykymittari oli luotettava (sisäinen yhtenevyys, 0.96; toistettavuuskerroin, 0.96). Myös validiteetti (korrelaatio 15D-liikuntakyvyn ulottuvuuteen,  $r= 0.77$ ) osoittautui vahvaksi jalkaterän ja nilkan toimintakyvyn arvioimisessa leikkauksen jälkeen.

Mikrovaskulaarisen latissimus dorsi scapula -luu-lihaskielekkeen siirto onnistui 25 (25/26) potilaalla sääriluun avomurtuman ja myöhäiskomplikaatioiden hoidossa. Yhdessä tapauksessa kieleke menetettiin ja potilaalle tehtiin sääriamputaatio. Täysipainovaraus ja kliininen luun stabiliteetti saavutettiin viidessä kuukaudessa. Täydellinen radiologinen luutumisen kesti keskimäärin seitsemän kuukautta. Kokonaisuudessaan 14 potilaan itse kuvaama haitta sekä 12 potilaan kliinisi- radiologiset arvioinnit osoittivat nilkan toimintakyvyn vaihtelevan täydellisestä

oleellisesti rajoittuneeseen. Useimmilla potilailla saavutettiin hyvä olkapään toimintakyky siirteen ottokohdassa mikrokirurgista LD-scapula luu-lihaskielekettä käytettäessä.

Kun mikrovaskulaarista LD-lihaskielekettä käytettiin sääriluun avomurtuman hoidossa, 3/16 potilasta tarvitsi uusintaleikkauksen lievien kielekekomplikaatioiden takia. Yhdelle potilaalle kehittyi osittainen kielekkeen menetys, joka vaati pehmytkudoskorjauksen. Pehmytkudosrekonstruktion jälkeinen Ilizarovin luunvenytys ( $n = 11$ ) tai luunpidennys ( $n = 5$ ) eivät vaarantaneet LD-lihaskielekkeen verisuonisaumaa. Täysipainovaraus ja luun kliininen stabiliteetti saavutettiin keskimäärin viidessä kuukaudessa. Täydellinen radiologinen luutumisen kesti keskimäärin 23 kuukautta. Uutta luuta saatiin muodostettua keskimäärin 3,8 cm. Poikkileikkaustutkimuksen tulokset osoittivat alaraajan kohtalaista toimintakykyä ja olkapään hyvää toimintakykyä niillä 11 potilaalla, jotka osallistuivat toimintakykyarvioon.

Anteriorisen suoliluunharjan mikrovaskulaarisen luu-ihokielekkeen hyödyntäminen on luotettava menetelmä jalkaterän ja nilkan alueen kudostorjauksissa. Keskimääräinen aika radiologiseen luutumiseen oli 22 kuukautta. 1/13 potilaalla siirre ei luutunut. Toisella potilaalla päädyttiin sääriamputaatioon pitkäaikaisten kipuongelmien vuoksi. Yksi potilas tarvitsi pehmytkudosrekonstruktion siirteen ottokohdan ongelmien takia. Korjatun raajan ja siirteen ottokohdan toiminnalliset tulokset vaihtelivat ole mattomasta haitasta merkittävästi alentuneeseen toimintakykyyn kyselyihin vastanneiden potilaiden (7/13) välillä.

Elämänlaatu oli verrattavissa suomalaisen verrokkiväestöön potilailla, joille oli tehty LD-lihaskielekerekonstruktio yhdistettynä Ilizarovin menetelmään säären alueen kudospuutoskorjausleikkauksessa, sekä suurimmalla osalla potilaista, joilla anteriorisen suoliluunharjan mikrokirurgisen luu-ihokielekettä oli käytetty nilkan ja jalkaterän alueen luu-pehmytkudoskorjauksessa.

### **Johtopäätökset**

Suomenkielinen LEFS-alaraajan toimintakykymittari on luotettava ja validi jalkaterän ja nilkan leikkauksen jälkeisen toimintakyvyn arvioimisessa. Latissimus dorsi -lihaskieleke yhdistettynä osaan lapaluun ulkoreunaa on luotettava tekniikka sääriluun avomurtumien ja myöhäiskomplisoituneiden luu-pehmytkudospuutosten hoidossa. Ilizarovin menetelmä on luotettava tekniikka yhdistettynä LD-lihaskielekerekonstruktioon hoidettaessa säären laajoja traumaattisia luu-pehmytkudospuutoksia ja raajojen pituuseron korjaamisessa kielekerekonstruktion jälkeen. Mikrovaskulaarisen anteriorisen suoliluunharjan luu-ihokielekkeen käyttäminen osoittautui hyväksi vaihtoehdoksi jalkaterän ja nilkan alueen laajojen luu-pehmytkudospuutosten hoidossa. Toiminnalliset tulokset ovat yleensä hyvät, kun ottaa huomioon näiden harvinaisten traumaattisten kudospuutosten vaikeusasteen. Siirteen ottokohdan morbiditeetti on hyväksyttävä.

**Avainsanat:** alaraaja, distraktio-osteogeneesi, elämänlaatu, Ilizarovin menetelmä, LEFS, Lower Extremity Functional Scale, luunpidennys, mikrokirurgia, ortopedia, plastiikkakirurgia, rekonstruktiiivinen kirurgia, rekonstruktiiiviset leikkaukset, raajan pelastava kirurgia, siirteet



## **1. INTRODUCTION**

Both injury and sequelae of bone healing complications, such as infection and nonunion, are commonly associated with extensive bone defects of the lower extremity. Depending on the defect type and extent, the bone defect may also be accompanied by a significant loss of soft tissue (skin, subcutaneous tissue, muscle, nerves, and vessels). Reconstruction of bone and soft tissue requires intimate knowledge of anatomy and its regional structural differences, including tissue composition. The most suitable reconstructive option is chosen based on defect composition, extent, and location. Every effort should be made to restore the anatomical, physiological, and functional features of the extremity when limb salvage is attempted.

The development of microsurgical techniques has brought new possibilities in lower extremity reconstruction. Daniel and Taylor (1973) were the first to describe the technique of free flap transfer in 1973. The first free muscle flap based on the pectoralis muscle was harvested in the Research Laboratory for Replantation of Severed Limbs in Shanghai in July 1973 to reconstruct a traumatic forearm soft tissue defect (Research Laboratory for Replantation of Severed Limbs 1976). In 1976 in Bordeaux, Baudet performed the first microvascular latissimus dorsi flap reconstruction in treatment of a soft tissue defect of the knee region (Baudet et al. 1976). Two years later, compound lower extremity defects in two patients were successfully reconstructed using a free osteocutaneous iliac crest flap by Taylor and Watson (Taylor and Watson 1978).

The technique of distraction osteogenesis pioneered by Gavrilov Ilizarov has served for compensating bone loss, especially in long bones, and correcting limb length discrepancy (Ilizarov 1989a, Paley et al. 1989). Reconstructive surgeons combined the Ilizarov technique with microvascular soft tissue reconstruction, enabling treatment of massive tibial compound defects with extensive absolute tissue loss (Jupiter et al. 1991, Tukiainen et al. 1993, Lowenberg et al. 1996).

Further, in a 12-patient series by Allen and colleagues in 1994, traumatic compound tibial defects of bone and soft tissue loss were reconstructed using a free osteomuscular flap consisting of the latissimus dorsi muscle and the lateral border of the scapula nourished by the thoracodorsal pedicle (Allen et al. 1994).

These techniques and many others have enabled successful limb salvage where previously no alternative to amputation existed. Amputation rate of lower extremity Gustilo type III open fractures has decreased from 18.7% to 3.6% in the last 30 years (Gustilo et al. 1987, Tampe et al. 2014). Lower limb salvage can be expected to have an impact on functional capability and health-related quality of life (HRQoL). However, limited data are available on the effectiveness and long-term patient-reported outcomes of using vascularized bone transfers, vascularized bone flaps, and free soft tissue flaps together with distraction osteogenesis in compound tissue reconstruction of the tibia and ankle.

This work was initiated to evaluate the long-term outcomes of traumatic compound defect reconstruction of the tibia and ankle. The first study investigates the reliability and validity of the Finnish version of the Lower Extremity Functional Scale (LEFS). The second and third studies assess the outcomes of the microvascular combined osteomuscular latissimus dorsi scapula flap and the microvascular latissimus dorsi flap combined with Ilizarov distraction osteogenesis in reconstruction of compound tibial defects. The fourth study assesses the outcomes of the free iliac crest flap in foot and ankle reconstruction.

## 2. REVIEW OF THE LITERATURE

### 2.1 Epidemiology

Ankle and tibial fractures represent 13-25% of all fractures (Court-Brown and Caesar 2006, Somersalo et al. 2014). The annual rate of ankle and tibial fractures requiring inpatient treatment in the Finnish adult population can be estimated at around 1660 and 800 cases per 100,000 persons, respectively (Somersalo et al. 2014). Open fractures are characterized as fractures where the bone protrudes from the skin or a wound extends from the skin to the fractured bone. Approximately 2% of ankle fractures are classified as open fractures, whereas 23% of fractures of the diaphyseal tibia are of the open fracture type (Connelly et al. 2014, Bugler et al. 2015).

### 2.2 Etiology

Acquired bone defects are obtained after birth due to external and internal factors such as trauma, infection, and complications in bone healing.

Trauma is commonly divided into low-energy and high-energy categories. A low-energy trauma is caused by moderate impact to the extremity (e.g., falling on the same level). Fracture of the lower extremity due to low-energy trauma can include joint involvement, impaction, and fracture dislocation. A high-energy trauma is caused by high-impact injuries such as motor vehicle collision, industrial machine accidents, falling from heights, crush injuries, gunshot injuries, blasts, and combat injuries (Bartlett et al. 2000, Champion et al. 2003, Hettrich and Browner 2012). This kind of high-impact trauma frequently results in a large zone of injury, comminution, fragmentation, and extensive absolute bone loss. High-energy traumas frequently result in a severe open fracture, whereas low-energy fractures are most often less severe (Court-Brown et al. 2012, Bugler et al. 2015).

#### 2.2.1 Open fracture classification

Several open fracture classifications have been developed for surgeons. The most widely used is the Gustilo-Anderson open fracture classification (**Table 1**) (Gustilo and Anderson 1976, Gustilo et al. 1984). The Gustilo-Anderson open fracture classification published in 1976 (Gustilo and Anderson 1976) consists of three open fracture grades, I-III. The Gustilo-Anderson classification was later modified by Gustilo et al. to contain three additional subcategories (A, B, and C) for the grade III fracture (Gustilo et al. 1984).

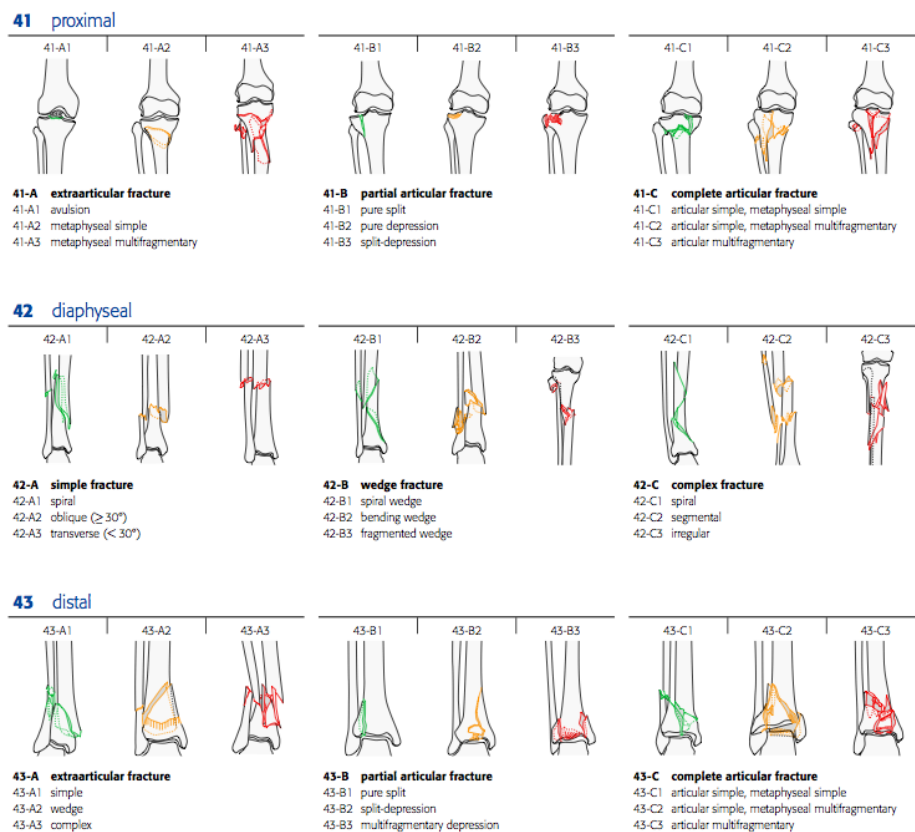
High-energy lower extremity trauma leads to Gustilo-Anderson type III open fracture in approximately half of the cases (MacKenzie et al. 2000). Altogether 27% of open fractures are Gustilo-Anderson type III fractures (Court-Brown et al. 2012). This type of open fracture has extensive soft tissue loss and/or damaged vasculature (Gustilo and Anderson 1976).

The comprehensive AO (Arbeitsgemeinschaft für Osteosynthesefragen) classification for fractures and dislocation has given further depth to fracture classification (AO Trauma). It has a separate description for tibial fractures (**Figure 1**). In Finland, the AO fracture and dislocation classification is often used together with the Gustilo-

Anderson open fracture classification. Even though these two classifications are the ones mostly used in Finland, others do exist (Byrd et al. 1985, Collins and Temple 1989, Suedkamp and Tschern 1993, Evans et al. 2010).

**Table 1.** Gustilo and Anderson open fracture classification.

Gustilo-Anderson grade	Definition
I	An open fracture with a wound less than one centimeter long and clean.
II	An open fracture, with a laceration more than one centimeter long without extensive soft tissue damage, flaps, or avulsions.
III	Either an open segmental fracture, an open fracture with extensive soft tissue damage, or traumatic amputation.
III A	Adequate soft tissue coverage of a fractured bone despite extensive soft tissue laceration of flaps, or high-energy trauma irrespective of the size of the wound.
III B	Extensive soft tissue injury with periosteal stripping and bony exposure. This is usually associated with massive contamination.
III C	Open fracture associated with arterial injury requiring repair.

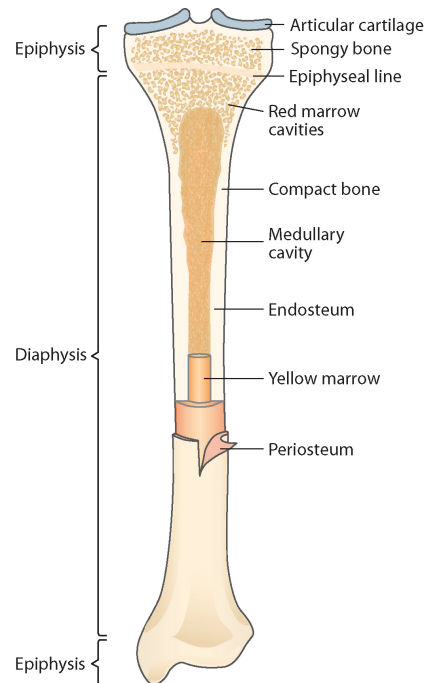


**Figure 1.** AO classification for tibia fractures (copyright AO Foundation. Published with permission from AO Foundation, Switzerland. Source: AO Trauma Reference, www.aofoundation.org).

### 2.3 Anatomy

Bone structure can be divided into cancellous and cortical bone. The cancellous, spongy, trabecular bone has a 3-dimensional mesh-like porous conformation. Cancellous bone is covered by the periosteum. Cortical bone has a compact structure and is much stronger than cancellous bone.

The lower leg comprises the tibia, fibula, ankle bones, foot bones, and soft tissues surrounding the bones. The tibia is a typical long bone that is divided into the diaphysis (tibial shaft), metaphysis, and epiphysis (**Figure 2**). The metaphysis is the wide part of a long bone between the diaphysis and the epiphysis. The epiphyseal and metaphyseal parts consist mainly of cancellous bone containing red marrow. The epiphysis is located at both ends of a long bone and is covered by cartilage plates that form the articular cartilages of joints.



**Figure 2.** Anatomy of the tibia.

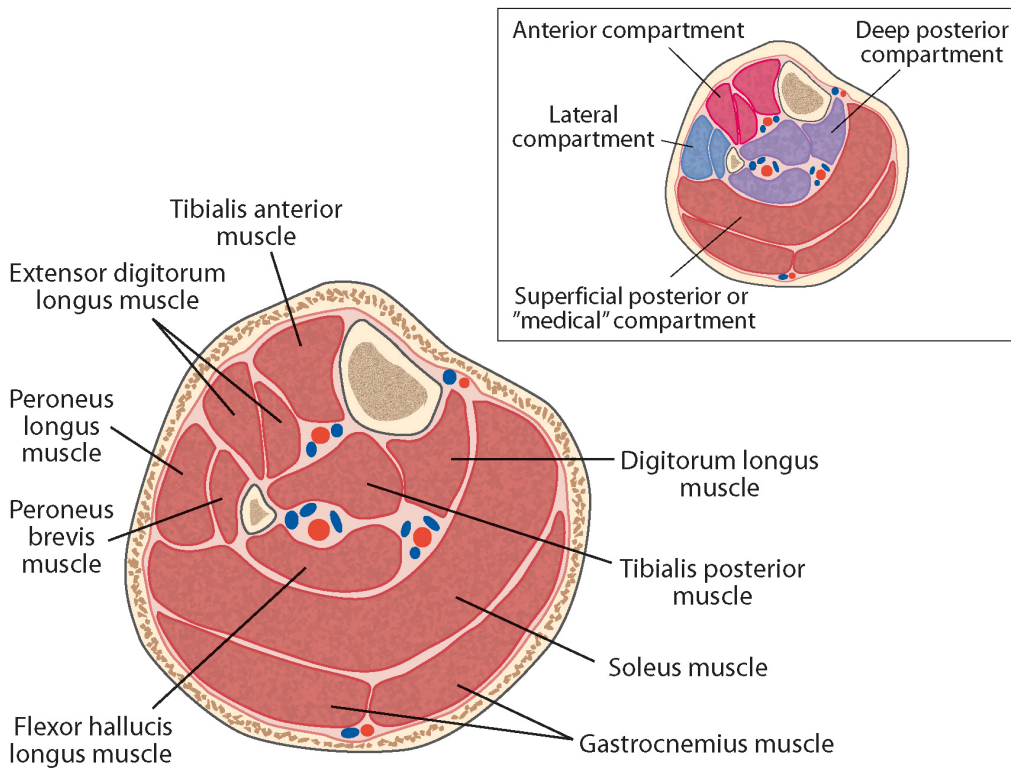
Lateral to the tibia is the slender and long fibular bone.

The popliteal artery divides into anterior and posterior tibial arteries and the peroneal artery. Drainage is achieved through superficial and deep veins.

Flat bones, such as the scapula and pelvic bones, are covered with a thin layer of cortical bone surrounding a mesh of cancellous bone.

Four fascial compartments separate the muscles of the leg (**Figure 3**). The anterior compartment contains nerves and vessels. The muscles of this compartment contract to create ankle dorsiflexion. The deep posterior muscle compartment contains nerves and vessels. It is responsible mainly for ankle plantar flexion and flexion at the big toe. The muscles of the superficial posterior compartment are also responsible for ankle plantar flexion and several functionally minor tasks. The lateral muscle compartment comprises the peroneus muscles, which evert the foot and have a weak role in plantar flexion.

The talocrural joint, also called the ankle joint, comprises three bones: the tibia, fibula, and talus (**Figure 4**). The ankle movement is closely related to the bones adjacent to the talus. The talus has articular surfaces with the calcaneus and the cuboid and navicular bones. Several ligaments stabilize the bones of the ankle region. Muscle tendons are attached to specific parts of the bone to provide ankle movement. The anterior section of the ankle requires flexible and padded tissue to protect local nerves and allow tendon movement (Gould and Shi 1995).

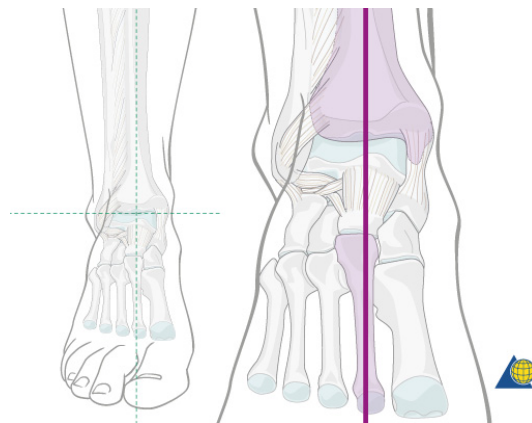


**Figure 3.** Cross-sectional view of the leg and its muscle compartments.

## 2.4 Tissue healing

### 2.4.1 Bone healing

New healthy bone can form in two ways. One way is through primary fracture healing, intramembranous ossification, where the new bone is produced without cartilage. The other way is through secondary bone healing, endochondral ossification, where bone forms through differentiation from chondroblasts, with bone cells (osteocytes) replacing the cartilage (Gilbert 2000). Fractures heal via coagulation, inflammation, and repairing and remodeling phases (Basi 2009). The inflammatory phase consists of vasodilatation and infiltration of inflammatory cells (monocytes and macrophages) (Schmidt-Bleek et al. 2012). The soft cartilaginous callus starts to harden and calcify when osteoblast and osteoclast



**Figure 4.** Correct alignment of the ankle. Tibia on the top in in contact with the fibula. Beneath the tibia is the talar bone. (copyright AO Foundation. Published with permission from AO Foundation, Switzerland. Source: AO Trauma Reference, [www.aofoundation.org](http://www.aofoundation.org)).

quantities rise at the fracture site (Ulma et al. 2012). In the last phase, fibroblast and collagen activation starts and bone resorption increases (Ulma et al. 2012).

#### **2.4.2 Complications in bone healing**

Injury type, including trauma energy level and zone of injury, has an impact on the bone healing process. Damaged periosteum together with soft tissue loss and impairment of limb vascularity often lead to problems in bone healing. The extremity can have pathophysiological situations due to diabetes, ischemia, or previous radiation therapy. Diabetes can cause microvascular impairment that delays bone healing (Perlman et al. 1999). Accompanying infection and patient-related factors such as smoking have a negative impact on bone healing (Kyrö et al. 1993, Perlman et al. 1999, Adams et al. 2001, Zura et al. 2016). Some evidence supports the presumption that malnutrition reduces bone healing (Hak et al. 2014). Non-steroidal anti-inflammatory drugs (NSAIDs) have been shown to alleviate the bone healing process and increase the risk for non-union by two-fold in long-bone fractures (Jeffcoach et al. 2014). However, a short-term period of NSAID use in the acute phase of healing is safe (Kurmis et al. 2012). The most important factors affecting bone healing are presented in **Table 2**.

**Table 2.** Most relevant factors affecting fracture healing.

Main factor	Subfactor	Reference(s)*
<b><i>Injury type</i></b>		
	Energy level (high/low)	Karlani et al. 2001, Zura et al. 2016 <sup>#</sup>
	Fracture type (open/closed)	Frey et al. 1994, Perlman et al. 1999, Salem 2012, Zura et al. 2016 <sup>#</sup>
	Zone of injury (extent)	Karlani et al. 2001, Oostenbroek et al. 2009, Salem 2012
	Degree of bone loss	Oostenbroek et al. 2009, Salem 2012
	Displacement	Ferrandez et al. 1991, Karlani et al. 2001, Robinson et al. 2004
	Fracture pattern	Robinson et al. 2004, Salem 2012
	Contamination	Karlani et al. 2001
	Bone blood supply	Frey et al. 1994
	Fracture location	Zura et al. 2016 <sup>#</sup>
	Soft tissue involvement (extent)	Gustilo et al. 1987, Salem 2012
	Vascular injury	Brinker et al. 1997
<b><i>Patient-related</i></b>		
	Infection	Struijs et al. 2007, Alemdaroğlu et al. 2009, Egol et al. 2012
	Substance abuse	Perlman et al. 1999
	Comorbidities	Zura et al. 2016 <sup>#</sup>
	NSAID treatment	Zura et al. 2016 <sup>#</sup>
	Metabolic disease	Cheung et al. 2016,
	Diabetes	Perlman et al. 1999, Zura et al. 2016 <sup>#</sup>
	Smoking	Kyrö et al. 1993, Perlman et al. 1999, Zura et al. 2016 <sup>#</sup>
	Age	Ferrandez et al. 1991, Robinson et al. 2004
	Gender	Zura et al. 2016 <sup>#</sup>
	Obesity	Zura et al. 2016 <sup>#</sup>
	Treatment cooperation	Perlman et al. 1999
<b><i>Treatment-related</i></b>		
	Primary treatment	Egol et al. 2012
	Treatment method	Karlani et al. 2001, Salem 2012, Zura et al. 2016 <sup>#</sup>
	Treatment timing	Fischer et al. 1991
	Treatment complications	Egol et al. 2012
	Compartment syndrome and fasciotomy	Reverte et al. 2011

NSAID, non-steroidal anti-inflammatory drug; BMI, body mass index, \*Level IV Studies; # Level III Study

### ***Infection***

Osteomyelitis is a bacterial infection of the bone that causes destruction through several different processes (Mynter 1889). Osteomyelitis can be caused by open fractures with impaired soft tissue vasculature and a damaged periosteum after trauma, infected foreign material (fixation material or endoprostheses), and impaired vasculature due to diabetes or through a hematogenous spreading of an infectious agent (Lew and Waldvogel 2004, Harris et al. 2009, Schmidt et al. 2014).



The most common pathogen causing osteomyelitis is *Staphylococcus aureus* (Dirsch and Almekinders 1993). A retrospective study by Ovaska et al. (2013), revealed that approximately 50% of monobacterial ankle fracture infections are caused by *Staphylococcus aureus*. According to the same study, other bacteria in monobacterial infections of ankle fractures are *Staphylococcus epidermidis* and *Pseudomonas aeruginosa*. Multibacterial ankle fracture infections occur in 33% of infected ankle fractures and are caused by *Staphylococcus aureus*, *Staphylococcus epidermidis*, and *Enterococcus faecalis* (Ovaska et al. 2013).

At Helsinki University Hospital, antibiotic treatment in open fractures is started with a combination of Cefuroxime and Metronidazole after taking a bacterial sample from the wound (oral information from Inka Liesmaa, a specialist in infectious diseases at Helsinki University Hospital). If the patient has diabetes, antibiotic treatment begins with Meropenem. The antibiotic treatment lasts at least seven days. Every case is considered uniquely and the antimicrobial treatment is adjusted after the results from bacterial samples are available. Open fractures are usually multibacterial and comprise mainly *Streptococci*, *Enterococci*, *Escherichia coli*, and soil bacteria. When osteomyelitis is suspected, a bacterial sample is taken from the bone. Antibiotic treatment is chosen based on the bacterial sample results. The duration of antibiotic treatment is usually from six weeks to one year. Mycobacterial osteomyelitis must be treated with antibiotics for two years.

A study at the Leicester Trauma Unit, Leicester, UK, showed that methicillin-resistant *Staphylococcus aureus* (MRSA) carriers have a 2.5-fold risk for MRSA wound infection relative to a healthy control population (Shukla et al. 2009). MRSA cases have been increasing in certain parts of Finland for the past 20 years, with occasional epidemic outbursts (Kotilainen et al. 2003, Laine et al. 2013). Further, a retrospective cohort study of 189 patients with 202 open fractures treated at the Pittsburgh Medical Center, Pennsylvania, USA, found that 25% of infected open fractures were positive for MRSA (Chen et al. 2013). Rare cases of vancomycin-resistant enterococcus osteomyelitis have been reported (Holtom et al. 2002). However, generalization to Finnish centers cannot be done due to the fact that the MRSA problem is much less severe in Finland.

In prolonged cases of osteomyelitis unresponsive to antibiotic treatment, bone necrosis may require radical resection of bone and bone reconstruction together with antibiotic treatment (Lew and Waldvogel 2004, Parsons and Strauss 2004).

### **Non-union**

Extensive open fracture causes local musculoskeletal inflammation that impairs tibia fracture healing and can lead to delayed union or non-union (Hurtgen et al. 2016). Non-union may be also referred to as pseudarthrosis. Non-union is diagnosed through patient history and medical records, clinical examination (fracture stability), and radiographic imaging. The radiographs usually show open fracture lines and absence of definitive callus. There are two different types of non-union: hypertrophic and atrophic (Naimark et al. 1981).

**Hypertrophic non-union** can be seen where callus has formed, but the bridging of the fracture has failed. Hypertrophic non-union is usually caused by improper immobilization or failure of fixation material (Xu et al. 2015).

In **atrophic non-union**, there is no callus formation. Atrophic non-union may occur in cases where the fracture site has extensive fragmentation with impaired vasculature. Open fractures, comminuted fractures, and fractures that have less than 25% cortical consistent bone are more prone to atrophic non-union than closed fractures (Antonova et al. 2013, Fong et al. 2013). Infection increases the risk for non-union (Struijs et al. 2007, Egol et al. 2012). Other risk factors for non-union include patient-related factors such as smoking, diabetes, and alcoholism (malnutrition and non-compliance) (Kyrö et al. 1993, Perlman et al. 1999, Adams et al. 2001, Zura et al. 2016).

#### **Malunion**

After a fracture has healed, the position of the bone may not be anatomically optimal. Permanent change in the bone alignment due to primary malalignment or failure in osteosynthesis may lead to functional impairment (Engsberg et al. 2014). Malalignment results in unbalanced stresses to weight-bearing surfaces of the joints, increasing the risk of chondral damage.

#### **2.4.3 Wound healing**

Wound healing is the repairing mechanism of tissues due to a wound of internal or external etiology. The extent of the wound surface influences the wound healing process. Traumatic events can cause either open or closed wounds. Closed wounds include contusion and comminution of tissues without skin involvement.

A tissue wound sets off a biochemical cascade. The wound healing process is divided into three separate overlapping phases: inflammation, proliferation, and maturation (Edington 1992, Werner and Grose 2003). The first aim of wound healing is to control bleeding, i.e. to achieve hemostasis. The second aim of wound healing is to fill the wound with new granulation tissue in the proliferative phase. In the last phase, the maturation phase, the tissue is remodeled. A similar healing process is activated in all wounds.

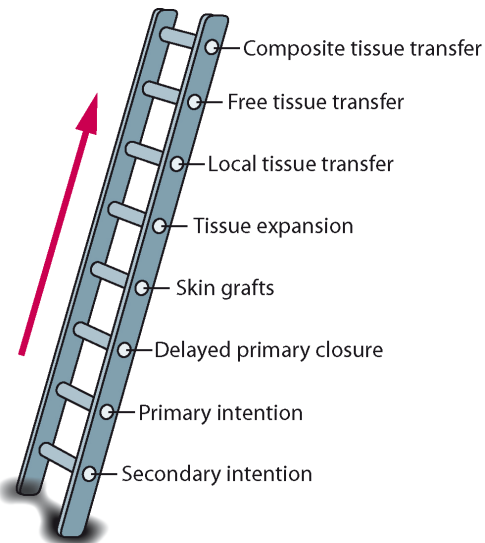
#### **2.4.4 Complications in wound healing**

Normal wound healing can be disturbed due to several factors, including comorbidities, infection mechanical forces, postoperative complications, and nutrition (Schweinberger and Roukis 2009). Diabetes causes microangiopathy, negatively affecting the wound healing process. Atherosclerosis obliterans can cause macroangiopathy, which decelerates wound healing. Infectious exogenous agents can infect the wound, causing soft tissue damage and disturbances in wound healing. In addition, endogenous mechanical forces after surgical procedures, such as hematoma or seroma, can lead to wound rupture. Hematoma is believed to also offer infectious pathogens a good environment for colonization, leading to further problems in wound healing. Scar problems are rare in lower extremity reconstruction. Management of scars includes pressure-dressing treatments (Wolfram et al. 2009).

## 2.5 Reconstructive ladder

Mathes and Nahai introduced the concept of the reconstructive ladder (**Figure 5**) in 1982 (Mathes and Nahai (1982)). It was designed to clarify the options in wound closure and reconstructive surgery. In this scheme, the surgeon should always consider the simplest possible approach to a reconstructive problem. The surgeon should move up the ladder towards more demanding techniques only if necessary.

On the first rung of the ladder lies **secondary intention**, which means healing through granulation from the bottom of the wound by leaving the wound open. The wound can be closed also with **primary intention**. If primary closure is not possible due to infection, swelling, or wound extensiveness, the wound can be allowed to heal by **delayed primary closure**.



**Figure 5.** The reconstructive ladder. Modified from Woong JW. J Korean Fract Soc. 2010;23(2):251-256.

On the next rung is autologous **skin grafting** (split-thickness and full-thickness). **Tissue expansion** can provide soft tissue for defect coverage. Next is **local tissue transfers**, including **local flaps** (transposition, rotation, and advancement flaps) and **pedicular flaps**. **Free tissue transfers** lie on the upmost rung of the reconstructive ladder. These tissue transfers are indicated in cases where other options are unavailable or the defect is too extensive to cover using local flap options. In addition, **composite tissue transfers** offer options in treatment of compound tissue defects. Basic plastic surgical free flap approaches are presented in **Table 3**.

The reconstructive ladder was further modified to form the reconstructive elevator (Gottlieb and Krieger 1994). The reconstructive elevator illustrates the possibility to freely move up and down the reconstructive ladder to select the reconstructive technique most likely to result in an optimal outcome in contrast to choosing the simplest method. Nowadays, the most appropriate method is preferred over the simplest method.

**Table 3.** Basic plastic surgical free flap approaches.

### Free flaps

- fasciocutaneous
- musculous
- osseous

### Composite tissue transfers

- musculocutaneous
- osteofasciocutaneous
- osteomusculous
- osteomusculocutaneous

## **2.6 Soft tissue reconstruction**

Soft tissue defects require debridement of pathological tissue (Hallock 2013). Compartment syndrome is associated with open tibial fractures. Fasciotomy is performed through the soft tissues to remove muscle compartment pressure. All devitalized soft tissues are then debrided. Superficial defects of the lower leg region can be reconstructed using split-thickness skin grafting (Kirsner et al. 1997). Court-Brown et al. (2015) retrospectively analyzed 3297 consecutive open fracture cases and found that primary split-skin grafting was used in the management of 5.6% open fractures, whereas 7.2% of patients underwent flap reconstruction. Local fasciocutaneous and muscle flaps are viable reconstructive options in more extensive defects. In cases where local flap options are unavailable due to extent of defect or location or vital structures such as nerves, tendons, and vessels being exposed, free fasciocutaneous and muscle flaps are frequently used to reconstruct soft tissue defects of the tibia and distal third of the leg (Gould and Shi 1993, Chang and Robb 2000, Hollenbeck 2010).

### **2.6.1 Negative-pressure wound therapy**

Negative-pressure wound therapy (NPWT) uses subatmospheric pressure through a vacuumed dressing to promote wound healing, increasing wound bed granulation and contracting the wound (Chariker et al. 1989). Recently, it has become a widely used technique in soft tissue reconstruction (Parrett et al. 2006). It often allows local flap reconstruction and the use of free flaps to be avoided as it contracts the wound (Schlatterer et al. 2015). The NPWT makes wound care easier because frequent daily changing of the wound dressing is not necessary. In cases of extensive compound defects, the use of NPWT buys the surgeon time to plan the definitive reconstruction using free flaps or vascularized bone transfers in cases of extensive bone and soft tissue defects (Rezzadeh et al. 2015). During NPWT the wound is covered and isolated, protecting it from nosocomial bacteria (Sandy-Hodgetts and Watts 2015).

### **2.6.2 Timing of soft tissue reconstruction**

The timing of the reconstruction depends on several factors. Trauma patient's overall status may require damage control procedures before any further measures are taken with tissue reconstruction. Early debridement of contaminated or necrotic tissue and removal of non-bleeding bone fragments may lead to better later reconstructive outcomes and prevent infection and non-union (Wan et al. 2013).

Godina et al. (1986) suggested that microsurgical reconstruction should be done within 72 hours of the injury in Gustilo grade IIIC fractures (Godina et al. 1986). Free flap reconstruction after 72 hours increases the risk of postoperative venous thrombosis (Khouri et al. 1998). Webb et al. (2007) declared that the timing of the soft tissue reconstruction does not have any impact on the outcome. Starnes-Roubaud and colleagues compared the lower extremity free flap reconstruction in a 51-patient retrospective series (Starnes-Roubaud et al. 2015). They found no association between timing and outcome. Steiert et al. (2009) clarified that using NPWT enables soft tissue reconstruction later than 72 hours from primary trauma. However, NPWT for more than 7 days increases the risk for infection and amputation (Hou et al. 2011).

### **2.6.3 Skin grafting**

Skin grafting can be divided into full-thickness and split-thickness grafting. The skin grafting is used in treatment of defects consisting of only skin or both skin and subcutaneous tissues, or in covering the muscular part of muscle flaps. In lower extremity reconstruction, mainly split-thickness skin grafts are used with meshing of 1 to 1.5 ratios or more to allow coverage of a larger defect area (Pu and Levine 2013). Split-thickness skin grafting can be used in regions where there are no vessels, bone, or nerves exposed. In skin grafting of infected chronic wounds, the wound bed undergoes debridement before the skin graft is applied. In some cases, maturation of the wound bed is warranted before covering the defect using a split-skin graft.

### **2.6.4 Local flaps**

There are several different options for raising a local flap in the lower leg. The most pertinent local flap options in lower leg reconstruction are reviewed in this section. Skin and fasciocutaneous rotation flaps can provide sufficient amounts of soft tissue for slightly deeper defects. Propeller flaps can be applied in selected cases to reconstruct soft tissue defects. They are raised together with a perforating vessel and a skin island. The flap is turned around 180 degrees to cover the defect. In extensive defects of the proximal and diaphyseal tibia, pedicled local muscle flaps, such as the gastrocnemius and soleus, are used (Hallock et al. 2013). In large defects with poor wound bed or exposed bone and tendons, the distally based peroneus brevis flap and the suralis flap are recommended techniques in ankle reconstruction (Hollenbeck et al. 2009, Chang et al. 2015, Ovaska et al. 2015). Free muscle flaps can be more suitable in reconstruction of the distal third of the leg due to their better esthetic and functional outcomes relative to local flap options (Chang and Robb 2000). Local flaps are usually insufficient for large defects.

### **2.6.5 Free fasciocutaneous flaps**

Here, the use of free fasciocutaneous flaps in reconstruction of lower leg soft tissue defects is reviewed. At present, the most frequently used free fasciocutaneous flap in lower extremity reconstruction is the free anterolateral thigh flap (ALT). Its advantages in lower leg reconstruction are durability, pliability, versatility, and similar tissue type (Hallock 2013, Yang et al. 2013, Bibbo et al. 2015). An additional advantage of the ALT is that the donor site can be closed directly, even when raising a larger flap. Other similar options include the free radial forearm, lateral arm, and groin flaps (Brownstein et al. 1977, Kaplan et al. 1998, Sofiadellis et al. 2012). Free fasciocutaneous flaps may be more reliable than free muscle flaps in traumatic lower extremity reconstruction (Sofiadellis et al. 2012). However, in larger soft tissue defects, such as Gustilo grade III fractures, the fasciocutaneous flap is usually insufficient to fill in the large 3-dimensional defect (Hallock 2013).

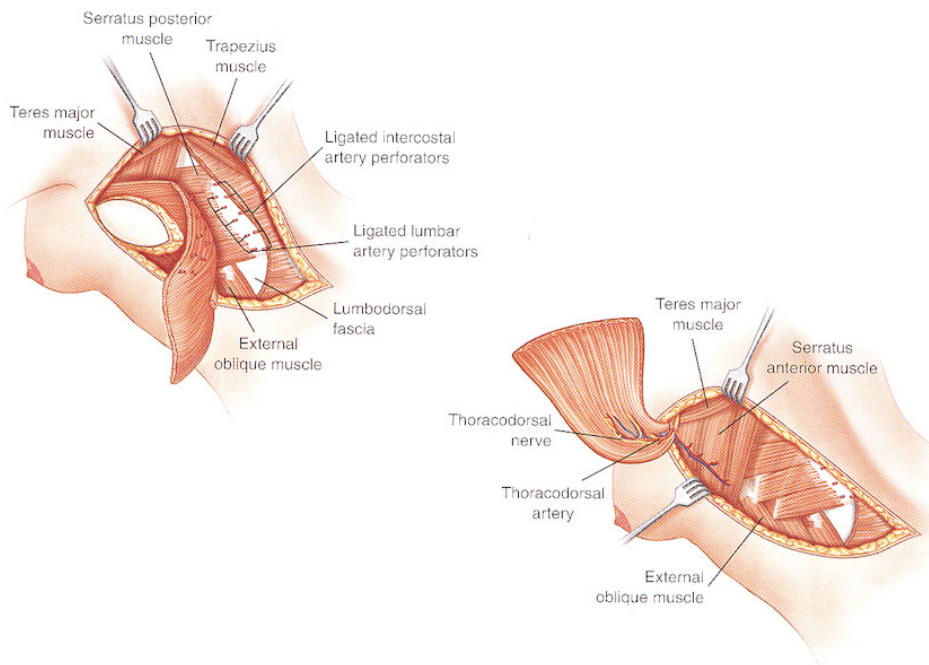
### **2.6.6 Free muscle flaps**

This section of the literature review introduces the most widely used methods of free muscle flap transfer in treatment of lower leg soft-tissue defects. The latissimus dorsi, gracilis, and rectus abdominis free muscle flaps are all useful in ankle and tibial reconstruction with equally low donor site morbidity (Salmi et al. 1995, Redett et al. 2000, Musharafieh et al. 2000, Vranckx et al. 2004, Koski et al. 2004, Baechler et al.

2010, Hollenbeck et al. 2010, Fischer et al. 2013, Kang et al. 2013). Radical resection of infected bone and free muscle flap reconstruction is a feasible option to evict infection (Kuokkanen et al. 2002, Lê Thua et al. 2015).

### **Free latissimus dorsi flap**

In 1976, two patients underwent free latissimus dorsi flap (**Figure 6**) reconstruction, one for a large back defect and the other for a soft tissue defect in the knee region (Baudet et al. 1976). Since then, the latissimus dorsi flap has gained popularity as a reconstructive option in extensive soft tissue defects. It is widely used also in the treatment of traumatic soft tissue defects in the tibial region (Knobloch et al. 2012, Sofiadellis et al. 2012, Fischer et al. 2013, Kang et al. 2013). Its virtues are the reliable, long, and relatively large-sized thoracodorsal vascular pedicle, large muscle bulk, and low donor site morbidity (Watson et al. 1979, Lee and Mun 2014).



**Figure 6.** Free latissimus dorsi flap. (copyright 2013 From *Reconstructive Surgery of the Lower Extremity* by Pu, Levine and Wei. Reproduced by permission of Taylor and Francis Group, LLC, a division of Informa plc.)

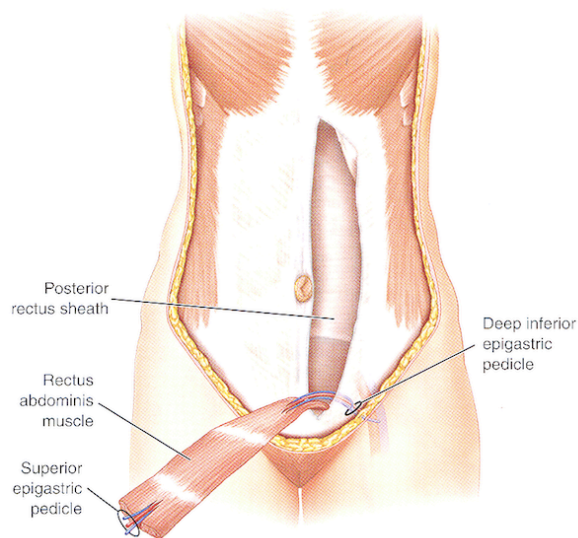
Raising only the latissimus dorsi muscle and covering it with split-skin grafting on the reconstructed site alleviates donor site morbidity (May et al. 1981). Shoulder function has been proclaimed to weaken after raising the free latissimus dorsi flap (Russell et al. 1986, Giordano et al. 2011). In a systematic review by Lee and Mun, free latissimus dorsi flap harvesting caused overall discomfort in 13.9% of the 46 patients (Lee and Mun 2014). Further, small proportions of patients suffered from weakness of the shoulder (3.4%) and limitations in sports activity (5.3%) and occupation (4.3%). Limitations in the shoulder range of motion were noted in 10.5% of patients and limitations in daily living in 11.1% (Lee and Mun 2014). Scant data exist on the true significance of raising the free latissimus dorsi flap on shoulder function.

### **Free gracilis flap**

The gracilis flap was first described by Pickrell (1952) in rectal sphincter reconstruction in 1952. It is still widely used as a pedicled flap for soft tissue reconstruction. The free gracilis flap is easy to harvest and donor site problems are rare (Lachiani et al. 2016). The free gracilis flap has proven reliable for reconstruction of Gustilo grade IIIB and IIIC open fractures (Redett et al. 2000). Its 7 cm pedicle and adequate muscle bulk is well suited for reconstruction of moderate-sized soft tissue defects and osteomyelitis of the lower limb (Kuokkanen et al. 2002, Vranckx et al. 2004). Vranckx et al. (2004) described only one flap loss in their 60-patient series of lower extremity reconstruction using the free gracilis flap.

### **Free rectus abdominis flap**

The free rectus abdominis muscle flap (**Figure 7**) has been used in lower extremity reconstruction by several authors (Musharafieh et al. 2000, Hammert et al. 2000, Xing-Quan et al. 2004). Its long configuration and pedicle make it a suitable option for soft tissue reconstruction, especially for long, thin defects in the lower leg. A study of 40 patients who underwent lower extremity reconstruction with a free rectus abdominis flap showed a success rate of 92.5% during an average follow-up of 3.6 years (Musharafieh et al. 2000). However, a study by Fischer revealed that the risk of delayed venous thrombosis is significantly higher using the free rectus abdominis flap than the free gracilis and the latissimus dorsi flaps (Fischer et al. 2013). The donor site fascia can be closed directly after raising the free rectus abdominis flap. However, the risk of donor site abdominal wall bulging and herniation negatively affects the overall feasibility of the free rectus abdominis flap (Kroll et al. 1995).



**Figure 7.** Free rectus abdominis flap. (copyright 2013 From *Reconstructive Surgery of the Lower Extremity* by Pu, Levine and Wei. Reproduced by permission of the Taylor and Francis Group, LLC, a division of Informa plc.)

## **2.7 Bone regeneration enhancement**

Here, the most widely used osteoconductive bone substitutes and osteoinductive growth factors are reviewed.

### **2.7.1 Osteoconductive bone substitutes**

Bone repair may require the use of bone substitutes (Calori et al. 2011). This section of the literature review focuses on the most important osteoconductive bone substitutes. The aim in the use of the bone substitute is to serve as a temporary scaffold, to increase osteogenesis, and to fill in bone voids (Drosos et al. 2015). Due to their osteoconductive properties, bone substitutes frequently serve as supplements for cancellous bone grafting or as carriers for other compounds that stimulate osteogenesis (Sen et al. 2007). However, the literature provides limited data on their efficacy. Here, the use of osteoconductive bone substitutes is reviewed in bone regeneration enhancement of the tibia and ankle.

Tricalcium phosphate is a mineral phosphoric acid calcium salt that can be used to substitute bone in selected cases where cancellous bone grafting is not possible, serving even in larger bone defects (Heaney 2002, Paderni et al. 2009). Nanocrystalline hydroxyapatite is a crystalline form of tricalcium phosphate and it can be indicated in large bone defects (Chimutenwende-Gordon et al. 2015).

Synthetic calcium phosphate cement has shown good results in treatment of complications due to *Staphylococcus aureus* infection after open-wedge tibial osteotomy (Seki et al. 2014). Calcium phosphate cement forms nanocrystalline hydroxyapatite (Campana et al. 2014). The hydroxyapatite provides the cement its osteoconductive properties (Campana et al. 2014).

Calcium sulphate combined with antibiotic filler appears to lower the need of reoperations and morbidity in cases of prolonged osteomyelitis with or without non-union (Beuerlein and McKee 2010). The calcium sulphate serves mainly as an antibiotic carrier.

Bioactive glass can be useful in substituting bone, especially in case of long bone infection (Aurégan and Bégué 2015). Aho et al. (2003) used bioactive glass combined with hydroxyapatite to reconstruct a defect of the tibia up to 20 cm in length after resection of fibrous dysplasia. In their 13-year follow-up, the defect had been filled with bone and connective tissue. Lindfors et al. (2010) studied the bioactive glass S53P4 in the treatment of osteomyelitis in 11 patients with prolonged osteomyelitis in the lower extremity or spine. Nine of the 11 patients were complication- or infection-free in a mean follow-up of 24 months. In a prospective study by Perna et al. (2011), the outcomes of tibial plateau fracture treatment using bioactive glass S53P4 proved to be similar to those of the autogenous bone graft at an 11-year follow-up. The existing evidence supports the use of bioactive glass as a bone substitute.

### **2.7.2 Growth factors**

Growth factors can be used to enhance bone healing. Growth factors stimulate growth in living cells (Steed 1997, Bolander 1992, Werner and Grose 2003, Bosetti et



al. 2007). The main types of growth factors used in clinical practice include bone marrow aspirate, bone morphogenic proteins, demineralized bone matrix, and platelet-rich plasma.

Bone morphogenic proteins (BMPs) are the most frequently used biomaterials to enhance bone union when conventional cancellous bone grafting has failed (Garrison et al. 2007). BMP-2 and BMP-7 have been used to increase osteoinduction. However, recent studies have shown an increased cancer risk for patients receiving BMPs (Nauth et al. 2009, Epstein 2014, Kelly et al. 2014). Thus, BMP use has been terminated in Finland.

Bone marrow aspirate (BMA) contains osteoprogenitor cells that are able to differentiate into osteoblasts, osteocytes, and bone-lining cells (Burwell et al. 1985, Marks and Odgren 2002). BMA can be obtained from several locations, such as the iliac crest, tibia, and calcaneus donor sites (Roukis et al. 2009, Hyer et al. 2013). BMA has been used to treat avascular necrosis and non-union (Hendrich et al. 2009).

## 2.8 Bone reconstruction

Several methods are available for bone reconstruction depending on the nature of the defect (**Table 4**). Bone reconstruction can be staged or performed simultaneously with the soft tissue reconstruction. No clear consensus of the optimal timing for bone reconstruction exists thus far. In cases where there is extensive soft tissue loss, the soft tissue coverage is usually established first or together with the bone reconstruction.

This literature review focuses on bone reconstruction of the tibia and ankle region after trauma and sequelae of bone healing complications. The most widely used methods in bone reconstruction are conventional autogenous cancellous bone grafting, bone substitutes, cancellous allografts, the Masquelet technique, distraction osteogenesis, vascularized bone transfers, or combinations of these. These methods are given special attention in this literature review. In addition, different methods for fixation can be used, e.g. Kirschner wire and external fixator as well as open reduction internal fixation methods (ORIF), including plates, reamed, or unreamed intramedullary nail and titanium elastic nail.

**Table 4.** List of techniques used in bone reconstruction.

---

Bone grafts
<i>Autografts</i>
<i>Cancellous bone grafts</i>
<i>Cortical bone grafts</i>
<i>Corticocancellous bone grafts</i>
<i>Allografts</i>
Induced membranes (the Masquelet)
Distraction osteogenesis
<i>Bone lengthening</i>
<i>Bone transport</i>
Endoprotheses
Vascularized bone transfers
Vascularized bone flaps

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### **2.8.1 Bone grafts**

Bone grafts used in modern clinical practice can be roughly divided into autogenous and allogeneous grafts (Finkemeier 2002). Further, the bone grafts can be divided into cancellous, cortical, or corticocancellous depending on their structural form. In this section, the focus is placed on bone auto- and allografts and their different forms.

Autogenous cancellous bone grafting is a classical method. At present, it is the most widely used method in bone reconstruction (Khan et al. 2005, Gómez-Barrena et al. 2015, Egol et al. 2015). It has traditionally been widely accepted that cancellous bone grafts can be used in bridging bone defects less than 4-5 cm in size (Zalavras et al. 2007, Bishop and Shin 2011, Myeroff and Archdeacon 2011). Cancellous bone grafts can be obtained from several distinct bony parts of the body. The anterior and posterior iliac crest and the femoral shaft are the most commonly used donor sites for conventional cancellous bone grafts (Myeroff and Archdeacon 2011, Baumhauer et al. 2014).

Cancellous bone grafts provide osteogenic bone material (Helm et al. 2001). Osteoinductive and osteoconductive properties of bone grafts make them suitable for treating small traumatic bone defects or non-union and for achieving arthrodesis (Myeroff and Archdeacon 2011, Herscovici and Scaduto 2012). After resection of articular cartilage of the joints, the autogenous bone grafting is a feasible option for achieving arthrodesis when enhancement of bone healing is warranted.

Cortical bone autografts are suitable in treatment of cases of bone defects where structural stability is warranted (Enneking et al. 1980). The cortical bone graft has superior compression durability relative to the cancellous bone graft (Parsch et al. 2008). However, the cortical graft enables osteoconduction, but has poorer osteogenic and osteoinductive features than the cancellous bone graft (Myeroff and Archdeacon 2011). It can be used for supportive purposes to achieve initial stability; however, during resorption and integration these properties diminish and thereafter the cortical bone graft acts mainly as a scaffold (Grenshaw 1992).

Corticocancellous autografts are harvested in one large structured bulk to allow reconstruction. This technique provides bone with a composition similar to that of the reconstructed site. It provides structurally stable osteoconductive material that has osteogenic and osteoinductive properties comparable with those of the cancellous bone graft (Myeroff and Archdeacon 2011). The bone graft can be placed directly on the defect. Graft fixation is usually performed through plates or Kirschner wire (K-wire). Most frequently, a tricortical block from the iliac crest is used for this indication (Finkemeier 2002).

Allogeneous bone grafts include cadaver bone grafts and donor allografts, such as the femoral head graft, that can be stored in biobanks for later use. Bone allografts are available in various forms: fresh, fresh frozen, and freeze-dried. Parenchymal cells including osteoblasts and osteocytes diminish in the process (Czitrom et al. 1985). However, allografts are osteoconductive and have mild osteoinductive properties, serving as scaffolds for bone growth, and growth factors may still persist in the graft (Campana et al. 2014). Fresh allografts have antigenic properties and are mainly

used in joint replacement procedures as osteochondral grafts. The fresh frozen allograft is less antigenic. The freeze-dried bone allografts have advantages in storage because they do not need low temperatures.

In traumatology, mainly structural allogeneous bone grafts are used to replace bone defects due to trauma (Pakarinen 2015). In Finland, there are at present 15 bone biobanks preserving over 1000 bone and connective tissue grafts yearly (Tammiruusu 2015).

### **2.8.2 Induced membranes (Masquelet technique)**

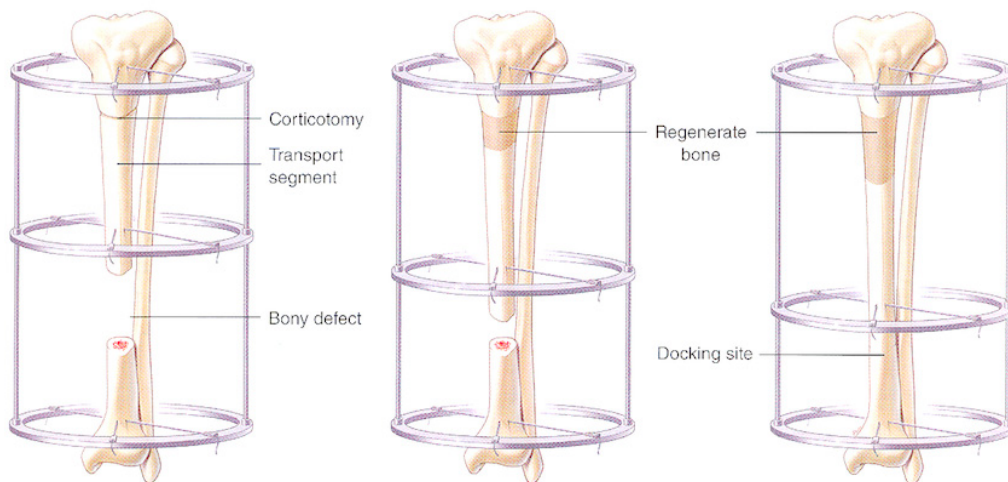
The Masquelet technique was introduced in 1986 (Masquelet and Begue 2010). This two-staged method of induced membrane is based on debridement of the defected bone and filling the defect with an antibiotic cement spacer (polymethylmethacrylate) (Masquelet and Begue 2010, Mauffrey et al. 2016). The spacer is thereafter covered with a soft tissue envelope. A biomembrane forms around the cement spacer. The cement spacer is removed in the second phase of the reconstruction within approximately one month. The generated cavity surrounded by the biomembrane is filled with cancellous bone grafting. The biomembrane is carefully preserved as much as possible because it contains among other things vascular endothelial growth factors to enhance bone graft healing (Aho et al. 2013). The optimal timing for bone grafting is proposed to be within one month of applying the cement spacer (Aho et al. 2013).

The Masquelet technique is used mainly in long bone reconstruction. A retrospective study of 84 patients showed that this technique is effective in treating posttraumatic diaphyseal defects (Karger et al. 2012). The study demonstrated bone union in 90% of cases. Masquelet has published good results in using flap reconstruction alongside bone reconstruction of bone defects up to 25 cm in size using the induced membrane technique (Masquelet 2003). Further, using the intramedullary nail to stabilize a tibial fracture and applying the Masquelet-induced membrane technique with or without soft tissue reconstruction is a feasible option for bone reconstruction (Aparid et al. 2010, Olesen et al. 2015).

### **2.8.3 Distraction osteogenesis**

The Ilizarov technique is based on an external ring fixator, osteotomy, and a slow distraction process (Ilizarov 1989a, 1989b). Modern modification of the device is the Taylor Spatial Frame (Smith & Nephew Inc., Memphis, TN, USA) that can have carbon fiber structure, allowing better radiological images and a lighter frame. The Ilizarov technique can be divided into bone transport and bone lengthening.

In bone transport (**Figure 7**), the bone is osteotomized from two sites and the bone segment slowly distracted towards the bone defect to diminish the void. The technique has been widely used in the treatment of non-unions (Paley et al. 1989, Yin et al. 2015, Xu et al. 2015). It has been used to reconstruct tibial defects of up to 22 cm in length (Abdel-Aal 2006).



**Figure 8.** The Ilizarov bone transport technique. (copyright 2013 From *Reconstructive Surgery of the Lower Extremity* by Pu, Levine and Wei. Reproduced by permission of Taylor and Francis Group, LLC, a division of Informa plc.)

Bone transport also serves for treating extensive absolute traumatic bone loss and infected bone defects of the tibia (Smrke and Arnez 2000, Chim et al. 2011, Hasler and Krieg 2012, Papakostidis et al. 2013, Fürmetz et al. 2016). The infected bone is first resected and then gradually replaced with healthy bone through the distraction osteogenesis process.

In bone lengthening, the osteotomy is performed on one site and the segment distal to the osteotomy site is slowly distracted distally. The osteotomy is usually performed in the distal or proximal end of the tibial shaft. Limb length discrepancy starting from 9 mm affects the lumbar spine, causing lower back pain (Kendall et al. 2014). Ilizarov bone lengthening is extensively used to treat posttraumatic limb length discrepancy (Sen et al. 2004, Vargas Barreto et al. 2007, Schep et al. 2009, Wagels et al. 2015). It can be used for secondary lengthening of long bones that have been initially shortened due to traumatic bone loss (Tukiainen and Asko-Seljavaara 1993, Rozbruch et al. 2006, Lavini et al. 2010). Distraction osteogenesis using an external ring fixator may be useful also in correcting malunion with limb length discrepancy (Paley 1990, Xu et al. 2015).

#### ***The Ilizarov technique combined with free muscle flap reconstruction***

In treatment of compound tibial fractures with extensive soft tissue and absolute bone loss or infected non-union, the Ilizarov technique can be combined with free flap reconstruction. Few papers have focused on the reliability and long-term outcomes of the combined technique of soft tissue coverage and Ilizarov distraction osteogenesis.

Jupiter et al. (1991) presented the combined technique of free flap reconstruction and Ilizarov bone transport in 1991. The free latissimus dorsi flap and bone transport have been described as a viable option in limb preservation of traumatic compound tibia defects (Tukiainen and Asko-Seljavaara 1993). Soft tissue coverage with a muscle flap before using the Ilizarov technique promotes bone healing by providing

well-vascularized tissue to the defected site (Lowenberg et al. 1996, Chim et al. 2011).

In a report by Chim et al. (2011), free flaps of various donor sites were used in tibia reconstruction followed by Ilizarov bone transport of the tibia in 28 patients who had suffered mainly grade IIIB ( $n = 18$ ) open fractures. The indications were infected non-union, acute traumatic absolute bone loss, soft tissue breakdown due to distraction osteogenesis, and soft tissue flap failure with exposed bone. The study showed that resection of infected bone and free flap reconstruction combined with the Ilizarov technique efficiently eliminate osteomyelitis (Chim et al. 2011).

Lower extremity reconstruction with muscle flap coverage and the Ilizarov technique is more cost effective than amputation (Lowenberg et al. 2013). However, Ilizarov distraction osteogenesis is a lengthy process. It stretches the tissues, can cause tissue degeneration and destructive joint contracture, and pin site problems such as infection and fistulation are frequent (Chim et al. 2011, Papakostidis et al. 2013). Further, late bone grafting can be required to enhance union of the docking site (Giotakis et al. 2007, Lowenberg et al. 2013). Rehabilitation programs are of high importance to prevent permanent restriction of joint movement. Further, Krappinger et al. (2013) showed that the Short-Form 36 Health Survey (SF-36) physical component is higher than in the general population at a mean of 17 months after removal of the external fixation after free flap reconstruction and bone transport. Their outcomes provided evidence that good functional capability is achieved when bone transport is combined with free muscle flap reconstruction.

Previous studies have shown that the distraction process does not compromise the microvascular flap (Jupiter et al. 1991, Hollenbeck et al. 2009).

#### **2.8.4 Open-wedge osteotomy**

Open-wedge osteotomy refers to a procedure in which the bone is osteotomized and wedged to correct alignment (Kerkhoffs et al. 2009). Open-wedge osteotomy serves in the treatment of tibial malunion (Giuseffi et al. 2015). Malunion after ankle arthrodesis can also require correction with this method (Casillas and Allen 2004). Open-wedge osteotomy is frequently used in the treatment of osteoarthritis-related deformities or other deformities, e.g. in metatarsal I, metatarsal V, the proximal tibia, and the radius.

#### **2.8.5 Endoprotheses**

Even though total endoprotheses and megaprotheses can be indicated in treatment of tibial or ankle pathologies, there are limited data on the outcomes for primary traumatic indications. Endoprotheses for the tibia have traditionally been indicated after resection of extensive bone malignancies, where large segmental defects are formed, however, they can also be used to reconstruct traumatic bone defects, especially on the proximal tibia. Total ankle replacement can be performed in selected patients with posttraumatic ankle arthritis (Kotela et al. 2014).

#### **2.8.6 Arthrodesis**

Mainly the tibiotalar arthrodesis is used to reconstruct posttraumatic bone deformities, where endoprosthetic surgery is not possible due to patient-related

factors (overweight, high activity, or ligament incompleteness), possibly leading to early failure of the prosthesis. Arthrodesis of talocalcaneal and/or Chopart joints might be a useful bone reconstruction method in cases where reconstruction of articular surfaces is complicated due to burst injuries or previous arthrotic changes (Scheepers 2012, Sharr et al. 2016).

### **2.8.7 Vascularized bone transfers**

Long-bone reconstruction has previously involved cancellous bone grafting or cortical bone grafts rather than vascularized transfers (Oner et al. 2013, Clarkson et al. 2013). The disadvantage of the non-vascularized bone graft is that in large defects it achieves union far less frequently than vascularized bone transfers (76% and 96%, respectively) (Pogrel et al. 1997). Moore et al. (1984) compared the biomechanics in dogs of autogenous vascularized bone transfers and conventional bone grafts by placing the reconstructive material into a foreleg resection bone defect of 6 cm in size. The contralateral foreleg served as a control. Nine dogs were assessed at three months with biomechanic torsion test. Vascularized bone transfers were much stronger (234%), tougher (483%), elastic (263%), and hypertrophied (246%) than the conventional bone grafts (Moore et al. 1984).

Vascularized bone transfers have good osteoconductivity, osteoinductivity, and osteogenicity, all promoting bone healing (Goldberg et al. 1987). Therefore, they are frequently used to reconstruct bone defects in the extremities (Yazar et al. 2004). The transfer is raised together with an artery and vein supplying the bone (vascular pedicle); these are anastomosed to a recipient artery and vein on the reconstructed site. The circulation through vessels of the transfer provides a good environment for the vascularized bone transfer to survive and well-vascularized bone to the defect site (Muramatsu et al. 2014). These transfers serve in cases of impaired vasculature or where other methods would not have succeeded or have failed (Gómez-Barrena et al. 2015). A special indication for vascularized bone transfers is infection due to their ability to provide vital bone after radical debridement (Yang et al. 2013).

Vascularized bone transfers have served for several indications in head and neck reconstruction, upper extremity reconstruction, spinal fusion, and treating femoral head osteonecrosis (Korompilias et al. 2011, Hartman et al. 2002, Ackerman et al. 2011, Repo et al. 2016a, Kokosis et al. 2016). In the present literature review, the focus is placed on tibia and ankle reconstruction using vascularized bone transfers.

#### ***Vascularized fibula transfer***

In reconstruction of the diaphyseal tibia, vascularized fibula transfer (**Figure 7**) is the workhorse in treatment of massive traumatic tibial defects due to its long and slender conformation suitable for long bone reconstruction (Takami et al. 1997, Chang et al. 1999, Lee et al. 2004, Yazar et al. 2004, El-Gammal et al. 2008, Cavadas et al. 2010, Gao et al. 2012, Özaksar et al. 2012, Yang et al. 2013, Taylor et al. 2016). El-Gammal et al. (2008) suggested that free vascularized fibula transfer would be more suitable in treatment of posttraumatic tibial defects less than 12 cm in size, whereas larger defects could benefit from bone transport. Other indications for the vascularized fibula transfer include extensive bone loss of the tibial shaft due to

posttraumatic infected non-union (Minami 1992, Tu et al. 2001, Yajima et al. 2004a). The vascularized fibula can be used in double-barrel formation to bulk its configuration. Even though the vascularized fibula is widely adopted in long bone reconstruction, several other techniques may be more suitable for bone reconstruction in other anatomical regions.

#### ***Ankle arthrodesis using vascularized bone transfers***

A recent retrospective study by Kodama et al. (2016) showed that ankle arthrodesis using a sliding vascularized tibial transfer after osteoarthritis secondary to osteonecrosis of the talus compares superiorly to non-vascularized grafts with regard to ankle functional outcome and bone union success. The vascularized tibial transfer is based on the peri-malleolar vascular pedicle. The vascularized fibular graft has also proven reliable for achieving pantalar arthrodesis in three separate series, with a total of 17 patients (Ring et al. 1999, Yajima et al. 2004b, Haddock et al. 2013). Further, Haddock et al. (2013) used the free lateral femoral condyle transfer for achieving tibiotalar arthrodesis. In addition, the vascularized iliac crest transfer has its advantages in pursuing ankle arthrodesis and is described in the following section.

#### ***Vascularized iliac crest transfer***

Hussl et al. (1989) applied the vascularized iliac crest to reconstruct a necrotic talus after failure of primary subtalar screw arthrodesis in the treatment of compound fracture. During a six-month follow-up revascularization of the transfer and full weight bearing without pain were noted. Bishop and colleagues used the vascularized iliac crest transfer to perform tibiotalar arthrodesis in four patients (Bishop et al. 1995). In their retrospective study, all patients achieved bone union and no transfers were lost.

In a German two-patient series, an aneurysmal bone cyst destructed the talus in a 54-year-old male (Hassenpflug et al. 2007). The defect was successfully reconstructed using the vascularized iliac crest, showing solid bone union at the two-year follow-up. The patient participated in sports activities and was satisfied with the result at the 10-year follow-up. The other patient, a 19-year-old, had a cystic lesion due to chondrosarcoma. The vascularized iliac crest was used for resection defect reconstruction. At the one-year follow-up, bone union was successful and the patient could walk unlimitedly, but had a slight restriction in the ankle range of motion.

Kraus et al. (2012) wrote a case report of a two-year-old child who had suffered a traumatic lawn-mower amputation of the calcaneus. The vascularized iliac crest transfer replaced a part of the calcaneus and was subsequently covered with a free latissimus dorsi flap. A fascia latae graft was used to reconstruct the Achilles tendon. At the one-year follow-up, the functional outcome was considered excellent. In addition, Roger et al. (2015) applied the vascularized iliac crest transfer for achieving subtalar arthrodesis in two patients after failure of other methods following calcaneal fracture. In both cases, successful arthrodesis with complete radiographic union was achieved.

### **2.8.8 Combining bone reconstruction techniques**

Management of bone defects often requires combining various bone reconstruction techniques. Here, the combinations of bone reconstruction methods are reviewed.

Capanna and colleagues introduced the technique of combining a vascularized fibula transfer and a massive allograft over two decades ago (Capanna et al. 1993). In this technique, the cortical graft is placed around the vascularized fibula. The fibular ends are then placed intramedullary inside the long bone or fixed with plates. This technique has been proven reliable in selected cases with extensive bone loss of the long bone (Aponte-Tinao et al. 2015, Halim et al. 2015). Vascularized bone grafts and the Ilizarov segmental bone transport can be applied in extensive absolute bone loss (Tukiainen and Asko-Seljavaara 1993). Distraction osteogenesis can be combined with the Papineau technique to reconstruct posttraumatic compound tibial defects of bone and soft tissue loss (Polyzois et al. 2010, Karargyris et al. 2014). The Papineau technique refers to open bone grafting where the wounds are packed with conventional cancellous bone grafting without soft tissue reconstruction (Brumback and Blick 1989). The Masquelet technique can be followed by the Ilizarov bone transport technique to reconstruct large bone defects (Peng et al. 2015).

### **2.8.9 Vascularized bone flaps**

Vascularized bone flaps consist of both bone and soft tissue components. Vascularized bone transfers, such as the free fibula, free iliac crest, free rib-bone, and the scapula transfer, can be raised as composite transfers with a muscular or fasciocutaneous part or skin island or both connected by the perforating vessels (Chepeha et al. 2010, Kanaya et al. 1996, Khouri et al. 1989, Melissinos et al. 1989, Momeni et al. 2006, Yajima et al. 2002, Yazar et al. 2002). These vascularized bone flaps of both bone and soft tissue are viable alternatives for ankle and tibia reconstruction, providing well-vascularized bone and simultaneous soft tissue coverage. The reconstructive approach should be chosen by considering the advantages and disadvantages of different methods (**Table 5**). In this section, the literature review focuses on different vascularized bone flap techniques used in lower leg reconstruction. The characteristics of the most widely used vascularized bone flaps based on general knowledge are presented in **Table 6**.

Raising the vascularized bone transfer with an accompanying soft tissue component allows one-stage reconstruction in treatment of extensive compound tissue loss of both bone and soft tissue. In addition, the reconstruction can usually be performed as a two-team procedure, reducing operative time by enabling one team to raise the flap while the other team prepares the recipient site for reconstruction.



**Table 5.** Advantages and disadvantages of different vascularized bone flaps in compound fracture reconstruction.

Flap type	Configuration	Bone			Soft tissue		
		Length	Width	Vascularity	Length	Width	Thickness
<i>Fibula flap</i>	Slender Long	+++++	++	++	++++	+++++	++
<i>Iliac flap</i>	Curvy Bulky	+++	+++++	++++	+++	++++	+++
<i>Serratus anterior-rib flap</i>	Slender Long Curvy	++++	+	++	+++	+++	++++
<i>Medial femoral condyle flap</i>	Small Cube-shaped	+	+	+++	+++	+	+
<i>Scapula flap</i>	Thin Slender Wide	++	+++	+++++	+++++	+++	+++++

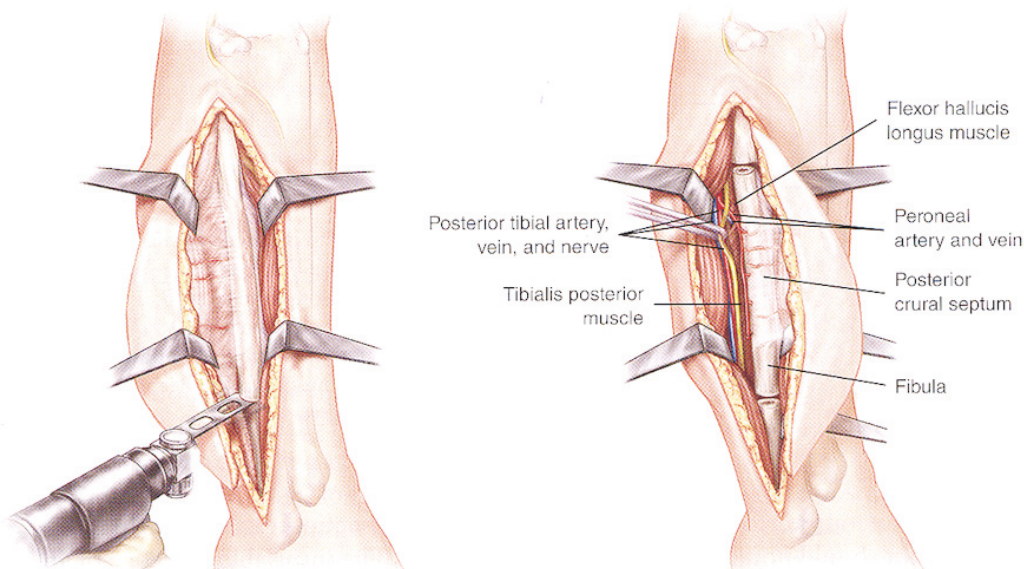
**Table 6.** Characteristics of the most widely used vascularized bone flaps (modified from *Reconstructive Surgery of the Lower Extremity 2013*).

Flap type	Dominant artery	Pedicle length (cm)	Artery diameter (mm)	Vein diameter (mm)	Flap size (cm)		Patient positioning
					Skin	Bone	
<i>Fibula flap</i>	Peroneal artery	2 (2-4)	1.5 (1.0-2.5)	3 (2-4)	Length: 10-32 Width: 4-14	Length: 16 (6-26) Thickness: 2 (1-3)	Supine decubitus
<i>Iliac flap</i>	Deep circumflex iliac artery	9 (8-10)	2-8 (2-3)	3.6 (2-5)	Length: 15 Width: 8-10	Length: 7-6 Width: 4-7	Supine decubitus
<i>Serratus anterior-rib flap</i>	Branch of thoracodorsal artery	5.5	2	3	Length: 12-16 Width: 8-9	Length: 12-16 Width: 0.7-1	Lateral decubitus
<i>Medial Femoral condyle flap</i>	Descending genicular artery	6.2-8	1.5	2	Length: 3-29 Width: 2-8	Length: 4 Width: 4	Supine decubitus
<i>Scapula flap</i>	Thoracodorsal artery	6-13	3-4	3-4	Length: 27 Width: 7	Length: 9 (4-12) Width: 2 (1-4)	Lateral decubitus

### **Vascularized fibula flap**

Free vascularized fibula flap was first described in 1975 by Taylor and colleagues (Taylor et al. 1975). The microvascular fibula is based on the peroneal artery and it can be raised with a fasciocutaneous island (**Figure 9**) or muscle component or both (Taylor et al. 1975, Lee et al. 1999, Beris et al. 2011, Hollenbeck et al. 2011). The fibula is preferred in long bone microsurgical reconstruction due to its suitable properties, including its diaphyseal straightness and long configuration. It serves in treatment of both primary traumatic compound defects and chronic infected non-union (Doi et al. 1995, Yang et al. 2013).

Wei et al. (1984) showed that one or two septocutaneous branches are able to supply a skin area of about 22-25 cm in length and 10-14 cm in width. However, Yang et al. (2013) demonstrated that a skin island of the vascularized fibula flap is sufficient to cover infected compound defects with soft tissue loss of up to 20 cm in length and 10 cm in width. A systematic review by Ling et al. (2012) revealed a mean donor site function of 85.5% using the American Orthopaedic Foot & Ankle Society (AOFAS) score. In the review, the most prevalent complication was delayed wound healing (17.4%). Partial skin island necrosis has been described to occur in 7% of patients (Ling et al. 2012, Pototsching et al. 2013).



**Figure 9.** Harvesting the vascularized fibular transfer. (copyright 2013 From *Reconstructive Surgery of the Lower Extremity* by Pu, Levine and Wei. Reproduced by permission of Taylor and Francis Group, LLC, a division of Informa plc.)

### **Vascularized iliac crest flap**

Taylor and colleagues introduced the free iliac crest flap (**Figure 10**) in 1979 (Taylor et al. 1979). Thereafter, this vascularized flap has gained wide popularity in head and neck as well as extremity reconstruction. The free iliac crest flap is based on the deep circumflex iliac artery and the accompanying veins (Sanders and Mayou 1979, Taylor et al. 1979). The vessels of the free iliac crest flap are relatively large, making it suitable for microsurgical procedures (Medalie et al. 2011, Pohlenz et al. 2012).

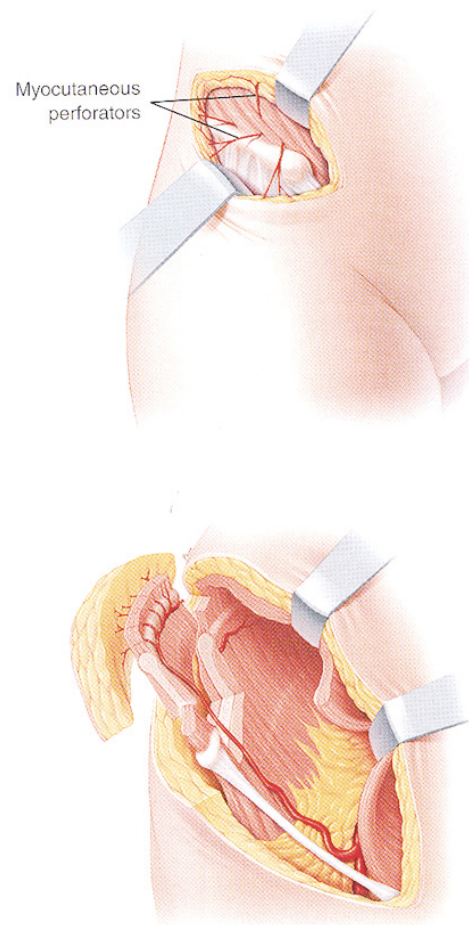
One of the virtues of the free iliac crest flap is that it can be raised with a pedicled musculous or cutaneous flap or both (Bergeron et al. 2007, Medalie et al. 2011). The one-stage technique allows a shorter operation time with a single donor site. Of all commonly used vascularized bone transfers, the iliac crest has shown the fastest bone union time (Taylor et al. 2016). However, the vascularized iliac crest flap has a bone length limitation of 12 cm (Wei et al. 1984). A study by Gomis indicated that iliac crest transfers larger than 12 cm are prone to donor site stress fractures (Gomis and Gomis 2010). In addition, raising a large graft may result in pain and herniation of the donor site (Valentini et al. 2009, Lyons et al. 2005).

The amount of soft tissue in the ankle is small and local flap options are frequently unavailable due to the extensive zone of injury or infection. **Figure 11** demonstrates the use of free iliac crest flap in ankle reconstruction. Only a few papers have previously described foot and ankle reconstruction using the free iliac crest flap.

The first report of use of the free iliac crest flap in heel reconstruction was published in 1987 (Stevenson et al. 1987).

This case report illustrated successful heel reconstruction of an 11-year-old girl who had as a result of a lawn-mower accident sustained loss of soft tissue padding and massive loss of the calcaneus. The patient was followed up for 31 months and full radiographic bone union and healing of the wound was noted.

In a study by Bishop and colleagues, four patients underwent ankle arthrodesis using the free iliac crest flap (Bishop et al. 1995). Partial soft tissue losses due to flap necrosis problems were encountered in all cases, necessitating a split-skin grafting reoperation. Peek and Giessler (2006) reported two cases of heel reconstruction using the free iliac crest flap decades later. A 44-year-old man had suffered an explosion injury losing his whole heel. After late reconstruction with a free iliac crest flap, the heel had good padding and radiographs showed bone union at the 19-month follow-up. The second case was a 55-year-old man who underwent free iliac crest flap reconstruction for an open fracture after a 2.5-meter fall. At eight months postoperatively, the patient had regained full weight bearing with the help of orthopedic shoes.



**Figure 10.** Harvesting of the free iliac crest flap. (copyright 2013 From *Reconstructive Surgery of the Lower Extremity* by Pu, Levine and Wei. Reproduced by permission of Taylor and Francis Group, LLC, a division of Informa plc.)

In a paper by Rieger et al. (2009), the free iliac crest flap was used to reconstruct the talar dome after extensive talar necrosis in a 48-year-old woman. At the 16-year follow-up, the AOFAS hindfoot score had risen to 100 from the baseline score of 33, indicating perfect function of the ankle. Roger and colleagues had good results using the free iliac crest flap for subtalar arthrodesis after a failed attempt to achieve arthrodesis with other methods in two patients (Roger et al. 2015). Radiological bone union and full weight bearing was achieved in approximately six months. At the one- and two-year follow-ups, respectively, the patients had had no complications. Nonetheless, there is a paucity of published functional and HRQoL data for patients who have undergone foot and ankle reconstruction using the free iliac crest flap.

**Vascularized latissimus dorsi scapula flap**

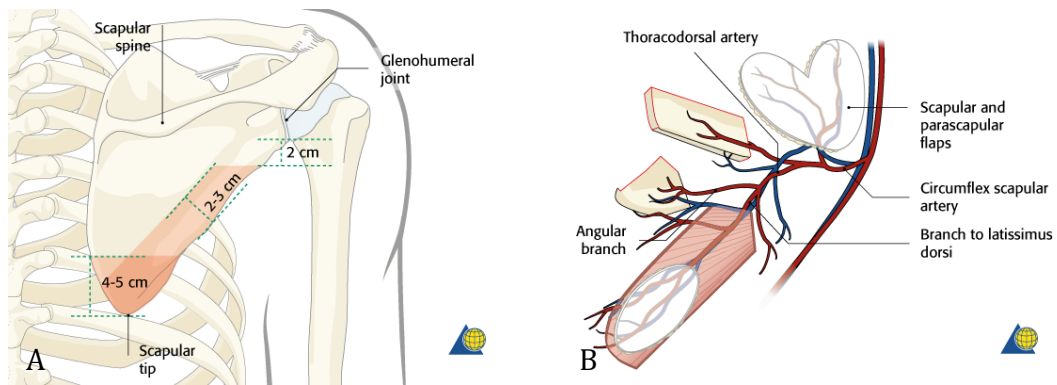
Evans and colleagues introduced the free osteomuscular latissimus dorsi scapula flap (Figure 12) for reconstruction of elbow defects in 1993 (Evans et al. 1993). The following year, Allen and his team described the experimental use of this flap in a 12-patient series of tibial reconstruction (Allen et al. 1994). Erdinger et al. (2000) described five cases where the free latissimus dorsi scapula flap was used to treat chronic posttraumatic osteomyelitis of the tibia with good outcomes.

In a case report by Momeni et al. (2006), the free latissimus dorsi scapula flap was used to reconstruct a comminuted compound fracture of the distal tibia after a paragliding accident. The patient was followed up for three months with no complications. A French paper by Coeugnet et al. (2007) illustrated a successful reconstruction of three patients with tibial defects. One patient underwent reconstruction due to an

extensive distal tibia defect after a motor vehicle accident. The two other patients required reconstruction after resection of soft tissue sarcoma. The authors described



**Figure 11.** (A) Lateral radiograph demonstrating a large primary defect of the distal tibial due to rally motor vehicle accident. (B) Intraoperative photograph illustrating large bone defect after resection of pathological tissue and modeling of the recipient site ready for vascularized composite transfer. (C) Intraoperative photograph illustrating the composition of the free osteomusculocutaneous iliac crest flap. (D) Postoperative lateral radiograph demonstrating tibiotalar arthrodesis using the free iliac crest flap fixed with K-wires. (E) Postoperative photograph illustrating the result of a musculous part of the flap covered by split skin grating. External fixation served for additional fixation

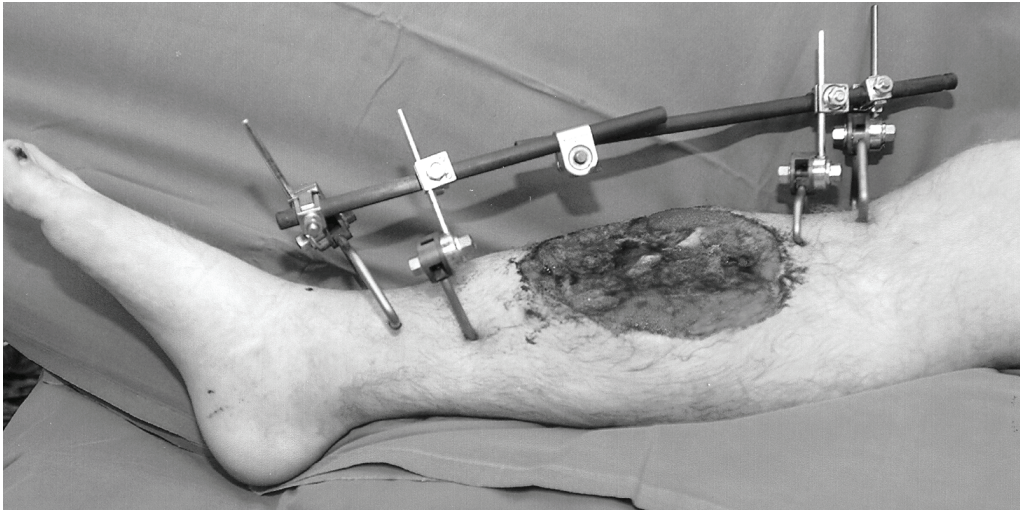


**Figure 12.** (A) Bony structure of the scapula showing the options for raising the scapula transfer. (B) Options for the composite vascularized osteomuscular or osteomusculocutaneous flap. (copyright by AO Foundation. Published with a permission of AO Foundation. Switzerland. Source: AO Trauma Reference, [www.aofoundation.org](http://www.aofoundation.org))

bone union and good functional outcomes for all three patients at the one-year follow-up. Tachi et al. (2010) used the free latissimus dorsi to treat osteomyelitis in nine patients with tibial defects and one patient with a femur defect after high-energy trauma. The patients were followed up for 3.3-13.9 years. Three patients had early infection postoperatively and one of the 10 patients suffered from an early venous thrombosis. All patients achieved bone union in 8-24 weeks.

Several reports of free latissimus dorsi scapula flap for tibia reconstruction have been published (Allen et al. 1994, Erdinger et al. 2000, Momeni et al. 2006, Tachi et al. 2010). However, there is a lack of long-term data for patients who have undergone reconstruction of the tibia using the free latissimus dorsi scapula flap. **Figures 13 and 14 (A-D)** illustrate the use of the free latissimus dorsi scapula flap to treat an extensive open fracture of the tibia. **Figure 14 (E)** illustrates the same patient at a clinical follow-up at 8.5 years after free osteomuscular latissimus dorsi scapula flap reconstruction.





**Figure 13.** A 27-year-old man with a Gustilo and Anderson type IIIC open fracture due to shotgun injury. Primary defect with an extensive soft tissue loss. The fracture has been stabilized using a pinless-fixator.



**Figure 14.** (A) Radiograph on admission showing a fragmented tibial fracture with large zone of injury. (B) Post-operative lateral tibial radiograph 8 days from reconstruction using free latissimus dorsi scapula flap. The bone is placed between the bone fragments and fixed with K-wires. The fracture has been stabilized with a Hoffman fixator. (C) Postoperative outcome 9 days from microvascular flap reconstruction showing the cutaneous section of the flap distally and the musculous section covered with split-thickness skin grafting. (D) Lateral radiograph 5 months after reconstruction showing full radiological bone union. (E) Postoperative photograph 8.5 years after reconstruction.

## **2.9 Patient-reported outcome (PRO) instruments**

In this section, the patient-reported outcome (PRO) instruments are reviewed. First, the properties of two of the most popular generic HRQoL instruments are described. The review then focuses on scores of lower extremity assessment and goes into depth concerning foot and ankle measures. PRO measures are reviewed with a special emphasis on those instruments that have been linguistically validated in Finnish. This review then provides insight into PROs used to assess disability and physical activity.

### **2.9.1 Health-related quality of life instruments**

Generic health-related quality of life (HRQoL) instruments for adults include the 15D, the EQ-5D, the SF-36, and the RAND-36. The RAND-36 is an equivalent free version of the commercial SF-36 instrument with minor interpretation differences (Hayes et al. 1993). Although the EQ-5D instrument is extensively used in generic HRQoL assessment, e.g. after injury, the Finns have not adopted it (Derrett et al. 2009, Laine 2014). This is partly due to its lower discriminatory power and poorer responsiveness relative to the 15D instrument (Stavem 1999, Vainiola et al. 2010). This review focuses on the most popular validated generic HRQoL instruments used in Finland.

#### **15D instrument**

The 15D is the most frequently used single-index HRQoL instrument in Finland (Sintonen 2001, 2003). The 15D (**Appendix 1**) is a generic and comprehensive HRQoL instrument (Sintonen 2001). It covers 15 dimensions (mobility, vision, hearing, breathing, sleeping, eating, speech, excretion, usual activities, mental function, discomfort and symptoms, depression, distress, vitality, and sexual activity). The 15D can be used as a profile or as a single index (15D score). The single-index score can range from 0 (equivalent to being dead) to 1 (the best possible value). The 15D score can also be calculated when one to three items are not completed.

The 15D is reliable and valid for assessment of generic HRQoL (Sintonen 2004). The estimated minimal clinically important difference (MCID) in the 15D score is considered to be at  $\geq 0.015$  (Alanne et al. 2015). MCID is the smallest change representing an important difference in measurement outcome (Jaeschke et al. 1989). The 15D has been well-adopted internationally and is available in several languages (<http://www.15d-instrument.net>). One of the virtues of using the 15D in a Finnish study population is that the results can be compared with that of an age-standardized sample of the general population. The control population can be obtained from the National Health 2011 Survey (Koskinen et al. 2011).

#### **Short-Form 36 Health Survey (SF-36)**

The SF-36 is a 36-item multi-purpose instrument (Ware et al. 1993). It is widely used to assess patients' HRQoL. The generic SF-36 has eight sections focusing on functional health, general health perception, physical and mental health, and well-being (Ware et al. 2000). Previous studies have shown the SF-36 to be a valid and reliable instrument (Ware et al. 1993). The SF-36 has been widely adopted also in foot and ankle research (Hunt and Hurvit 2013).



### **2.9.2 Lower extremity functional assessment**

There are two general lower extremity function-specific PRO instruments that are available in Finnish: the Lower Extremity Functional Scale (LEFS) (Binkley et al. 1999) and the Toronto Extremity Salvage Score lower extremity section (Davis et al. 1996, Repo et al. 2015). This section of the literature review introduces the reader to the properties of the LEFS instrument.

#### ***Lower Extremity Functional Scale (LEFS)***

The LEFS (**Appendices 2 and 3**) was developed by Binkley and colleagues to assess lower extremity disability (Binkley et al. 1999). It contains 20 function-related items, allowing the patient to choose the most suitable option on a five-point (0-4) Likert scale. The range of the LEFS is between 0 and 80 points (worst to best). Separate studies by Binkley et al. (1999) and Yeung et al. (2009) found high content and construct validity of the LEFS among a heterogeneous population of lower extremity musculoskeletal pathologies. Content validity refers to the extent that the instrument domain is sampled by the items of the instrument (Nunnally and Bernstein 1994). Binkley reported that the Pearson correlation coefficient between the LEFS and the SF-36 instrument Physical Function subscale and the Physical component were 0.80 and 0.64, respectively (Binkley et al. 1999). The ICC was 0.94. The ICC measures relative reliability, referring to the consistency of measurement and the extent that the participants' answers are differentiated from each other regardless of measurement errors (Streiner and Norman 2003, Terwee et al. 2007). The internal consistency was placed at 0.96 in the original LEFS validation study (Binkley et al. 1999). The internal consistency refers to the extent to which the scale items are homogeneous (Cronbach 1951, Nunnally and Bernstein 1994, Streiner and Norman 2003). The internal consistency can be computed using Cronbach's alpha (Cronbach 1951).

Pinsker et al. (2013) conducted a computerized adaptive test of the LEFS, showing a high ability to identify impairment in the ankle, foot, hip, or knee. Although it is a broad region-specific outcome measure, previous studies have proven the LEFS to be valid for functional evaluation of the leg as well as the foot and ankle (Lin et al. 2009, Shultz et al. 2013, Pan et al. 2014). A paper by Lin and colleagues reported a high internal consistency (0.90-0.94) of the LEFS among ankle fracture patients (Lin et al. 2009).

The psychometric properties of the LEFS in foot and ankle patients have proven superior to many other more widely used foot and ankle rating scales (Hunt and Hurvit 2013). The LEFS score is among the five instruments (Foot and Ankle Ability Measure, FFI, Foot Health Status Questionnaire, LEFS, and Sports Ankle Rating System quality of life measure) to show content validity, construct validity, reliability, and responsiveness in foot and ankle patients in a systematic review where 14 different foot and ankle outcome measures were compared (Martin et al. 2007). Responsiveness reflects the ability of an outcome measure to assess the clinically important difference over time (Guyatt et al. 1989).

The LEFS has been well-adopted internationally and is translated into several different languages (Cacchio et al. 2010, Hoogenboom et al. 2012, Naal et al. 2014, Hou et al. 2014, Cruz-Diaz et al. 2014, Nagahban et al. 2014, Alnahdi et al. 2015).

### **2.9.3 PRO instruments for foot and ankle assessment**

Scholars and clinicians have not reached universal agreement regarding the best foot and ankle outcome measure. A systematic literature review by Hunt and Hurvit revealed that there are around 140 different rating instruments available for foot and ankle assessment (Hunt and Hurvit 2013). Today, the most widely used instrument in foot and ankle research is the AOFAS rating scale (Lau et al. 2002, Button and Pinney 2004, Kearney et al. 2012, Hunt and Hurvit 2013). The AOFAS was used in 55.9% of articles including foot and ankle function assessment in six major orthopedic journals between 2002 and 2011 (Hunt and Hurvit 2013). The AOFAS scales have not been adopted by the Finns.

Also the visual analog scale for pain, the SF-36 Health Survey, and the Foot Function Index have been popular outcome measures in foot and ankle research (Lau et al. 2002, Martin and Irrgang et al. 2007, Hunt and Hurvit 2013). Goldstein and colleagues in their comparison of the six most widely used foot and ankle scores concluded that using one foot and ankle instrument for functional assessment after trauma is sufficient (Goldstein et al. 2010).

Based on the present literature review, the Kaikkonen scale has been the sole validated ankle-specific PRO measure in the Finnish language. The Kaikkonen scale is a partly patient-reported (three items), but mostly clinician-administered assessment tool for ankle injuries (Kaikkonen et al. 1994). Due to its clinician-administered section, it does not qualify completely as a PRO instrument.

#### ***Visual Analog Scale, Foot and Ankle (VAS-FA)***

The patient-reported VAS-FA (**Appendix 4**) was developed to assess the musculoskeletal condition of the foot and ankle (Richter et al. 2006). It was constructed on the basis of other previously developed foot and ankle instruments to offset their shortages (Richter et al. 2006). The VAS-FA has similar properties with the FFI and both are based on the visual analog scale (VAS). The VAS-FA is a valid instrument containing 20 items with 3 modules: pain (4 questions), function (11 questions), and other complaints (5 questions) (Richter et al. 2006, Stüber et al. 2011). Each item is awarded points on a scale from 0 to 100 (worst to best), yielding a total score between 0 and 2000 points. The computerized scoring allows easy access to the submodule and overall scores.

The VAS-FA has been claimed to have superior psychometric properties for studying foot and ankle pathologies relative to many more widely used foot and ankle instruments (Stüber et al. 2011). The VAS-FA instrument has been claimed to surpass the AOFAS in its validity and reliability (Richter et al. 2006, Stüber et al. 2011). The correlation between the VAS FA pain module and the Hannover Questionnaire and the SF-36 was strong ( $r = 0.90$  and  $r = 0.70$ , respectively) in the original validation

study by Richter et al. (2006). All preset hypotheses were statistically confirmed (Richter et al. 2006).

The Thai version of the VAS-FA showed both intra-class correlation and internal consistency of 0.995 (Angthong et al. 2011). The study revealed also a moderate correlation with the SF-36 Physical Component ( $r = 0.55$ ) and the Physical Role Functioning ( $r = 0.59$ ). The correlation was strong with Bodily Pain ( $r = 0.61$ ) and the SF-36 total score ( $r = 0.61$ ). The Finnish version of the VAS-FA (**Appendix 5**) has also shown good reliability (ICC, 0.97; standard error of measurement, 1.49) and validity in assessing musculoskeletal foot and ankle conditions among 165 surgically treated foot and ankle patients (Repo et al., unpublished data).

#### **2.9.4 Shoulder function**

There are several instruments available for the assessment of shoulder function (Beaton and Richards 1996, Angst et al. 2008, 2011). A review by Angst et al. (2011) described the most essential PRO instruments for shoulder function to include the Disabilities of the Arm, Shoulder, and Hand questionnaire (DASH) (Hudak et al. 1996) and its short version (QuickDASH) (Beaton et al. 2005), and the American Shoulder and Elbow Surgeons (ASES) Society Standardized Shoulder Assessment Form (Richards et al. 1994). These three outcome measures are available in Finnish (Aro et al. 2005, Piitulainen et al. 2014). In the present literature review, the focus is placed on the DASH and its shorter version, and the ASES.

##### ***Disabilities of the Arm, Shoulder, and Hand questionnaire (DASH) and QuickDASH***

The DASH (**Appendix 6**) is a 30-item valid, upper extremity-specific outcome measure (Hudak et al. 1996, Beaton et al. 2001, Schmitt and Di Fabio 2004). The items can be divided into two distinct sections: physical activities (23 items) and symptoms (7 items). These items assess the overall state of the upper extremity during the preceding week. Each item is awarded between 1 and 5 points.

The DASH has been well-adopted internationally and cultural adaptations are available in several languages (<http://dash.iwh.on.ca/available-translations>). These translations include also the Finnish version of the DASH questionnaire (Aro et al. 2009). The validity of the Finnish version of the DASH has remained untested. However, the existing literature places the absolute reliability (SEM) of the DASH at 4.6-5.2 and the relative reliability (ICC) at 0.91-0.96 in adult patients with upper extremity musculoskeletal problems (Beaton et al. 2001, Schmitt and Di Fabio 2004). Internal consistency has been placed at 0.97-0.98 (Gummersson et al. 2003).

The QuickDASH (**Appendix 7**) is a shorter version of the Disabilities of the Arm, Shoulder, and Hand questionnaire (Beaton et al. 2005). This valid PRO instrument consists of 11 items assessing the upper extremity function and symptoms. Each item of the QuickDASH receives between 1 and 5 points, where one is the best possible and five the worst possible score. Although the QuickDASH is shorter, it has shown similar precision and validity to the original DASH questionnaire (Gummersson et al. 2006).

## **ASES**

The ASES consists of patient-reported and clinician-administered sections (Richards et al. 1994). The ASES is a reliable, responsive, and valid instrument to assess shoulder disability (Beaton et al. 1996, Michener et al. 2002, Kocher et al. 2005). The Finnish version of the ASES patient-reported section has previously been validated among a heterogeneous population of Finnish of patients with shoulder symptoms (Piitulainen et al. 2014).

### **2.9.5 Disability**

Several disability measures are available in the literature for clinical and research purposes (Grotle et al. 2005, Ustun et al. 2010, Spanjer et al. 2011, Yang et al. 2014). These include the Roland and Morris disability questionnaire (Roland and Morris 1983, Roland and Fairbank 2000), the Oswestry Disability Index (ODI) (Fairbank and Pynset 2000), and the World Health Organization Disability Assessment Schedule, available also in Finnish (Saltychev et al. 2016). The section below describes the ODI instrument in more detail.

#### ***Oswestry Disability Index (ODI)***

The Oswestry Disability Index version 2.0 (**Appendix 8**) is a widely recognized back-specific outcome measure (Fairbank and Pynset 2000). The ODI is one of the most frequently used, reliable, and valid outcome measures for assessing back problems (Deyo et al. 1998). The ODI consists of 10 questions (lifting, pain, personal care, sitting, sex life, sleeping, social life, standing, traveling, walking) on an ordinal scale of six levels (from 0 to 5, worst to best). Respondents choose the level that best describes their health status at the time of answering. The total score is calculated by summing up the points of each answer and expressed as percentages scaled against maximum points. The ODI has previously been adapted into Finnish and validated among spinal fusion patients by Pekkanen et al. (2011).

### **2.9.6 Physical activity**

In the literature, there are at least 100 different PRO instruments available for assessing patients' physical activity (Williams et al. 2012, Pinto-Carral et al. 2016). Frequency Intensity Time index (Kasari 1976) and International Physical Activity Questionnaire (Graig et al. 2003) are available in Finnish.

#### ***Frequency Intensity Time (FIT) index***

The FIT index of Kasari (**Appendix 9**) assesses the level of physical activity (Kasari 1976). The FIT index is a behavioral assessment instrument that comprises three modules: frequency of exercise (times per week/month), intensity of exercise (strenuousness of physical activity), and time spent exercising per session (four levels from <10 minutes to >30 minutes with 10-minute increments). The index is obtained by multiplying the score of each question with each other, yielding a score between 0-100; the higher the score, the higher the physical activity level. Even though the FIT index has a weak correlation with cardiorespiratory fitness testing, it may serve in assessing general physical activity (Grant et al. 2014).

### 2.9.7 Translation and cross-cultural adaptation of PRO instruments

PRO instruments are usually available in English (Guillemin et al. 1993). Thus, different language versions to match the language of target populations are required. Rather than pursuing linguistically identical translations, the PRO instruments should be cross-culturally adapted to meet the cultural and linguistic needs in target populations. Correctly translated and cross-culturally adapted versions of PRO instruments will have equivalent psychometric properties and conceptual contents as the original versions.

There are around 40 different translation and cross-cultural guidelines available for outcome measures (Epsten et al. 2015). A recent systematic review of translation and cross-cultural adaptation guidelines published between 2005 and 2015 years revealed consistent trends in the distinct translation phases (Repo and Rosqvist 2016). The differences between published translation and cross-cultural adaptation guidelines based on this study are presented in **Table 7**. The most frequently used guideline phases (two forward-translations and a synthesis of these two versions, a back-translation panel review, a multidisciplinary committee review of the overall process, pilot-testing, committee review of pilot-testing outcomes) have previously shown good feasibility (Rosqvist and Repo 2016).

**Table 7.** Most pertinent phases in the translation and cross-cultural adaptation guidelines published between 2005 and 2015. (Repo and Rosqvist 2016)

Guideline	Forward Translation	Synthesis	Pre-test	Back-translation	Synthesis	Multidisciplinary Committee	Harmonization	Pilot-testing	Cognitive Debriefing	Final Committee	Proofreading
Wild et al. 2005	X	X		X	X	X	X	X	X	X	X
Koller et al. 2007	X			X	X	X		X	X		
Dewolf et al. 2009	X	X		X	X	X		X	X	X	
Gjersing et al. 2010	X	X		X	X	X	X	X	X	X	
Schuster et al. 2010	X	X		X		X	X	X			
Two et al. 2010	X			X		X	X	X			X
Puga et al. 2011	X	X				X		X			
Sousa et al. 2013	X	X		X	X			X	X		
Hou et al. 2013	X		X		X			X			
Oliveira et al. 2015	X	X	X			X		X			
Santo et al. 2015	X	X				X		X		X	
World Health Organisation	X	X				X		X	X		

### **3. AIMS OF THE STUDY**

**The aims of this study were as follows:**

- I** to investigate the reliability and validity of the Finnish version of the Lower Extremity Functional Scale (LEFS) among foot and ankle patients
- II** to assess the reliability and long-term outcomes of free osteomuscular latissimus dorsi scapula flap for compound tibial fractures
- III** to evaluate reliability and long-term outcomes of the combined method of microvascular latissimus dorsi flap and Ilizarov distraction osteogenesis (either bone transport or later lengthening) in the treatment of traumatic compound tibial defects
- IV** to assess the reliability and long-term outcomes of free iliac crest flap in reconstruction of foot and ankle defects

## 4. PATIENTS AND METHODS

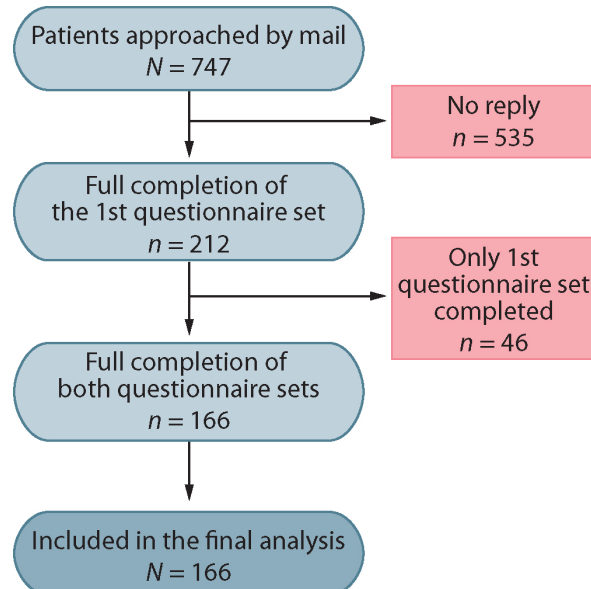
### 4.1 Identification of study population

Patients were prospectively entered before the electronic hospital database was established. Patients were identified from the hospital electronic database using the ICD-10 classification of diseases and the National Institute for Health and Welfare (THL) classification of surgical procedure codes. Procedure codes used for studies are presented in **Table 8**. All patients were treated at Helsinki University Hospital, Helsinki, Finland.

**Table 8.** Procedure codes for Studies I-IV.

THL code	Interpretation
<b>Study I</b>	
NHJ 10	Ankle fracture osteosynthesis
NHU 20	Removal of implants from foot or ankle
NHG 20	TC joint fusion
<b>Studies II-IV</b>	
ZZM 00	Composite graft
ZZQ 10	Free microvascular graft of skin and muscle
ZZQ 20	Free microvascular graft of skin, muscle, and bone
ZZQ 30	Free microvascular graft of muscle
ZZQ 40	Free microvascular graft of bone
NGK 69	Tibial lengthening
NGK 70	Tibial bone transfer, transport

**Study I.** A total of 166 patients who underwent foot and ankle surgery between 2001 and 2014 were included in the analysis. In 157 of these patients, the defect was due to trauma. The remaining nine patients four patients received treatment in management of infection ( $n = 6$ ) tumor resection ( $n = 2$ ), and stress fracture and destruction of the tibiotalar joint ( $n = 1$ ) in the foot or ankle. Overall 149 of the 166 patients underwent operation to establish fracture osteosynthesis. The inclusion criteria for this study were foot and ankle surgical management, full understanding of written Finnish, and age of over 18 years. **Figure 15** provides a flow chart of the inclusion of patients in the final psychometric analysis.



**Figure 15.** Flow chart for study I inclusion.

**Study II.** Twenty-six patients with a traumatic compound tibial defect treated using a free osteomuscular latissimus dorsi scapula flap between 1997 and 2010 were included in the study. Indications for operation were extensive primary traumatic tissue defect ( $n = 14$ ), secondary infection (between 15 and 40 days from primary trauma) of simple or complex fracture ( $n = 3$ ), or late infection and pseudarthrosis ( $n = 9$ ).

**Study III.** Sixteen patients treated using a microvascular latissimus dorsi flap combined with the Ilizarov method for compound tibial fractures were included. These 16 patients underwent soft tissue reconstruction between 1989 and 2014. Eleven of these patients underwent bone reconstruction using the Ilizarov technique of bone transport. The remaining five patients underwent primary soft tissue reconstruction using a free latissimus dorsi flap and secondary tibia lengthening using the Ilizarov technique to correct limb length discrepancy.

**Study IV.** The study population consisted of 13 patients who had undergone free iliac crest flap reconstruction in the treatment of foot and ankle compound bone defects between 1994 and 2012. One patient with cancer resection and free iliac crest flap reconstruction was excluded from the study. Twelve of the 13 patients had intra-articular involvement. In six cases, the free iliac crest flap was used to achieve subtalar ( $n = 2$ ), tibiotalar ( $n = 2$ ), or pantalar ( $n = 2$ ) ankle arthrodesis.

#### **4.2 Study design**

**Study I** was a cross-sectional study of the reliability and validity of the Lower Extremity Functional Scale among 166 patients who had undergone surgical intervention for foot and ankle pathology due to various indications. Patients who completed both the first questionnaire package and the retest package were eligible for this study.

**Study II** comprised a retrospective review of the patient records of 26 consecutive patients who underwent reconstruction of compound tibial fracture using a free latissimus dorsi scapula flap. A cross-sectional assessment using PRO instruments was performed. Three patients had died and one had moved abroad. Fourteen patients participated in the patient-centered outcome measures assessment. Twelve of the 14 patients who completed the questionnaires participated in a physical and radiological assessment. The remaining eight patients were lost to follow-up.

**Study III** was a retrospective review of hospital records of 16 consecutive patients who underwent soft tissue reconstruction using a free latissimus dorsi flap, followed by distraction osteogenesis of bone lengthening ( $n = 5$ ) or bone transport ( $n = 11$ ). Eleven patients were recruited in the PROs section. The remaining five patients were lost to follow-up.

**Study IV** comprised a retrospective review of hospital records of 13 consecutive patients treated using a free iliac crest flap to reconstruct a foot and ankle defect. One patient had died during follow-up. Seven of the 12 patients participated in the cross-sectional PROs follow-up. The remaining five patients were lost to follow-up.



Hospital records of patients were retrospectively reviewed for patient demographics and defect etiology (**Table 9**), preoperative treatment and perioperative information (**Table 10**), and postoperative complications, healing, and recovery. Patients' demographic details, significant predisposing factors, and comorbidities are presented in **Table 11**.

**Table 9.** Defect etiology and number of deep infection and pseudarthroses at the time of admission.

	Study I	Study II	Study III	Study IV
	<i>n</i> = 166	<i>n</i> = 26	<i>n</i> = 16	<i>n</i> = 13
Etiology				
Trauma	157	26	16	12
Closed fracture	131	3	3	4
Open fracture	18	23	13	7
Gustilo-Anderson I	N/A	2	-	1
II	N/A	-	-	2
IIIA	N/A	3	1	-
IIIB	N/A	16	5	1
IIIC	N/A	2	7	3
Rheumatoid	-	-	-	1
Deep infection	6	11	2	6
Pseudarthrosis	-	7	4	4
Soft tissue defect	8	26	16	12
Other	3	-	-	.

**Table 10.** Defect characteristics and location.

	Study I	Study II	Study III	Study IV
	<i>n</i> = 166	<i>n</i> = 26	<i>n</i> = 16	<i>n</i> = 13
Bone defect size, cm (range)	N/A	6 (1.5-10)	12 (5-22)	7 (5-9)
Bone defect location				
Tibia	78	26	16	8
Talus	1	-	-	3
Calcaneus	7	-	-	2
Fibula	61	-	-	-
Other	19	-	-	-
Compound defect	N/A	26	16	12

**Table 11.** Patient demographic details, significant predisposing factors, and comorbidities.

	Study I	Study II	Study III	Study IV
	<i>n</i> = 166	<i>n</i> = 26	<i>n</i> = 16	<i>n</i> = 13
Mean age, years (SD)	55 (16)	41 (17)	33 (13)	39 (13)
Sex (male/female)	78/88	23/3	16/0	13/0
Clinical follow-up time	3mo -14y	0.5mo - 14y	8mo - 21y	15mo - 8y
Smoking	N/A	8	5	4
Comorbidities	1	7	2	3
Diabetes mellitus	5	4	1	-
Acute renal failure	-	-	-	1
Osteoarthritis	-	-	-	1
Mental health problems	1	2	1	-
Alcoholism	N/A	3	-	1
Peripheral arterial disease	1	1	-	-

The values are presented as mean (SD, standard deviation) or number of patients. mo, months; y, years

### 4.3 Radiographic evaluation

The Finnish Radiation and Nuclear Safety Authority declares that the mean radiation of radiological imaging is 0.6 millisieverts (mSv). The radiation dose of one plain radiograph of the tibia is around 0.04 mSv (Schiedel et al. 2009). A native radiographic image of the thorax yields radiation of 0.1 mSv. The radiation amount of tibial lengthening using the Ilizarov method is known to be 0.3 mSv/cm of new bone (Schiedel et al. 2009).

In Studies II-IV, time until postoperative callus formation and bone union was obtained from native radiographs or radiological reports. The criterion for complete achieved radiological bone union was a solid bony bridge on both cortices in all projections. Limb length discrepancy, ante- and retrocurvatum, rotational deformities, and axial malalignment were assessed from radiographs. Also valgus and varus malpositions were evaluated from the radiographs.

In Study II, plain radiographs were obtained from the participants during the follow-up outpatient control visits to assess ossification and occurrence of posttraumatic arthritis in the knee and ankle. Bilateral lower extremity axial radiographs were obtained to assess the shortening, ante- and retrocurvatum, and mechanical and femorotibial axes of the operated lower extremity.

A radiologist and a clinician assessed the radiographic images independently. Thereafter, the findings of these two clinicians were compared. Posttraumatic arthritis of the knee was assessed according to the Kellgren and Lawrence (1957) grading from the native radiographs (**Table 12**). Arthritis of the ankle was evaluated using Takakura scoring (Takakura et al. 1995) (**Table 13**).

**Table 12.** Kellgren and Lawrence grading system for postoperative knee osteoarthritis. *Modified from Kellgren and Lawrence 1957.*

Grade		Explanation
0	<i>None</i>	Definitive absence of x-ray changes of osteoarthritis
I	<i>Doubtful</i>	Doubtful narrowing of joint space and osteophyte formation
II	<i>Minimal</i>	Osteophytes and narrowing of joint space
III	<i>Moderate</i>	Definitive osteophytes, joint space narrowing, potential deformity of bone contour
IV	<i>Severe</i>	Large osteophytes, significant joint space narrowing, sclerosis, definite bone contour deformity

**Table 13.** Takakura scoring for ankle osteoarthritis (Takakura et al. 1995).

Stage	Definition
I	No joint space narrowing, but early sclerosis and osteophyte formation
II	Narrowing of the joint space medially
III	Obliteration of the joint space with subchondral bone contact medially
IV	Obliteration of the whole joint space with complete bone contact

#### 4.4 Patient-reported outcomes

The studies used validated PRO instruments (**Table 14**). The PRO instruments were chosen based on a comprehensive review of the literature regarding the psychometric properties of PRO instruments. The copyright holders of the instruments were contacted for approval to use their instruments to conduct this study.

A generic 15D HRQoL instrument was added to the PRO package in Studies III and IV. In Study IV, the instructions of the ODI were modified by asking the participants to focus on the iliac crest donor site while completing the items.

Eight patients were excluded from the mailing list due to unknown mailing address ( $n = 4$ ) or death ( $n = 4$ ). The remaining patients were approached by mail. The participants returned the completed questionnaires in a prepaid return envelope. Two consecutive reminder letters were sent if there was no reply.

**Table 14.** PRO instruments used in Studies I-IV.

	PRO	FIT	DASH	LEFS	ODI	VAS FA	QuickDASH	15D
<b>Study I</b>		+		+				+
<b>Study II</b>						+	+	
<b>Study III</b>		+	+	+				+
<b>Study IV</b>		+			+	+		+

FIT, Frequency Intensity Time index; DASH; Disability of the Arm, Shoulder and Hand questionnaire; LEFS, Lower Extremity Functional Scale; ODI, Oswestry Disability Index; VAS-FA, Visual Analog Scale Foot and Ankle; QuickDASH, short version of the DASH; 15D, 15-dimension HRQoL instrument

##### 4.4.1 Pre-information questionnaires (I-IV)

All studies included a section for use of analgesics in the pre-information questionnaire (**Appendix 10**). In Study I, the patients reported their general health state during the previous week using a visual analog scale (VAS) of 0 to 100 mm. Patient-reported data of foot and ankle pain during activity and at rest, and the level of stiffness in the foot and ankle were also obtained using a VAS scale. In addition, sociodemographic questions concerning patients' age and sex, weight, height, smoking habits, occupation, and employment status were included in the questionnaire. In Study II, a pre-information questionnaire charted patients' occupational status, cane use, orthopedic footwear use, and donor site problems.

#### 4.5 Adaptation of the Lower Extremity Functional Scale (LEFS)

To conduct Studies I and III, a research group comprising scholars and clinicians from Central Finland Central Hospital, University of Jyväskylä, Helsinki University Hospital, University of Helsinki, and University of Eastern Finland set out to translate and cross-culturally adapt the LEFS instrument into Finnish, and to validate the Finnish versions among patients who had undergone surgical management in the treatment of musculoskeletal foot and ankle pathology.

The permission to adapt the LEFS to Finnish and to use it for research purposes was provided by the copyright holders. The translation and cross-culturally adaption to Finnish adhered to the guidelines set by the International Society for Pharmacoeconomics and Outcome Research (ISPOR) (Wild et al. 2005) (Figure 16). The process began by producing two forward-translations from English to Finnish by two translators who had Finnish as their first language. One of these translators was the key in-country person. The translators merged the forward-translations to a reconciliation synthesis version comparing the translations with each other and with the original English questionnaire. This phase resulted in a written report and the first Finnish version.

A back-translation from Finnish to English was then performed to reveal any flaws in the content compared with the original version. A native English translator who was fluent in Finnish and familiar with the Finnish culture produced the back-translation. The translator had no medical background and no knowledge of the original questionnaire. A written report of the translation problems encountered was produced. A “back-translation panel” reviewed all of the translations and reports. This panel consisted of all three translators (two forward-translators and one back-translator). The findings were discussed and a written report was produced. An expert committee of five clinicians, including the key in-country person, compared the forward-translations, back-translation, and the original English questionnaire with each other together with the written reports. This phase resulted in a pre-final version of the Finnish version and a written committee report.

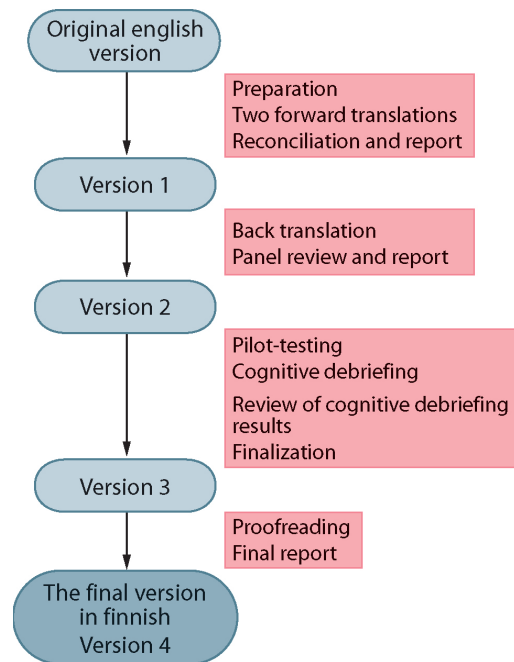


Figure 16. Translation and cross-cultural adaptation process of the Finnish versions of the LEFS instrument.

Following the guidelines by Beaton et al. (2000), the pre-final version was pilot-tested among 20 patients who had undergone foot and ankle surgery. Patients were later cognitively debriefed according to the European Organization for Research and Treatment of Cancer guidelines (Koller et al. 2007) to discover any offending content or difficulties in answering or understanding the questions and concepts. The participants were also asked whether there was anything they would ask differently. The expert committee assessed each phase separately and as a whole. The committee discussed the patient feedback and reviewed the results of the pilot tests. A written report was produced and a final Finnish version was proposed. The proposed final version was proofread by a Finnish language expert from the Finnish Medical Association (Duodecim). The final Finnish version was thereafter introduced (Appendix 3) together with a final report.

#### **4.6 Clinical assessment and functional tests (II)**

The clinical assessment was performed by a clinician and included ligament testing of both knees and measuring the length ratio of the legs. A physiotherapist performed the functional evaluations involving measurement of the range of motion and manual muscle strengths of the glenohumeral joints, knees, and ankles. The results were compared with those of the healthy contralateral limb, and the patient's handedness was noted.

In addition, a dynamic shoulder muscle test was performed. In this test, the patient lifted a four-kilogram weight upwards over a 30-second period as many times as possible. The number of lifts was recorded. The outcomes between the donor limb and the healthy contralateral side were compared.

#### **4.7 Statistical analysis**

In Study I, the intraclass correlation coefficient (ICC) was measured by two-way mixed model with absolute agreement. Standard error of measurement (SEM) was calculated by taking the root square of the mean square error term of the analysis of variance (Lexell and Downham 2005). The confidence intervals (CIs) for the SEM were analyzed using the degrees of freedom associated with estimated residual variance and percentage points from corresponding Chi-square distribution (Milliken and Johnson 2009). Internal consistency was estimated by calculating Cronbach's alpha (Cronbach 1951). The 95% CIs were obtained by using corrected bootstrapping (1000 replications). Floor and ceiling values were obtained by calculating the percentage of participants with minimum or maximum total scale scores. The floor or ceiling effect of an instrument is considered reached when 15% or more of the participants receive minimum or maximum points, respectively (McHorney and Tarlov 1995).

Construct validity was studied by maximum likelihood factor analysis with oblimin rotation for the LEFS items matrix of polychoric correlations (construct validity) (Lee et al. 1995). Factor analysis clarifies the relationships among observed variables.

The discriminatory power (corrected item-total correlation) was estimated using the Spearman correlation coefficient in the item analysis. Further, Spearman method was used to calculate the correlation coefficients (Spearman 1904). The correlation was classified according to Andresen (2000) as weak ( $<0.30$ ), moderate ( $0.30-0.59$ ), or strong ( $\geq 0.60$ ). Bias-corrected bootstrapping was used to obtain confidence intervals for mean changes and correlation coefficients. Bootstrapped type t-test for independent samples was used to test the difference between groups.

In Study II, the findings of the assessments as well as of the radiographic images of the operated side were compared with those of the contralateral side using McNemar's two-tailed test.

The significance of the differences between the 15D outcomes of patients and the Finnish general population were compared using the Mann-Whitney U-test for independent samples in Study III and the independent samples t-test in Study IV.

Analyses were performed with IBM SPSS Statistics (SPSS Inc., Chicago, IL, USA) and R version 3.0.1. Significance level was set at  $p$ -value  $<0.05$ .

#### **4.8 Ethical considerations**

The study protocol was approved by the Ethics Committee of the Hospital District of Helsinki and Uusimaa. Permission to conduct the study was provided by the Head of Surgery of Helsinki University Hospital.

Written consent in accordance with the principles of the Declaration of Helsinki (World Medical Association 2013) was obtained from all participants. Participation in this study was completely voluntary. Patients were informed that they could terminate their participation at any time with no impact on their medical care. Validated PRO measures were used to meet the international standards of ethical research. Finnish-Swedish patients were provided with Swedish versions of the information leaflet and the consent form.

Patients received an ID number at the time of identification as a suitable participant for the study. The ID number was used to code the questionnaire booklet so that the patients were able to complete it anonymously. Patients were unidentifiable thereafter and their answers were treated confidentially to guarantee the respondents' anonymity. Disassembling of the code was possible only for the principal investigator. All data were kept in a secure place at Helsinki University Hospital or behind computer passwords.

## 5. RESULTS

### 5.1 Study I

A total of 166 patients participated in the study to assess the reliability and validity of the Finnish version of the LEFS instrument. Mean (SD) age of the study population was 55 (16). Altogether 53% of participants were female. Indications for foot and ankle operation were fracture (90%) and soft tissue defect (10%). The location of the procedure was the ankle (84%) or the foot (16%). Time since last operation varied from four months to 14 years. The mean total score of the 15D instrument was 0.91 (0.09). The scores in the reference dimensions of the 15D were as follows: "Mobility" 0.85 (0.18); "Usual activities" 0.91 (0.17); "Discomfort and symptoms" 0.80 (0.21); "Vitality" 0.88 (0.16). The mean (SD) subjective pain (0-100) on the visual analog scale (VAS) was 12 (19) at rest and 19 (25) during activity. Foot and ankle stiffness of the operated limb was reported at a mean of 22 (25) on the VAS scale. The physical activity level (FIT index) was estimated at a mean of 25 (22).

The psychometric study found no floor effect in the LEFS questionnaire among foot and ankle patients who had undergone a surgical procedure in the treatment of musculoskeletal pathology. Twenty-nine patients (17%) scored the maximum total value, indicating a minor ceiling effect. The mean value (SD) of the LEFS score on the first assessment was 66.2 (15.4). The mean change (95% CI) to the second measurement was -0.5 points (-1.5 to 0.2). Means scores of patients who had undergone surgery within a year were slightly lower than those of patients with more than a year from surgery (64.5 vs. 67.3 points). Patients who had undergone surgery within a year had slightly more change in the score between the 1<sup>st</sup> and the 2<sup>nd</sup> completion of the LEFS (-0.6 [-2.9 to 1.1]) than those with over a year from the procedure (-0.4 [-1.1 to 0.2]).

The overall reproducibility intraclass correlation coefficient (ICC) was 0.93 (95% CI 0.91 to 0.95). In the group of patients that had undergone foot and ankle surgery in the preceding year, the ICC value was lower (0.88 [95% CI 0.82 to 0.93]) than that of the study population for which the procedure had been performed more than one year from the assessment (0.97 [95% CI 0.96 to 0.98]). The SEM was 4.1 (95% CI 3.7 to 4.6) for the total study group. The SEM value was higher in patients who had undergone surgery within one year (5.8 [5.0 to 7.1]) indicating larger variance. Patients for whom the procedure was performed within one year had a better SEM value in the absolute reliability testing (2.5 [2.2 to 2.9]).

The LEFS showed a Cronbach's alpha of 0.96, indicating high internal consistency. The internal consistency between patient groups separated according to time from surgery varied slightly (**Table 15**). All items showed at least moderate item correlation. The highest corrected item correlation was seen in four items: "Running on even ground", "Running on uneven ground", "Making sharp turns while running fast", and "Hopping". The median (IQR) of all items together was 4.0 (3.4).

**Table 15.** Internal consistency of the 20 items in the LEFS.

	<b>N</b>	<b>Cronbach's alpha (95% CI)</b>
All participants	166	0.96 (0.94 to 0.97)
Within one year of procedure	63	0.96 (0.93 to 0.98)
More than one year after procedure	103	0.95 (0.92 to 0.96)

Factor analysis for the construct validity showed that the LEFS items loaded on two factors. Factor 1 contained questions about daily activities. Factor 2 contained items that were distinctly function-related (“Running on even ground”, “Running on uneven ground”, “Making sharp turns while running fast”, “Hopping”). Factor 2 explained 83% of the total variance

Spearman’s correlation coefficient was strong between the LEFS total score and the 15D (0.66 [95% CI 0.57 to 0.75]). The strongest correlation was found between LEFS and the 15D “Mobility” dimension (0.74 [95% CI 0.66 to 0.80]). Strong correlations were also found in two additional dimensions: “Usual activities” (0.60 [CI 0.49 to 0.69]) and “Discomfort and symptoms” (0.54 [95% CI 0.42 to 0.65]). The correlation with the “Vitality” dimension was moderate (0.48 [95% CI 0.34 to 0.60]). Strong negative correlations emerged between the LEFS and foot and ankle pain during activity (-0.69 [95% CI -0.76 to -0.59]) and foot and ankle stiffness (-0.62 [95% CI -0.71 to -0.52]). A moderate negative correlation was found in the visual analog scale of foot and ankle pain in rest (-0.50 [95% CI -0.60 to -0.37]). The correlation with physical activity was moderate (0.46 [95% CI 0.32 to 0.58]).

The LEFS correlated poorly with patients’ age (-0.25 [95% CI -0.39 to -0.09]) and BMI (-0.24 [95% CI -0.40 to -0.08]). The location of the surgical intervention in known-groups validity assessment did not affect the LEFS score ( $p = 0.57$ ). Patients who underwent the ankle procedure scored a mean (SD) of 65.9 (15.8) points on the LEFS, and patients who underwent the foot procedure a mean of 67.6 (13.5).



## 5.2 General results of Studies II-IV

Postoperative complications occurred in 35 of the 55 patients in Studies II-IV (**Tables 16 and 17**). The most prevalent early complication was partial flap necrosis. Of the late complications, delayed union was most frequent. Forty-one patients underwent reoperations, with a total number of 61 performed surgical procedures. Early and late reoperations are presented in **Tables 18 and 19**, respectively. Times for mobilization and complete radiological bone union are presented in **Table 20**. **Table 20** presents also the patient-reported return-to-work rate, daily analgesics use, and need for special insoles.

**Table 16.** List of early complications ( $\leq 30$  days).

	Study II	Study III	Study IV
	<i>n</i> = 26	<i>n</i> = 16	<i>n</i> = 13
No. of patients with early complications	5	6	6
No. of early complications	8	7	6
Thrombosis	2	2	2
Failure of osteosynthesis	1	-	-
Pin site infection	2	2	-
Superficial infection	1	1	-
Partial flap necrosis	1	2	5
Skin graft necrosis	1	-	-
Total flap loss	-	-	-

**Table 17.** List of late complications ( $> 31$  days).

	Study II	Study III	Study IV
	<i>n</i> = 26	<i>n</i> = 16	<i>n</i> = 13
No. of patients with late complications	11	12	9
No. of late complications	14	26	14
Infection	1	-	-
Pin site infection	1	4	-
Fistulation	1	5	4
Partial flap necrosis	1	1	5
Fracture	-	4	-
Delayed union	7	3	3
Pseudarthrosis	1	2	1
Iliac spine avulsion fracture	1	-	-
Incisional hernia	-	-	1
Malunion	-	3	-
Osteomyelitis	-	4	1
Total flap loss	1	-	-

## Results

**Table 18.** List of early reoperations ( $\leq 30$  days).

	<b>Study II</b>	<b>Study III</b>	<b>Study IV</b>
	<i>n</i> = 26	<i>n</i> = 16	<i>n</i> = 13
No. of patients with early reoperations	5	5	7
No. of early procedures	6	7	8
Revision	5	4	5
Reanastomosis	1	2	1
Evacuation	-	-	1
Vein grafting	-	1	1

**Table 19.** List of late reoperations ( $>30$  days).

	<b>Study II</b>	<b>Study III</b>	<b>Study IV</b>
	<i>n</i> = 26	<i>n</i> = 16	<i>n</i> = 13
No. of patients with late reoperation	14	15 <sup>#</sup>	10
No. of late procedures	27	30	17
Cancellous bone grafting	6	4	8
Biomaterials	1	1	1
External fixator change	2	-	2
Revision	3	4	2
Osteofixation	1	2	1
Removal of osteosynthesis	1	2	-
Tissue repair	2	-	-
Bone lengthening	2	-	-
Release of structural units	1	1	-
Tendon reconstruction	1	-	-
Flap debulking	2	3	1
Scar repair	3	2	-
Vascularized fibula transfer	1	-	-
Amputation	1	1	-
Soft tissue reconstruction	1	3	-
Arthrodesis	-	4	-
Donor site refinement	-	1	-
Exploration	-	1	-
Malunion correction	-	2	2

<sup>#</sup>For one patient, this information was unavailable.

**Table 20.** Time (months) for full mobilization and complete radiological bone union. Patient-reported return-to-work ratio, analgesics, and special insole use.

	<b>Study II</b>	<b>Study III (a)</b>	<b>Study III (b)</b>	<b>Study IV</b>
	<i>n</i> = 26	<i>n</i> = 11	<i>n</i> = 5	<i>n</i> = 13
Full weight bearing	4 (1-10)	14 (3-36)	11 (4-34)	5 (3-46)
Bone union	10 (3-27)	16 (7-56)	32 (12-60)	22 (7-46)
Return to work	18/20	9/9	3/4	6/6
Analgesics use	1/14	1/8	0/3	1/7
Special insoles	5/14	6/8	1/3	N/A

The time for full mobilization and bone union are presented in averages (ranges). In Study III, the subclassification indicates: (a) tibia transport and (b) tibial lengthening groups. N/A, not available.

### 5.3 Study II

#### ***Complications and reoperations***

The median clinical follow-up time was 5.6 years (IQR 11.4; range 2 weeks to 14.0 years). Overall, eight early complications ( $\leq 30$  days) were encountered (36%) (**Table 16**). Microvascular flap anastomosis revision and reanastomosis were needed due to venous or arterial thrombosis in two cases, one each. Pin site infection occurred in two patients necessitating change of the fixator pins. One superficial infection of the flap was treated with antibiotics. In one patient, the skin graft used for covering the muscular part of the flap was lost.

Late complications ( $>31$  days after operation) occurred in 11 patients (14 late complications, 64%). Pin site infection subsiding with conservative treatment with antibiotics was encountered in one patient. External fixation had to be replaced with new pins due to fixation failure in two cases. In two patients, fistulation on the border of the flap needed surgical revision. A persistent infection and partial flap necrosis led to a flap failure in one patient, requiring amputation of the lower limb. One patient underwent intramedullary nailing for osteosynthesis.

The most common complication was delayed bone union, which was encountered in 7 of the 26 patients. In six of these seven patients, cancellous bone grafting from the iliac crest was performed to enhance bone union. In one case, iliac spine avulsion fracture of the donor site of the cancellous bone graft was encountered. One patient received two sticks of bone morphogenetic protein to enhance union before treatment with cancellous bone grafting. One patient was later reconstructed using a vascularized fibula transfer and osteosynthesis with plate fixation after an unsuccessful attempt to achieve union with cancellous bone grafting.

Two patients underwent late tibia lengthening using distraction osteogenesis to correct limb length discrepancy. Two patients underwent late flap debulking of the latissimus dorsi part of the osteomuscular transfer. In three cases, release of scar tension was performed. One patient underwent release and reconstruction of tendons in the ankle area.

#### ***Return to work***

Eighteen of the 20 patients in the working population returned to work after reconstruction. Two patients were referred to disability pension. For four patients, this information was unavailable in the retrospective data.

#### ***Full weight bearing and bone union***

The median time for full weight bearing in 25 of the 26 patients was 3 months (IQR 3; range 1 to 10 months). One patient underwent transtibial amputation due to flap loss before achieving full weight bearing. Radiological bone union was achieved at a median of 7 months (IQR 6; range 3 to 27 months). One patient developed permanent pseudarthrosis of the reconstructed site.

**Measurement outcomes**

Fourteen participants completed the questionnaires at a median of 9.2 years after microvascular reconstruction (IQR 7.0; range 1.3 to 13.6 years). Three of the 14 patients used mild analgesics irregularly. One patient needed daily analgesics. One patient used a walking stick to aid ambulation. Five of the 14 patients used special insoles.

**Reconstructed site**

The mean score on the VAS-FA questionnaire was 73.8 (SD 21.2). Patients' mean overall outcomes and outcomes of the three modules (pain, function, and other complaints) are presented in **Table 21**. Patient numbers in different tables are not comparable. The sequential order is score-related.

**Table 21.** VAS-FA module and overall scores.

	Pain	Function	Other complaints	Overall
<b>Patient</b>				
1	100.0	100.0	100.0	100.0
2	100.0	71.4	85.6	80.9
3	95.8	75.9	66.0	77.4
4	95.3	98.2	96.0	97.1
5	88.3	89.7	95.4	90.9
6	87.3	82.2	81.2	83.0
7	85.0	94.8	88.6	91.3
8	77.8	78.1	73.2	76.8
9	68.8	80.6	71.0	75.9
10	55.0	70.9	77.0	69.3
11	44.8	81.2	70.0	71.1
12	34.8	63.2	54.4	55.3
13	28.0	33.0	45.0	35.0
14	19.8	34.7	24.8	29.3
Mean (SD)	70.0 (28.3)	75.3 (20.5)	73.4 (21.1)	73.8 (21.2)

SD, standard deviation

**Donor site**

Based on the QuickDASH results, excellent performance of the free osteomuscular latissimus dorsi scapula flap donor site is achieved in most patients; the shoulder performed perfectly in 10 of the 14 patients. However, there also appears to be a risk of moderate to severe functional limitation of the donor site; the remaining four patients received scores indicating minor to significant functional shoulder impairment. **Table 22** presents all patients' QuickDASH scores.

**Table 22.** Patients' QuickDASH scores from worst to best. For item content, see Appendix 7.

Item	1	2	3	4	5	6	7	8	9	10	11	QDASH SCORE
<b>Patient</b>												
1	4	4	3	3	4	5	1	2	2	2	2	47.7
2	2	1	1	3	1	1	1	2	1	3	2	25.0
3	1	3	2	2	1	1	1	1	2	2	2	15.9
4	1	5	1	2	1	1	1	1	1	1	1	11.4
5	1	1	1	1	1	1	1	1	1	1	1	0.0
6	1	1	1	1	1	1	1	1	1	1	1	0.0
7	1	1	1	1	1	1	1	1	1	1	1	0.0
8	1	1	1	1	1	1	1	1	1	1	1	0.0
9	1	1	1	1	1	1	1	1	1	1	1	0.0
10	1	1	1	1	1	1	1	1	1	1	1	0.0
11	1	1	1	1	1	1	1	1	1	1	1	0.0
12	1	1	1	1	1	1	1	1	1	1	1	0.0
13	1	1	1	1	1	1	1	1	1	1	1	0.0
14	1	1	1	1	1	1	1	1	1	1	1	0.0

**Radiographic evaluation**

In radiographic analysis, no trauma-induced knee arthritis was found based on Kellgren – Lawrence scoring. Talocrural joint deformities were found in six patients, grading I ( $n = 4$ ), II ( $n = 1$ ), and IV ( $n = 1$ ) according to the Takakura score.

**Physical evaluation**

Clinical tests showed a significant incidence ( $p = 0.016$ ) of impaired ankle dorsiflexion of 20 degrees on average (range 12-30) relative to the contralateral ankle in 7 of the 12 patients participating in outpatient controls. There was no knee joint instability on clinical evaluation.

**5.4 Study III****Complications and reoperations**

The median clinical follow-up time of patients in Study III was 4.7 years (IQR 4.5; range 0.7 to 21.8 years). Seven early complications (within 30 days) were identified (21%). Thrombosis of the microvascular flap necessitated reanastomosis and vein grafting in two cases each. Superficial infection and partial flap necrosis (1 of 16 flaps) required revision procedures. No flaps were lost. Early pin site infection occurred in two patients, leading to late fistula formation that required antibiotic treatment and revision procedures.

There were 26 late complications, occurring more than 31 days postoperatively (79%) (**Table 17**). Four pin site infections requiring surgical revision were encountered. Three additional fistulation cases of fistulation were found, leading to osteomyelitis in one case. Late osteomyelitis requiring surgical revision was present in four cases. Cancellous bone grafting was used in 8 of the 16 cases to enhance bone union. Two patients in the bone transport group underwent late corrective

open-wedge osteotomy to treat malunion. Overall, 5 of the 16 patients had limitations in ankle dorsiflexion during clinical visits.

### **Full weight bearing and bone union**

**Table 20** shows the time until complete mobilization and radiological bone union in patients in the tibia bone transport and the tibia lengthening groups. Median time for complete radiological bone union was 22 months (IQR 12). Even in the lengthening group, where usually smaller amounts of bone are produced, it took several years to achieve radiological bone union in some of the cases.

### **Measurement outcomes**

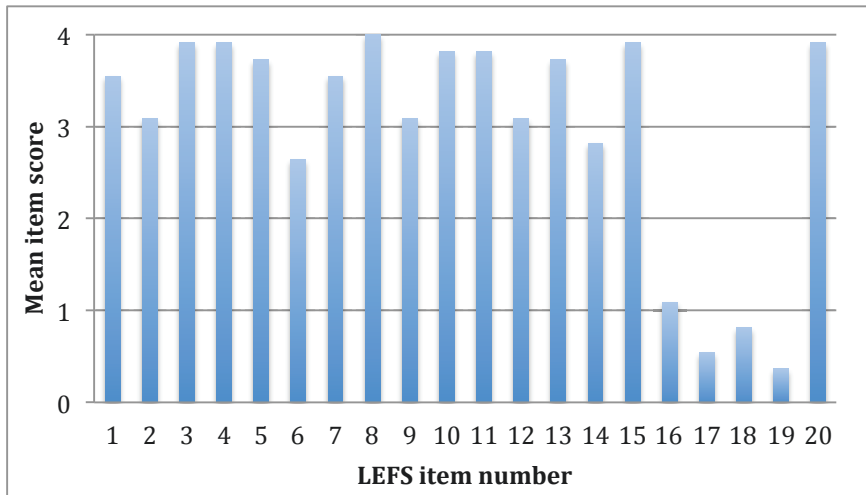
The mean time between microvascular reconstruction and the questionnaire assessment was 22.5 years (SD 2.4; range 19.3 to 25.8 years) in Study III. Eleven of the 16 patients completed the questionnaire set. Seven of the 11 patients used special insoles at the time of questionnaire completion. One patient reported using mild daily analgesics due to pain in the reconstructed limb. This patient had had an extensive tibial defect and minor limitations in lower extremity mobility.

### **Reconstructed site**

The study showed significant limitations of the reconstructed limb in 10 of the 11 patients (**Table 23**). The average score of items was 3.0 points (range 0.7 to 4.0 points), yielding a total average score of 59.4 points (out of a possible 80 points) (range 49 to 74 points) (**Figure 17**). The mean score in the bone transport group was 59 points (SD 8.6). The mean score of the tibial lengthening group was 62 points (SD 5.3). In half of the LEFS items, most patients received good scores. The reconstructed limb performed well in most activities; however, moderate limitations were found in squatting (item six) and standing for one hour (item 14). Overall, 10 of the 11 patients were extremely limited in running on even ground (item 16) and uneven ground (item 17), making sharp turns while running fast (item 18), and hopping (item 19).

**Table 23.** Bone gain and total LEFS score.

No.	Bone reconstruction method	New bone (cm)	LEFS score (max 80 points)
1	Transport	3.0	74
2	Elongation	3.5	68
3	Transport	7.0	66
4	Elongation	3.0	60
5	Transport	2.5	60
6	Transport	2.0	60
7	Elongation	3.2	58
8	Transport	5.5	54
9	Transport	4.0	53
10	Transport	6.0	51
11	Transport	4.0	49

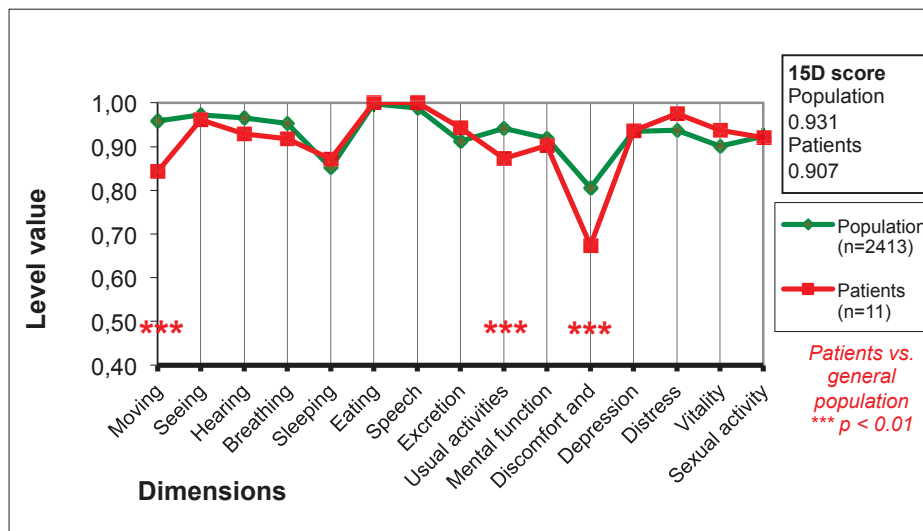


**Figure 17.** Mean scores of each of the LEFS items completed by 11 of the 16 patients. For item content, see Appendix 2.

**Donor site.** The assessment revealed a mean DASH score of 8.9 points (SD 7.0; range 0 to 19.2). Six of the 11 patients received scores between 0.0 and 6.7 points, indicating minimal disability of the donor site (**Table 24**).

**Health-related quality of life**

Study III showed a clinically important impairment of the HRQoL (0.907) relative to that of an age-standardized Finnish general control population (0.931). Patients were significantly impaired in the dimensions of “Moving”, “Usual activities”, and “Discomfort and symptoms”. **Figure 18** shows the mean HRQoL scores of 11 patients in Study II compared with the age-standardized Finnish general population ( $n = 2413$ ).



**Figure 18.** Mean 15D dimension scores compared with that of an age-standardized general population.





### **Physical activity**

The mean FIT index was 36 (SD 22). The patient-reported physical activity FIT index ranged from 8 to 60, indicating very low to average physical activity. Nonetheless, all of the patients were physically active, with seven of the 11 patients cycling, swimming, or going to the gym. The remaining four patients reported taking walks.

## **5.5 Study IV**

### **Complications and reoperations**

Patients were clinically followed up for a median of 3.0 years (IQR 3.7; range 1.3 to 8.0 years). In the early postoperative phase ( $\leq 30$  days), a total of seven complications were encountered (**Table 16**). In two patients, early thrombosis of the microvascular anastomosis required re-exploration together with arterial and venous reanastomosis ( $n = 1$ ) or great saphenous vein graft ( $n = 1$ ). Despite reanastomosis and vein grafting, both patients suffered a partial necrosis of the flap skin island. This complication was addressed using negative-pressure wound therapy (NPWT) and a local skin flap. In four additional cases, superficial infection ( $n = 3$ ) or hematoma ( $n = 1$ ) was encountered. Three of these led to partial necrosis of the island flap. Surgical revision together with split-skin grafting, and in two cases additional NPWT or a propeller skin flap, was used to reconstruct the defect.

Fifteen complications presented late ( $>30$  days). Four patients underwent surgical revision due to late fistulation. In one case, resection of the fistula resulted in a defect that was subsequently reconstructed using a local skin flap and split-skin grafting.

Pseudarthrosis and deep infection necessitated late removal of osteosynthesis material in two patients. In three cases, late cancellous bone grafting was used to enhance union. In one patient, correction of vagus malunion and tibiotalar arthrodesis with bone grafting was performed due to pseudarthrosis of the microvascular transfer.

One late severe incisional hernia of the donor site occurred. Complications in hernia repair led to an extensive soft tissue defect. The hernial defect was reconstructed using a pedicled tensor of fascia lata flap and covered with split-skin grafting.

### **Full weight bearing and bone union**

Patients reached full weight bearing at a median of five months (range 3 months to 3.8 years). The median time for radiological bone union was 22 months (range 7 months to 3.8 years). One permanent pseudarthrosis occurred in a patient who suffered from chronic alcoholism and severe depression. The free iliac crest flap had been used to attempt a pantalar arthrodesis for this patient.

### **Measurement outcomes**

In Study IV, the median time from reconstruction to questionnaire assessment was 14.7 years (IQR 13; range 2.0 to 26.9 years). All patients (6/6) of the working population returned to work. Two unemployed patients were referred to working disability pension. Of the remaining five unemployed patients, one was a student

and the other four were retired. One patient proclaimed needing daily analgesics with opioids due to intensive pain at the donor site of the microvascular transfer. One patient reported low scores due to unrelated general illness. Participants in the cross-sectional assessment did not need analgesics for the reconstructed limb.

### **Reconstructed site**

The assessment of the reconstructed site in Study IV revealed an average VAS-FA score of 52.7 points (range, 8.0-85.3 points). Patients' mean scores on each of the VAS-FA modules and the mean overall scores are presented in **Table 25**.

**Table 25.** Patients' VAS-FA scores.

	<b>Reconstructed site</b>	<b>Pain</b>	<b>Function</b>	<b>Other complaints</b>	<b>Overall</b>
<b>Patient</b>					
1	TC arthrodesis	91.8	83.8	83.2	85.3
2	Talus	84.8	80.7	80.7	81.6
3	Calcaneus	63.0	87.8	71.2	78.7
4	Tibia	49.8	59.7	55.7	56.6
5	Tibia	40.0	9.0	19.4	17.8
6	TC arthrodesis	21.3	55.6	55.6	40.7
7	Pantalar arthrodesis	2.3	2.7	2.7	8.0
Mean (SD)		50.4 (32.5)	51.0 (28.5)	73.4 (14.0)	52.7 (31.5)

SD, standard deviation; TC, talocrural

### **Donor site**

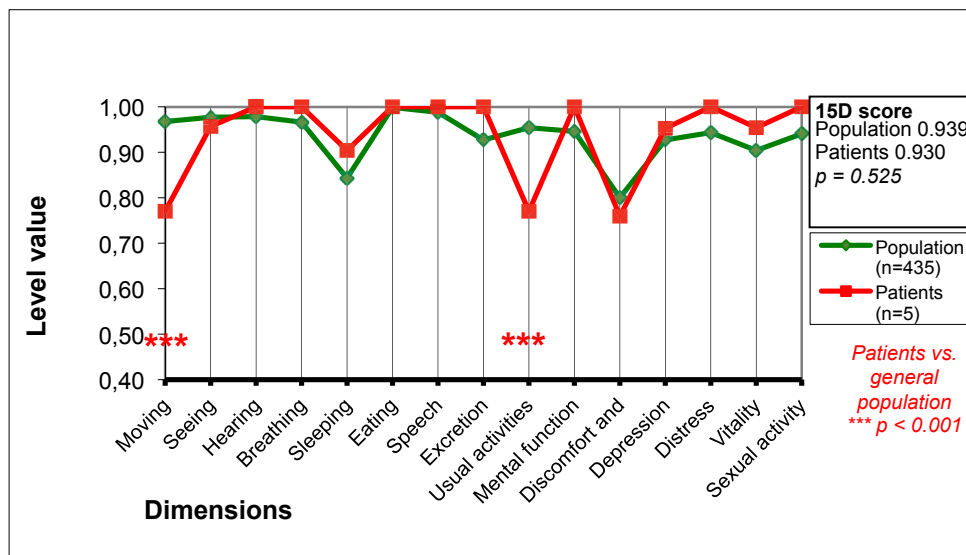
The study showed that the donor site performed perfectly or almost perfectly in five of the seven patients participating in the cross-sectional assessment. One of these patients had minor limitations in seven of the 10 completed items of the Oswestry Disability Index (ODI) (**Table 26**).

**Table 26.** ODI scores from worst to best (see Appendix 8).

Item	Pain	Personal care	Lifting	Walking	Sitting	Standing	Sleeping	Sex Life	Social life	Traveling	ODI score	Disability level
<b>Patient</b>												
1	3	2	4	4	3	4	4	4	3	3	34	Severe
2	4	5	5	4	2	4	1	N/A	N/A	N/A	23	Severe
3	1	0	1	1	1	1	0	0	1	1	7	Minimal
4	0	0	0	0	0	0	1	0	0	0	1	Minimal
5	0	0	0	0	0	0	0	0	0	0	0	Minimal
6	0	0	0	0	0	0	0	0	0	0	0	Minimal
7	0	0	0	0	0	0	0	0	0	0	0	Minimal

**Health-related quality of life**

The health-related quality of life assessed by the 15D instrument revealed an average 15D score (0.930) comparable with that of an age-standardized Finnish general population for the five patients who underwent foot and ankle reconstruction using a free iliac crest flap. However, these five patients were significantly impaired in the dimensions of "Moving" and "Usual activities". **Figure 19** illustrates the HRQoL of five patients in Study III relative to that of an age- and gender-standardized Finnish general population ( $n = 435$ ). Two patients received significantly worse scores, 0.423 and 0.530, respectively, indicating severely lowered HRQoL. One of these two patients had a severe general impairment due to generalized osteoarthritis and lumbar degenerative disc disease.



**Figure 19.** Mean 15D dimension scores compared with age- and gender-standardized general population.

**Physical activity**

The mean FIT index was 49 (SD 35). The score ranged from 0 to 100, indicating low to extremely high physical activity. All but one patient reported being physically active by engaging in walking, cycling, jogging, swimming, or skiing. One patient walked only with a walker or crutches and was not physically active for unrelated reasons. After assessing the completed questionnaires, a high suspicion of one outlier respondent arose. The patient described doing high-intensity physical exercise over six times a week and over 30 minutes each time, but at the same time got the lowest scores on all questionnaires other than the FIT.

## 6. DISCUSSION

### 6.1 General discussion

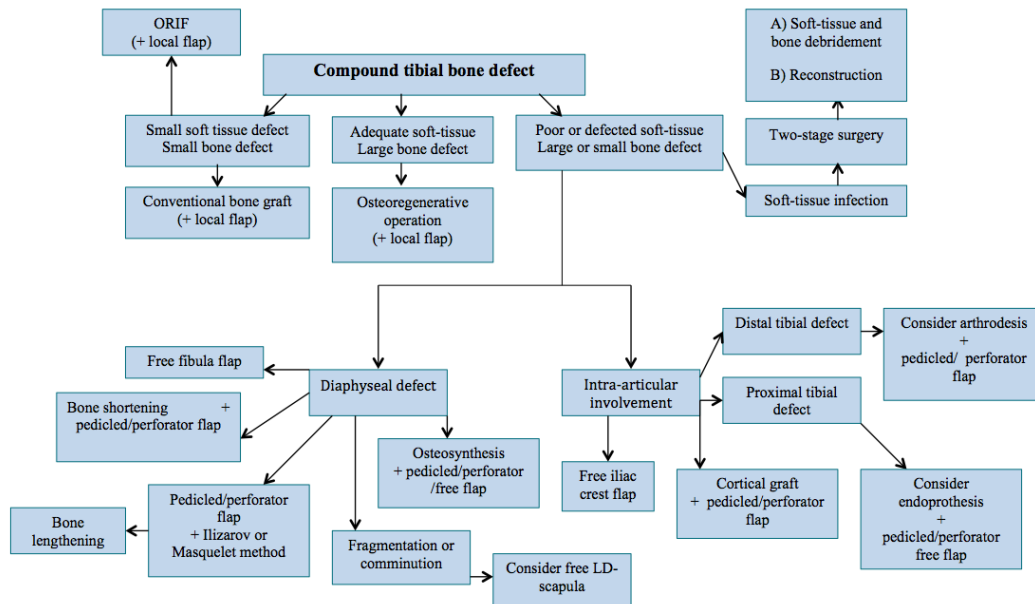
Extensive traumatic compound bone and soft tissue defects in the tibia and ankle region present a significant challenge for the reconstructive surgeon. The defects are usually complex, patients often present late, and several techniques have typically already been attempted before admission. All non-viable tissue is to be debrided to avoid serious complications before reconstruction. Complications in bone healing and prolonged infection can complicate the treatment further, leading to non-union (Hak et al. 2014, Struijs et al. 2007, Egol et al. 2012). At Helsinki University Hospital, a Finnish level I trauma and academic referral center, these defects are treated by orthoplastic teams consisting of orthopedic and plastic surgeons to address both bone and soft tissue reconstruction. **Figure 20** illustrates an algorithmic approach for different reconstructive techniques in treatment of traumatic compound tibial defects and prolonged complications.

Even though the workhorse of bone reconstruction is the conventional cancellous bone autograft, its use is limited to bone loss of less than 4-5 cm (Zalavras et al. 2007, Bishop and Shin 2011). However, in cases of impaired bone vasculature or osteomyelitis, using cancellous bone graft will usually lead to poor outcomes, even in small bone defects. Using the Masquelet technique of induced membranes, cancellous bone grafting can be used up to 25 cm in length (Masquelet 2003). The tibia has poor and thin soft tissue coverage, and even in a closed fracture the extent of the soft tissue damage may be significant. When the compound fracture or soft tissue loss due to complications is extensive, composite free bone flaps serve the needs of the reconstructive surgeon. In case of relative bone loss from a fragmented fracture with bleeding bone fragments, a free osteomuscular latissimus dorsi scapula flap can act as a living component together with soft tissue coverage, providing well-vascularized tissue that is believed to promote bone healing. However, in case of absolute bone loss, the vascularized scapula is insufficient because the bone is thin and weak. In these cases, the vascularized fibula flap is a viable option in reconstruction of tibial defects, especially in the diaphyseal area. However, raised as a composite flap the soft tissue amount it provides is insufficient to treat extensive 3-dimensional soft tissue defects. Combined with free muscle flap reconstruction, the Ilizarov and the Masquelet techniques are feasible reconstructive approaches in the treatment of compound tibial defects with absolute bone loss and extensive soft tissue deficiency. Also endoprotheses and flap coverage can be indicated in selected cases of compound tibial fractures.

Both tibial reconstruction and amputation are legitimate options in treatment of compound tibial fractures. In cases where the leg has been traumatically amputated, possibilities for microvascular replantation have to be also evaluated. When the limb is unsalvageable, lower extremity major amputation must be performed (Harris et al. 2009). The decision to amputate is affected also by cooperation, nerve and blood vessel damage, age, and comorbidities. Microvascular reconstruction on patients suffering from substance abuse or with low treatment cooperation should be

meticulously assessed. However, these unfortunate situations are not absolute contraindications for microvascular reconstruction.

Using different reconstructive methods should be evidence-based and patient-perceived treatment effects should be considered when choosing the optimal reconstructive approach. Treatment outcome assessments should be performed with validated outcome measures. The present study aimed to validate the Finnish version of the LEFS rating scale among foot and ankle patients. It also assessed the reliability and long-term outcomes of microsurgical reconstruction using selected microvascular techniques. In some cases microvascular reconstruction was combined with Ilizarov distraction osteogenesis in the treatment of compound tibial and ankle fractures or sequelae of complications.



**Figure 20.** Algorithm for reconstruction of compound tibial defects of both bone and soft tissue loss.

## 6.2 Reliability and validity of LEFS among foot and ankle patients

The LEFS is the most widely used generic instrument to assess lower extremity function (Shultz et al. 2013). Further, a myriad of patient-reported rating scales is described in the literature to assess foot and ankle musculoskeletal pathologies (Button and Pinney 2004, Martin et al. 2007, Hunt and Hurvit 2013, Shultz et al. 2013). The LEFS is one of the instruments previously validated among foot and ankle patients (Binkley et al. 1999, Alcock et al. 2002, Lin et al. 2009). Thus far, no valid PRO instrument has been available for Finns to assess foot and ankle function. Validation of an outcome instrument is a laborious and multistage process. The Finnish version of the LEFS underwent psychometric testing and validation among foot and ankle patients to assess the foot and ankle function of patients who had undergone free latissimus dorsi flap reconstruction combined with distraction osteogenesis. The process was undertaken to critically evaluate the study methodology and to fill in methodological gaps. The reliability and validity of the VAS-FA instrument were investigated in a separate study. The present study showed good internal consistency and reproducibility as well as convergent validity for the Finnish LEFS. These outcomes support the use of the Finnish version of the LEFS in the Finnish population for assessing foot and ankle musculoskeletal function after foot and ankle surgical procedures.

Previous studies of the LEFS instrument have shown no floor or ceiling effects (Lin et al. 2009, Cacchio et al. 2010, Hoogenboom et al. 2012, Naal et al. 2014, Hou et al. 2014, Cruz-Diaz et al. 2014, Nagahban et al. 2014, Pan et al. 2014, Alnahdi et al. 2015). This study had a low ceiling effect, as 17% of the participants received the maximum score in the first assessment. The ceiling value may indicate that extreme items were missing from the scale maximum, suggesting restricted content validity (Terwee et al. 2007). A large proportion of patients included in the study was operated on more than one year from the assessment. This may have had an impact on reaching the ceiling effect.

The ICC is a widely used measure of reliability and reproducibility. Excellent ICC was found, with a value of 0.93 (95% CI 0.91 to 0.95). Patients who had undergone surgical management within one year of completion of the questionnaire received slightly lower ICC values than patients over one year from the operation (0.88 vs. 0.97). The Taiwan Chinese version of the LEFS instrument also showed a high ICC (0.97) among patients with large variety of lower extremity pathologies (Hou et al. 2011). The Brazilian Portuguese version of the LEFS was tested with 87 patients suffering from knee pathologies of heterogeneous etiologies (Metsavaht et al. 2012). Reproducibility (ICC) proved to be as high as 0.96 (Metsavaht et al. 2012). It seems that the ICC of the LEFS may vary significantly depending on the patient group.

The absolute reliability or standard error of measurement (SEM) measures the score accuracy. In the present psychometric study of the LEFS, the absolute reliability was good. The study by Hou and colleagues reported an SEM value of 4.1, equal to that of the Finnish LEFS (Hou et al. 2014). In the Arabic version, the SEM was 3.5 (Alnahdi et al. 2015). Low SEM indicated that the LEFS has a high score accuracy. Therefore, the LEFS can be considered a reliable instrument for assessing foot and ankle musculoskeletal pathology. The SEM value was higher in the group undergoing surgical operation within one year of assessment. More substantial change in functional capability may take place in the subacute recovery phase.

The correlation between the LEFS values and the reference instruments was classified according to Andresen (2000). The strongest correlation was found between the LEFS total score and the 15D Mobility dimension. The outcomes indicate that the Finnish LEFS has good convergent validity. The LEFS instrument is highly function-related, which explains the strong correlation. The criterion validity of the Finnish version of the LEFS instrument was strong, as a correlation was found also with the overall 15D index. To confirm the criterion validity, the LEFS had to prove accurate at least with the 15D instrument, which has previously been validated in Finnish. The Italian version of the LEFS was tested for its criterion validity in a highly heterogeneous study population with lower extremity problems (Cachion et al. 2010). Foot and ankle pathology was present in 32 of the 250 patients. The Italian study showed a moderate correlation with the SF-36 Physical component summary score.

Factor analysis in this study revealed that the LEFS loaded on two factors. The second factor explained 83% of the total variance, indicating a strong result. Construct validity of the Finnish LEFS showed that factor one included items of daily activities and factor two consisted of function-related items. Hoobenboom found LEFS to load on two factors (Hobenboom et al. 2012). Naal and colleagues in validation of the German version of the LEFS instrument also noted loading on two factors (Naal et al. 2015). The German study also had items 16 to 19 loading on the second factor after 6 months from baseline assessment. Interestingly, their study found three additional items (2, 12, and 14) to load on the second factor at baseline. However, at 6 months the second factor explained 8.6% of the total variance. The factor should explain over 10% of the total variance to be accepted. Thus, one clear factor was seen in Naal's study of the German version of the LEFS. The study by Alnahdi et al. (2015) found all items to load heavily on one factor in the Arabic version of the LEFS in a sample of heterogeneous lower extremity pathologies.

### **6.3 Free osteomuscular latissimus dorsi scapula flap**

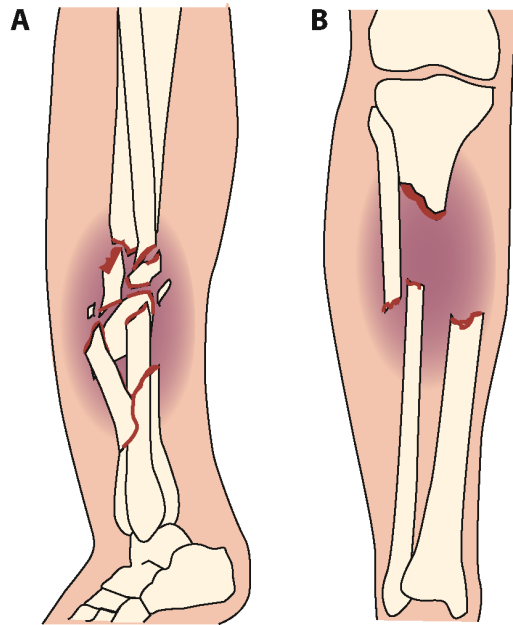
This study showed that the free osteomuscular latissimus dorsi scapula flap is reliable in reconstruction of extensive compound fractures of the tibia, supporting the outcomes of previous reports. The results indicate that this composite flap should belong in the surgeons' arsenal for tibial reconstruction. It seems to work well especially in largely fragmented and comminuted fractures combined with an extensive soft tissue defect. However, slight limitations in ankle movement are possible in the long-term. The shoulder performed perfectly or almost perfectly in most patients after raising the free latissimus dorsi scapula flap.



In this series of 26 patients, two early free flap complications occurred: one arterial thrombosis and one venous thrombosis in separate patients. In one patient, infection led to total flap loss, ultimately leading to below-knee amputation. Previous studies have shown a 100% flap success rate and no late amputations have been required when the free latissimus dorsi scapula flap is used in tibia reconstruction (Allen et al. 1993, Sawaizumi et al. 1995, Momeni et al. 2006, Coeugnet et al. 2007, Tachi et al. 2010,). However, the study population has been small in these studies, ranging from one to 12 patients, and thus, the total number of published cases of free latissimus dorsi scapula flap in lower extremity reconstruction is only 28. The findings of this study, with a significantly larger study population (26 patients) than in previous papers, had a 95% flap success. Described flap complications have been extremely rare. The most frequent early complication of previous studies has been venous thrombosis, occurring in one patient in a 10-patient series by Tachi et al. (2010). In our series, two of the 26 flaps developed arterial or venous thrombosis.

The mean time for full weight bearing in 25 of the 26 patients was 4 months (SD 3). This compares favorably with the outcomes in Study III, where the Ilizarov bone transport method was used for bone reconstruction; with this method, it took 14 months to achieve full weight bearing. One reasonable explanation for the discrepancy is the extensive absolute bone loss, which takes more time to heal, in the Ilizarov group. Also, the Ilizarov osteogenesis undeniably takes longer to perform. **Figure 21** illustrates the differences for indication of free latissimus dorsi scapula flap and free latissimus dorsi flap combined with the bone transport technique in tibial reconstruction.

It took a mean of 10 months (SD 6.1) for the free osteomuscular latissimus dorsi scapula flap to achieve radiological bony union. In Study III, where patients underwent either bone lengthening or transport, the mean time for bone union was 14 months. The majority of patients in Study II had sustained a Gustilo IIIB open fracture (16/26), and two (2/26) had a Gustilo type IIIC fracture. The free latissimus dorsi flap combined with distraction osteogenesis was indicated for seven patients (7/11) who had suffered a Gustilo IIIC open fracture. Radiological bone union was achieved 6 months earlier in the free osteomuscular latissimus dorsi scapula flap reconstruction group than in the bone transport group (**Table 22**). Both techniques have their place in compound fracture reconstruction in selected patients. Even though the vascularized fibula is the most widely used transfer in tibial reconstruction, in these cases it was not applicable due to its insufficient amount of soft tissue. The outcomes of the present study indicated that the free latissimus dorsi scapula flap should be chosen over the free latissimus dorsi flap and bone transport technique in treatment of fragmented or comminuted compound fractures.



**Figure 21.** (A) A fragmented compound fracture of the tibia, where free latissimus dorsi scapula flap can be indicated in the treatment. (B) Absolute bone loss of the tibia due to an open fracture. Free latissimus dorsi transfer combined with the bone transport can be indicated for bone reconstruction.

The wide range of 3 to 27 months for achieving bone union reflects the variety and complexity of these devastating compound defects with extensive fragmentation and comminution. However, functional outcomes and the outcomes in radiographs do not always correlate. Even when the radiographic finding is good, there can be significant functional impairment, and vice versa. The two patients for whom achieving radiological bone union took the longest both suffered from primary grade IIIB open fractures with a significant soft tissue defect, but no loss of functional muscle units. These patients underwent reconstruction 25 and 44 days after primary trauma, respectively. One of these two had no complications apart from the delayed bone union. The other patient had, however, fistulation on the edge of the flap. No explanation or correlation between comorbidities or complications and delayed union was found. Three patients suffered from alcoholism. In one of these patients, the bone union process was significantly complicated.

The 10-patient series of lower extremity reconstruction (tibia,  $n = 9$ ; femur,  $n = 1$ ) by Tachi et al. (2010) indicated that it takes approximately 3 months on average for the free osteomuscular latissimus dorsi scapula flap to achieve bone union. Nine of the ten patients had osteomyelitis at the time of reconstruction. Allen described an average time of 6 months for bone union using this technique in reconstruction of the tibia (Allen et al. 1998). In Allen's series, four of the 12 patients were reconstructed within 30 days of trauma. Further, Coeugniet and colleagues had a mean time of 4 months for bone union in their series of three patients who underwent tibial reconstruction using the free osteomuscular latissimus dorsi

scapula flap (Coeugniet et al. 2006). However, their series was small and generalizability of the results is weak. In the present series of 26 comparable patients, the mean time for achieving bone union was 10 months (SD 5). Time to radiological bone union was significantly longer than in previous studies.

Ankle function of the reconstructed limb ranged from significantly impaired to perfect. Based on these outcomes, it appears that the more distal the defect with intra-articular involvement, the more it affects ankle function. However, the study population was too small to draw solid conclusions concerning the impact of defect location on ankle motion.

Shoulder function of the donor site ranged from significantly impaired to no limitations. The outcomes of this cross-sectional assessment should be interpreted with caution because the cohort was small, no baseline data were available, and knowledge of, for instance, rotator cuff or shoulder joint status was lacking. Previous studies have, however, assessed shoulder function after free latissimus dorsi flap transfer. These outcomes are discussed in more detail in Section 6.1.2.

#### **6.4 Free latissimus dorsi flap and the Ilizarov technique**

There has been limited data on PROs of free latissimus dorsi muscle flap reconstruction combined with the Ilizarov technique in tibial reconstruction; however, evidence supports the use of this technique in selected cases (Krappinger et al. 2013). The present study confirmed that the microvascular anastomoses or flaps are not compromised when Ilizarov distraction osteogenesis is used for tibial bone defects or correcting tibial limb length discrepancy after soft tissue reconstruction using the free latissimus dorsi muscle flap. The long-term outcomes indicate that acceptable function of the reconstructed site is achieved, even in Gustilo type III fractures. HRQoL was found to be comparable with an age-standardized general population when using this combined technique for reconstruction of compound tibial fractures.

Spiro reported the outcomes of a case series of five patients with tibial grade IIIB and IIIC open fractures reconstructed using free latissimus dorsi, rectus abdominis, or tandem latissimus dorsi/serratus flap combined with the Ilizarov bone transport (Spiro et al. 1992). Their study showed that at a minimum of 17 months all patients achieved full weight bearing and radiological bone union. Duman's investigation showed that the disability period was between 16 and 25.5 months in nine Gustilo grade IIIB and IIIC tibia fracture patients using free muscle flap and the Ilizarov technique (Duman et al. 2001). These studies by Spiro and Duman have shown a 100% bone union (Spiro et al. 1992, Duman et al. 2001). In the present series of 16 patients, one patient had Gustilo grade IIIA and 12 patients had grade IIIB or IIIC fractures. The last three had either a type IIIA ( $n = 1$ ) or closed fracture ( $n = 2$ ). All patients finally achieved full weight and radiological bone union. Chim et al. (2011) reported that for two patients in their series of 28 patients who underwent free flap reconstruction combined with Ilizarov distraction osteogenesis late secondary lower limb amputation was performed. In the present series, there were no complications leading to amputation. The outcomes support the use of latissimus dorsi flap reconstruction and Ilizarov technique in acute trauma with extensive absolute bone

loss and sequelae of bone healing complications such as non-union and osteomyelitis.

The outcomes support the findings that distraction osteogenesis does not compromise the free muscle flap. However, distraction osteogenesis using an external fixator is a tedious process. External fixators disturb ambulation and pin site problems are common (Papakostidis et al. 2013). In the present series, six patients suffered a pin site infection. This complication has to be taken into consideration when using the Ilizarov method.

A prospective study by Tay et al. (2014) compared the HRQoL and return-to-work ratios in patients ( $n = 423$ ) with delayed union or non-union after a femoral or tibial shaft fracture ( $n = 138$ ) with patients with complete radiological bone union ( $n = 285$ ). Both outcomes were significantly worse in the group with delayed union or non-union (Tay et al. 2014). In the present series, 12 of 13 patients in working life returned to work. For four of the six patients treated due to tibial non-union, the preoperative working status was available. All four patients were in active working life and returned to work postoperatively.

Penn-Barwell et al. (2013) included in their study 57 open tibial fractures, 43 of which were Gustilo type III fractures. At the one-year follow-up, the median New Injury Severity Score was 22 out of a maximum of 75 points (29% injury level), indicating significant impairment (Penn-Barwell et al. 2013). In the present series of long-term assessment with the LEFS instrument, an average score of 59.4 out of 80 points (74%) was awarded for functional outcome at a mean follow-up of 22.5 years. The outcomes of the present study are in concordance with those of Penn-Barwell, however, they are not directly comparable due to the different outcome measures used.

Schep et al. (2009) assessed the long-term outcomes at a mean of 6 years postoperatively in patients with segmental tibial fractures treated using bone transport. Their study revealed a mean LEFS score of 47 points for three patients of closed fractures or Gustilo type II fractures that did not require soft tissue reconstruction. In the present study, eight patients who underwent tibia bone transport due to extensive absolute tibial bone loss received 59 (SD 8.6) out of 80 LEFS points. There are several factors, such as loss of functional units, which may have an impact on outcome. In the present series, patients had more severe open fractures than those in Schep et al. (2009). The outcomes of these two studies indicate that soft tissue reconstruction using the LD-muscle flap could even elevate the functional outcome. Schep's mean result for four patients in the tibial lengthening group was 62 points (SD 18). Two of the patients had Gustilo type III open fractures, but no data were available for soft tissue reconstruction. In the present series, three patients who underwent LD reconstruction and late bone lengthening received a mean of 62 LEFS points.

In most patients in this study, shoulder function proved to be good after raising the flap. Giordano et al. (2011) found significantly lower function of the donor site than of the contralateral upper extremity after raising the free latissimus dorsi flap. A

recent systematic review showed that significant limitations can initially occur, but shoulder function is slowly regained with time (Lee and Mun 2015).

The HRQoL assessment using the 15D instrument at a mean follow-up of 22.5 years showed lower scores in the dimensions of Mobility, Usual activities, and Discomfort and symptoms relative to an age- and gender-standardized general population. The lower score in the mobility dimension is in concordance with the other outcomes in this study. Further, a higher discomfort and symptoms score was noted. The mental function score was comparable with that of the general population and higher than that of Krappinger et al. (2013).

### **6.5 Free iliac crest flap in foot and ankle reconstruction**

The fasciocutaneous composition of the free iliac island flap gives the right contour to the recipient site and provides enough soft tissue to cover defects around the ankle and calcaneus. The flap is pliable and can be applied to the curved shape of the ankle region. It follows the “Replace like with like” principle preferred in plastic surgical soft tissue reconstruction. This kind of fasciocutaneous island flap allows reoperations of the bone when the surgical procedure is performed in several steps due to its elastic nature compared with muscle flaps. In the present series, three of the skin islands developed a partial necrosis, needing reoperation. No total loss of flap soft tissues was encountered. The long-term functional and HRQoL outcomes were encouraging in most patients considering the devastating traumatic etiology and the extent of the defects.

The iliac crest provides bone up to 24 cm in length and 4 cm in width (Zaker et al. 2014, Roger et al. 2015). However, the curved conformation of the iliac crest makes it unsuitable to reconstruct defects larger than 8 cm in size in the distal tibia. Larger bone transfers from the iliac crest are at risk of stress fractures at the donor site (Valentini et al. 2009). For large defects of the diaphyseal tibia, vascularized fibula transfer or distraction osteogenesis offers a better reconstructive alternative. Valentini et al. (2009) described herniation after raising the free iliac crest flap in one patient (3%) in a case series of 31 patients. A study by Lyons et al. (2005), on the other hand, estimated herniation at 17% after raising the vascularized iliac crest transfer in their 26-patient series. In the present series, one patient suffered from donor site herniation requiring local flap reconstruction. Even though complications may occur, the iliac crest is a viable option for harvesting vascularized bone transfers and composite vascularized bone flaps.

Valentini et al. (2009) noted that 8 of their 31 patients had pain lasting for 60 days or more. They also noted that 8 of the 31 patients suffered from walking difficulties for 60 days or more postoperatively. In the present series, severe disability of the donor site was noted in one of seven patients. This patient had severe donor site pain needing daily strong opioids. Minor donor site pain was reported by one of the seven patients. What remains undisputed is that donor site complications may occur after harvesting the free iliac crest flap. The lateral femoral cutaneous nerve must be identified and isolated to avoid nerve damage.

Bishop and colleagues retrospectively reviewed four cases of ankle arthrodesis using the free iliac crest flap (Bishop et al. 1995). All patients achieved bone union. However, twelve debridement and nine split-skin grafts were required due to partial soft tissue loss. Ultimately, secondary flap reconstruction was not necessary (Bishop et al. 1995). In the present series, three of the 12 patients who underwent foot and ankle reconstruction using the free iliac crest flap suffered from partial flap necrosis. All patients needed a revision procedure and one of them required a local flap. In the two-patient series of heel reconstruction using the free iliac crest flap by Peek and Giessler (2006), one of the patients suffered partial flap necrosis that required an instep island flap. In light of these findings, partial flap necrosis must be considered when using this technique. Reoperations may be required. However, the long-term outcome after the free iliac crest flap is used in foot and ankle procedures is generally good.

Bishop and Shin (2011) found in their review of 97 patients that the median time until bone union was 7 months after vascularized iliac crest transfer. Previous reports have shown that it takes 5 to 31 months for the free iliac crest flap to achieve complete radiographic bone union when used in foot and ankle reconstruction (Stevenson et al. 1987, Bishop et al. 1995, Peek and Giessler 2006, Rieger et al. 2009, Roger et al. 2015). In the present series, the median time for complete radiographic bone union was approximately 23 months in those patients for whom the transfer achieved successful union. One patient did not achieve bone union of the vascularized bone flap. This patient was previously diagnosed with alcoholism. Alcoholism may significantly impair patients' capacity to achieve bone union due to non-compliance and malnutrition. Further, one patient of the present series underwent late amputation due to chronic pain problems. Even if the vascularized bone flap achieves union, the overall extensiveness, nerve damage, and loss of functional units may lead to prolonged problems necessitating late amputation. The reconstruction can still be worthwhile pursuing in patients with extensive compound tissue loss and failure with other methods.

Rieger et al. (2009) reconstructed a 48-year-old woman's talar dome due to necrotic tissue damage. At the 16-year follow-up, ankle function had risen from the baseline score of 33 to 100 (perfect function) assessed using the AOFAS hindfoot scale. In the present series, two patients underwent talar reconstruction using the free iliac crest flap for achieving ankle arthrodesis. No baseline data were collected before initiating treatment with microvascular transfer. The cross-sectional functional results of the foot and ankle assessed showed 56.6 and 17.8 points of the total of 100 points, respectively, using the VAS-FA instrument. Hence, severe limitations were noted. Nonetheless, both patients were able to keep their limb and they had a HRQoL comparable with the Finnish general population.

### **6.6 Strengths and weaknesses of the study**

The LEFS PRO instrument underwent rigorous translation and cross-cultural adaptation into Finnish to guarantee equivalence with the original LEFS. The Finnish version Lower Extremity Functional Scale (LEFS) was also quantitatively validated with a commendable number of Finnish-speaking individuals. A further strength was the use of a comprehensive set of validated PROs in the cross-sectional assessment.

The location of the reconstructed site, loss of functional units, and patients' overall status may all have an impact on the patient-reported scores. This information was meticulously collected from patient records to provide a clear picture of patients' trauma and previous treatments.

The clinical follow-up time in Studies II-IV can be considered extensive compared with previously published studies of similar scope. Studies I-IV used the largest patient groups for the specific indications published in the literature to date. The numbers of patients treated with the particular surgical intervention in the retrospective review were considerable taking into account the low general incidence of these rare cases. However, the loss to follow-up (23 of the 55 patients) in Studies II-IV may have had an impact on the overall outcomes in the cross-sectional assessment. Further, the heterogeneity of the study populations makes it difficult to generalize the outcomes of the studies.

The Takakura rating system (Takakura et al. 1995) showed poor interobserver kappa values in a recent reliability study by Claessen et al. (2016). This may have had an impact on the study results. Nonetheless, at present, all of the rating systems available for assessing ankle arthritis have low interobserver agreement (Claessen et al. 2016). In light of this, the chosen approach for the assessment of ankle arthritis was justified.

In the assessment of donor site morbidity, no baseline data were available. The follow-up time was long. There might have been other underlying morbidities, such as impingement, rotator cuff injuries, or arthrosis, which affected the DASH score. Thus, the outcomes of the donor site function assessment should be interpreted with caution.

No specific instruments exist for assessing donor site disability after using the iliac crest as bone graft or transfer donor site. The Oswestry Disability Index (ODI) is a general disability measurement instrument that has been validated for back problems (Fairbank et al. 1990, Fairbank and Pynset 2000). It has been validated for the Finnish spinal fusion population (Pekkanen et al. 2011). It served well for the purposes of assessing donor site disability in Study IV. However, the ODI had not been validated for the assessment of donor site disability in patients after harvesting the free iliac crest flap. Its psychometric properties for this purpose remain unraveled.

In the scope of the present study, further validation of the LEFS for patients with open proximal tibia fractures could have offered even more insight into the psychometric properties of the LEFS for tibia fractures. However, validation of the LEFS for extensive open fractures reconstructed using the free latissimus dorsi flap and Ilizarov method would have been impossible due to the small number of patients treated with this combined method in Finland. Nonetheless, validation of the Finnish version of the LEFS with 165 foot and ankle patients serves the scientific community and has contributive value also for the literature. It also strengthens the reliability of the assessment of outcomes.

### **6.7 Clinical implications and future prospects**

This study provided a reliable and valid instrument for assessing lower extremity function in Finnish patients. The Finnish version of the LEFS instrument can be used for clinical and scientific purposes in assessing change in lower extremity function. It serves a wide variety of purposes and has previously been validated in different patient groups. The LEFS is compact and easy to administer. It would be, however, interesting to investigate the psychometric properties of the LEFS in a cohort of open tibia fractures. Further, the Finnish version of the lower extremity section of the Toronto Extremity Salvage Score could be validated among tibial fracture patients and the results compared with those of the LEFS instrument to provide insight into the clinicometrics of these two measures and perspective regarding which instrument to use for PRO assessment after tibial fracture.

The outcomes of the present study indicated that demanding methods of microsurgical tissue transfers are worth using in selected cases of extensive compound fractures or sequelae with massive bone and soft tissue loss. This study provides information for medical staff on the available microvascular techniques and their indications to facilitate treatment decisions. Patients must be meticulously selected for the treatment. Most patients achieve acceptable functional long-term outcomes using microvascular techniques in reconstruction of fractures and sequelae of complications in the tibia and ankle. These outcomes support the use of these challenging reconstruction techniques for compound defects in the ankle and tibia.

Composite tissue transfers, free muscle flaps, and Ilizarov bone transport and lengthening should be included in the arsenal of plastic and reconstructive surgeons. All surgeons who handle trauma patients should be aware of the indications for these techniques in tibia and ankle reconstruction. Our results showed that ankle arthrodesis can be achieved using the free iliac crest flap in patients for whom previous techniques have failed. In addition, massive compound defects of the foot and ankle due to trauma can be successfully reconstructed using the free iliac crest flap in cases where both bone and soft tissue are required. It would be interesting to know whether raising the free iliac crest flap negatively affects patients' HRQoL and disability in a larger study population. Some of the patients in the present series suffered from mild to severe limitations of the free iliac crest flap donor site.

The Visual Analog Scale Foot and Ankle PRO instrument has also been validated in a Finnish population undergoing foot and ankle surgery (Repo et al., unpublished data). It will soon be available for clinical and research purposes in assessing foot and ankle pain, function, and other complaints.

A prospective study to assess the long-term recovery of the latissimus dorsi donor site would give deeper insight into the functional limitations. Baseline data together with two-year, five-year, and ten-year follow-up assessments would shed light on the rehabilitation process. Further, the size of the harvested flap could be compared with the functional outcomes. The Finnish versions of the DASH and the QuickDASH as well as the upper extremity Toronto Extremity Salvage Score instruments could be



validated among patients who have undergone free latissimus dorsi flap transfer to investigate the construct validity of these outcome measures.

Functional status and HRQoL of patients who underwent traumatic amputation or late amputation due to open fracture of the tibia could be compared with those who underwent free latissimus dorsi flap limb salvage. It could be hypothesized that patients who undergo amputation would enjoy a higher functional and physical activity status as well as HRQoL than patients with a reconstructed limb. In this light, also data of HRQoL of major lower extremity amputees who have rehabilitated to prosthetic users after limb loss due to trauma could help us to understand the impact of the lost limb on patients' well-being. Thus far, no amputee-specific HRQoL measures have been available in Finnish. Nor have there been validated lower limb amputee-specific PRO instruments available for functional evaluation of major lower limb amputees and lower extremity prosthesis users. In further studies, lower limb amputee-specific outcome measures could be validated to provide tools for clinical and research purposes to assess the rehabilitation of major lower limb amputees.

## **7. CONCLUSIONS**

On the basis of Studies I-IV, the following conclusions can be drawn:

- I** The Finnish version of the Lower Extremity Functional Scale (LEFS) is reliable and valid to assess functional capability among foot and ankle patients. The Finnish LEFS showed good reproducibility and construct validity in Finnish participants who underwent surgical treatment for foot and ankle pathology.
- II** The free latissimus dorsi scapula flap is reliable in reconstruction of compound tibia defects of bone and soft tissue loss in selected patients. This technique can be used especially in fragmented and comminuted tibial fractures with an extensive soft tissue defect and in treating sequelae of complications in bone and soft tissue healing. The overall long-term outcomes of both the donor site of the latissimus dorsi transfer and the reconstructed site support the use of this technique.
- III** The combined method of microvascular latissimus dorsi flap and the distraction osteogenesis is reliable in treating absolute bone loss with a massive soft tissue defect in selected patients. This combined method is also reliable in correcting limb length discrepancy. The donor site of the latissimus dorsi flap performs well in the long-term, whereas acceptable long-term functional limitations may be expected in the reconstructed limb. The HRQoL outcomes are comparable with those of an age-standardized Finnish general population.
- IV** The free iliac crest flap is reliable in reconstruction of bone defects and compound bone and soft tissue defects in the foot and ankle in selected patients. The long-term functional outcomes using this method for foot and ankle reconstruction are acceptable considering the complexity of the defects. The possibility of donor site complications must, however, be considered when the free iliac crest flap is used. The HRQoL outcomes are comparable with those of an age-standardized Finnish general population.

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**APPENDICES**



**Appendix 1.** 15D Health-related quality of life instrument (15D©).  
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**QUALITY OF LIFE QUESTIONNAIRE (15D©)**

Please read through all the alternative responses to each question before placing a cross (x) against the alternative which best describes **your present health status**. Continue through all 15 questions in this manner, giving only **one** answer to each.

**QUESTION 1. MOBILITY**

- 1 ( ) I am able to walk normally (without difficulty) indoors, outdoors and on stairs.
- 2 ( ) I am able to walk without difficulty indoors, but outdoors and/or on stairs I have slight difficulties.
- 3 ( ) I am able to walk without help indoors (with or without an appliance), but outdoors and/or on stairs only with considerable difficulty or with help from others.
- 4 ( ) I am able to walk indoors only with help from others.
- 5 ( ) I am completely bed-ridden and unable to move about.

**QUESTION 2. VISION**

- 1 ( ) I see normally, i.e. I can read newspapers and TV text without difficulty (with or without glasses).
- 2 ( ) I can read papers and/or TV text with slight difficulty (with or without glasses).
- 3 ( ) I can read papers and/or TV text with considerable difficulty (with or without glasses).
- 4 ( ) I cannot read papers or TV text either with glasses or without, but I can see enough to walk about without guidance.
- 5 ( ) I cannot see enough to walk about without a guide, i.e. I am almost or completely blind.

**QUESTION 3. HEARING**

- 1 ( ) I can hear normally, i.e. normal speech (with or without a hearing aid).
- 2 ( ) I hear normal speech with a little difficulty.
- 3 ( ) I hear normal speech with considerable difficulty; in conversation I need voices to be louder than normal.
- 4 ( ) I hear even loud voices poorly; I am almost deaf.
- 5 ( ) I am completely deaf.

**QUESTION 4. BREATHING**

- 1 ( ) I am able to breathe normally, i.e. with no shortness of breath or other breathing difficulty.
- 2 ( ) I have shortness of breath during heavy work or sports, or when walking briskly on flat ground or slightly uphill.
- 3 ( ) I have shortness of breath when walking on flat ground at the same speed as others my age.
- 4 ( ) I get shortness of breath even after light activity, e.g. washing or dressing myself.
- 5 ( ) I have breathing difficulties almost all the time, even when resting.

15D©/Harri Sintonen ([www.15D-instrument.net](http://www.15D-instrument.net))

**QUESTION 5. SLEEPING**

- 1 ( ) I am able to sleep normally, i.e. I have no problems with sleeping.
- 2 ( ) I have slight problems with sleeping, e.g. difficulty in falling asleep, or sometimes waking at night.
- 3 ( ) I have moderate problems with sleeping, e.g. disturbed sleep, or feeling I have not slept enough.
- 4 ( ) I have great problems with sleeping, e.g. having to use sleeping pills often or routinely, or usually waking at night and/or too early in the morning.
- 5 ( ) I suffer severe sleeplessness, e.g. sleep is almost impossible even with full use of sleeping pills, or staying awake most of the night.

**QUESTION 6. EATING**

- 1 ( ) I am able to eat normally, i.e. with no help from others.
- 2 ( ) I am able to eat by myself with minor difficulty (e.g. slowly, clumsily, shakily, or with special appliances).
- 3 ( ) I need some help from another person in eating.
- 4 ( ) I am unable to eat by myself at all, so I must be fed by another person.
- 5 ( ) I am unable to eat at all, so I am fed either by tube or intravenously.

**QUESTION 7. SPEECH**

- 1 ( ) I am able to speak normally, i.e. clearly, audibly and fluently.
- 2 ( ) I have slight speech difficulties, e.g. occasional fumbling for words, mumbling, or changes of pitch.
- 3 ( ) I can make myself understood, but my speech is e.g. disjointed, faltering, stuttering or stammering.
- 4 ( ) Most people have great difficulty understanding my speech.
- 5 ( ) I can only make myself understood by gestures.

**QUESTION 8. EXCRETION**

- 1 ( ) My bladder and bowel work normally and without problems.
- 2 ( ) I have slight problems with my bladder and/or bowel function, e.g. difficulties with urination, or loose or hard bowels.
- 3 ( ) I have marked problems with my bladder and/or bowel function, e.g. occasional 'accidents', or severe constipation or diarrhea.
- 4 ( ) I have serious problems with my bladder and/or bowel function, e.g. routine 'accidents', or need of catheterization or enemas.
- 5 ( ) I have no control over my bladder and/or bowel function.

**QUESTION 9. USUAL ACTIVITIES**

- 1 ( ) I am able to perform my usual activities (e.g. employment, studying, housework, free-time activities) without difficulty.
- 2 ( ) I am able to perform my usual activities slightly less effectively or with minor difficulty.
- 3 ( ) I am able to perform my usual activities much less effectively, with considerable difficulty, or not completely.
- 4 ( ) I can only manage a small proportion of my previously usual activities.
- 5 ( ) I am unable to manage any of my previously usual activities.

**QUESTION 10. MENTAL FUNCTION**

- 1 ( ) I am able to think clearly and logically, and my memory functions well
- 2 ( ) I have slight difficulties in thinking clearly and logically, or my memory sometimes fails me.
- 3 ( ) I have marked difficulties in thinking clearly and logically, or my memory is somewhat impaired.
- 4 ( ) I have great difficulties in thinking clearly and logically, or my memory is seriously impaired.
- 5 ( ) I am permanently confused and disoriented in place and time.

**QUESTION 11. DISCOMFORT AND SYMPTOMS**

- 1 ( ) I have no physical discomfort or symptoms, e.g. pain, ache, nausea, itching etc.
- 2 ( ) I have mild physical discomfort or symptoms, e.g. pain, ache, nausea, itching etc.
- 3 ( ) I have marked physical discomfort or symptoms, e.g. pain, ache, nausea, itching etc.
- 4 ( ) I have severe physical discomfort or symptoms, e.g. pain, ache, nausea, itching etc.
- 5 ( ) I have unbearable physical discomfort or symptoms, e.g. pain, ache, nausea, itching etc.

**QUESTION 12. DEPRESSION**

- 1 ( ) I do not feel at all sad, melancholic or depressed.
- 2 ( ) I feel slightly sad, melancholic or depressed.
- 3 ( ) I feel moderately sad, melancholic or depressed.
- 4 ( ) I feel very sad, melancholic or depressed.
- 5 ( ) I feel extremely sad, melancholic or depressed.

**QUESTION 13. DISTRESS**

- 1 ( ) I do not feel at all anxious, stressed or nervous.
- 2 ( ) I feel slightly anxious, stressed or nervous.
- 3 ( ) I feel moderately anxious, stressed or nervous.
- 4 ( ) I feel very anxious, stressed or nervous.
- 5 ( ) I feel extremely anxious, stressed or nervous.

**QUESTION 14. VITALITY**

- 1 ( ) I feel healthy and energetic.
- 2 ( ) I feel slightly weary, tired or feeble.
- 3 ( ) I feel moderately weary, tired or feeble.
- 4 ( ) I feel very weary, tired or feeble, almost exhausted.
- 5 ( ) I feel extremely weary, tired or feeble, totally exhausted.

**QUESTION 15. SEXUAL ACTIVITY**

- 1 ( ) My state of health has no adverse effect on my sexual activity.
- 2 ( ) My state of health has a slight effect on my sexual activity.
- 3 ( ) My state of health has a considerable effect on my sexual activity.
- 4 ( ) My state of health makes sexual activity almost impossible.
- 5 ( ) My state of health makes sexual activity impossible.

**Appendix 2.** The original English Lower Extremity Functional Scale (LEFS).

We are interested whether you are having any difficulty at all with the activities listed below because of your lower limb problem for which you are currently seeking attention. Please provide an answer for **each** activity.

Today, do you or would you have any difficulty at all with:

Activities	Extreme Difficulty or Unable to Perform Activity	Quite a Bit of Difficulty	Moderate Difficulty	A Little Bit of Difficulty	No Difficulty
1. Any of your usual work, housework, or school activities	0	1	2	3	4
2. Your usual hobbies, recreational or sporting activities	0	1	2	3	4
3. Getting into or out of the bath	0	1	2	3	4
4. Walking between rooms	0	1	2	3	4
5. Putting on your shoes or socks	0	1	2	3	4
6. Squatting	0	1	2	3	4
7. Lifting an object, like a bag or groceries from the floor	0	1	2	3	4
8. Performing light activities around your home	0	1	2	3	4
9. Performing heavy activities around your home	0	1	2	3	4
10. Getting into or out of a car	0	1	2	3	4
11. Walking 2 blocks	0	1	2	3	4
12. Walking a mile	0	1	2	3	4
13. Going up or down 10 stairs (about 1 flight of stairs)	0	1	2	3	4
14. Standing for 1 hour	0	1	2	3	4
15. Sitting for 1 hour	0	1	2	3	4
16. Running on even ground	0	1	2	3	4
17. Running on uneven ground	0	1	2	3	4
18. Making sharp turns while running fast	0	1	2	3	4
19. Hopping	0	1	2	3	4
20. Rolling over in bed	0	1	2	3	4
Column totals:					

Score: \_\_\_\_\_/80 p.

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**Appendix 3.** The Finnish version of the Lower Extremity Functional Scale (LEFS). LEFS –alaraajan toimintakyky mittari.

**Ohjeet:** Olemme kiinnostuneet, onko teillä vaikeuksia alla esitetyissä toiminnoissa **alaraajaongelmaanne liittyen?** Ympyröikää yksi vaihtoehto kullakin riviltä.

Onko (tai olisiko) teillä vaikeuksia **tänään...** :

Toiminnot	Erittäin suuria vaikeuksia tai ei onnistu lainkaan	Melko suuria vaikeuksia	Kohtalaisia vaikeuksia	Lieviä vaikeuksia	Ei vaikeuksia
1. Selviytyä työstä, opiskelusta tai tavanomaisista askareista?	0	1	2	3	4
2. Osallistua harrastuksiin tai vapaa-ajan liikuntaan?	0	1	2	3	4
3. Päästä kylpyammeeseen?	0	1	2	3	4
4. Liikkua sisällä?	0	1	2	3	4
5. Pukea sukat tai kengät?	0	1	2	3	4
6. Kyykistyä?	0	1	2	3	4
7. Nostaa painavia tavaroita, kuten kauppakassia lattialta?	0	1	2	3	4
8. Suorittaa kevyitä kotitöitä?	0	1	2	3	4
9. Suorittaa raskaita kotitöitä?	0	1	2	3	4
10. Siirtyä autoon ja autosta pois?	0	1	2	3	4
11. Kävellä 200 metriä?	0	1	2	3	4
12. Kävellä 2 kilometriä?	0	1	2	3	4
13. 10 portaan kävelyssä (n. 1 kerrosväli)?	0	1	2	3	4
14. Seistä yhden tunnin ajan?	0	1	2	3	4
15. Istua yhden tunnin ajan?	0	1	2	3	4
16. Juosta tasaisella?	0	1	2	3	4
17. Juosta epätasaisella?	0	1	2	3	4
18. Tehdä nopeita käännöksiä juostessa?	0	1	2	3	4
19. Hyppiä kipeällä jalalla?	0	1	2	3	4
20. Kääntyä vuoteessa?	0	1	2	3	4
Yhteispisteet sarakeittain					

Kokonaispistemäärä \_\_\_\_\_/80 p.

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**Appendix 4.** The Visual Analogue Scale Foot and Ankle. © 2006 Martinus Richter. Reprinted with permission.

Foot and Ankle		Visual Analogue Scale (VAS)	
Name _____	Sex <input type="checkbox"/> m / <input type="checkbox"/> f	Date VAS □□.□□.□□	
Date of birth □□.□□.□□	Internal nr. □□-□□□□		
	Examiner □□□		
	Time <input type="checkbox"/> 1 preoperatively; 2 postoperatively, before implant removal; 3 at the time of implant removal; 4 after implant removal		

**Instructions for filling out the questionnaire**

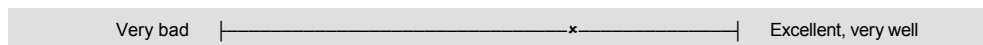
**Period:**

- Describe only the period before the accident or the surgery
- Describe only the period between the accident / surgery and the implant removal (IR)
- Describe only the actual period

(To be marked by the examiner)

On the reverse page is a questionnaire with questions relating to "foot problems" (e.g. pain of foot). For the answer of the questions a scale is available in form of a line. Please mark the appropriate point on the line with a cross, which describes best your personal situation at the above mentioned period. At the very left side of the line is the most negative value, at the very right the most positive. Please use only marks, do not write text!

This is an example for an answer of the question "How are you today?" as shown:



The answer at the cross on the line means in this example that you feel today "well", however not "very well".

Please answer the questions only negatively when the foot problems are really responsible for your limitation relating to a certain activity. Example: You would answer the question about foot problems when running with „running not possible“ because you do not have the necessary stamina for running. What we mean is that you could run in principle without foot problems or, whether your foot problems - like pain - make running impossible.

**You do not have to answer each question!** Answer only the questions which you would like and which you have understood! Please use the field "additions/characteristics/remarks" for suggestions for improvement and/or criticism.

**Explanation of some terms:**

**Physical rest:** This means that you do not do arduous things, i.e. you are reading a paper, lying on the sofa or in bed, watching television etc.

**Physical stress:** This means that you perform physical activities, i.e. arduous garden work, occupational work, sport etc.

**Housework:** Everyday activities like cleaning windows, ironing, dusting, washing up, cooking etc..

**Activities of daily life:** Personal activities such as getting out of bed, eating, washing yourself, getting dressed, tying your shoes etc.. The answer to this question should not refer to activities which are already mentioned in another place of the questionnaire (e.g. standing, bending forward, stretching etc.)!

**Additions / characteristics / remarks**

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<b>Strong limping</b>	<b>No changes, normal gait</b>
<b>How much do foot problems affect your gait?</b>	
Constantly, always	Never, very rarely
<b>How often do you have foot pain in physical rest?</b>	
<b>Extreme pain</b>	<b>No pain</b>
<b>How intense is this foot pain in physical rest?</b>	
Constantly, always	Never, very rarely
<b>How often do you have foot pain during physical activity?</b>	
<b>Extreme pain</b>	<b>No pain</b>
<b>How strong is this foot pain during physical activity?</b>	
<b>Do you have the impression that one leg is weaker than the other?</b>	
The weakness restricts me substantially	Same strength as in the healthy leg
<b>Do you have callous at the foot / feet ?</b>	
Widespread, painful callus	No callus
<b>Do you have a limitation of ankle or foot range of motion?</b>	
My foot/ankle joint is constantly rigid	No limitation of range of motion at any time
<b>Do you have problems when climbing stairs?</b>	
Climbing stairs impossible	Climbing stairs without limitation possible
<b>How much do foot problems affect your occupation?</b>	
Occupation cannot be practiced any more	No limitation
<b>How much do foot problems hinder you driving a car (operating clutch, accelerator, brake pedals)?</b>	
Driving a car not possible	Driving a car without limitation possible
<b>How long can you stand without foot problems?</b>	
Only briefly, and with crutches/stick	For hours, without limitation
<b>How much do foot problems affect your ability to stand on one leg?</b>	
Standing on one leg impossible	No limitation
<b>How long can you walk without foot problems?</b>	
Impossible, or briefly with crutches/stick	For hours, without limitation
<b>Do foot problems stop you from running (e.g jogging / on soft or uneven ground)?</b>	
Even short jogging is impossible	Jogging for extended periods possible
<b>How much do foot problems affect your daily activities (e.g. getting dressed, eating, washing etc)?</b>	
Impossible on my own, need constant help	No limitation
<b>How much do foot problems restrict traveling (traveling with trains, busses, aircrafts etc.)?</b>	
Traveling impossible	No limitation
<b>Do you have problems finding good footwear?</b>	
Can only wear orthopaedic shoes	Can wear any type of shoe
<b>How much do foot problems restrict walking on uneven ground?</b>	
On uneven ground walking is impossible	No limitations on uneven ground
<b>How much is your sensation in your foot/feet reduced?</b>	
No sensation	Normal sensation

**Appendix 5.** The Finnish version of the Visual Analogue Scale Foot and Ankle.

Tutkimusnumero \_\_\_\_\_

**Jalkaterä ja nilkka**

**Kipujana, Visual Analogue Scale (VAS)**

**Kyselyn täyttöohjeet:** Tämä kysely koskee "jalkaongelmia" (jalkaterän tai nilkan alueen kipuja). Kysymysten asteikko on esitetty janan muodossa. Olkaa hyvä ja merkitkää janalle pystyviiva sille kohdalle, joka parhaiten kuvaa tilannettanne **tänään**. Äärimmäisenä janan vasemmassa laidassa on huonoin mahdollinen ja äärimmäisenä oikeassa laidassa paras mahdollinen tilanne. Merkitkää ainoastaan pystyviivalla, älkää kirjoittako tekstiä. Voitte jättää vastaamatta sellaisiin kysymyksiin, jotka eivät kosketa teitä (esim. autolla ajo).

**Vastausesimerkki** (tähän kysymykseen ei tarvitse vastata):

**Kuinka voitte tänään?**

Erittäin huonosti |-----| Erittäin hyvin

Janalla oleva vastaus tarkoittaa tässä esimerkissä, että vointinne on kohtalainen, ei huono mutta ei hyväkään.



**1. Kuinka paljon jalkaongelmat vaikeuttavat kävelyä?**

Aiheuttavat voimakasta ontumista |-----| Ei poikkeavaa

**2. Kuinka usein jalkakipua esiintyy levossa (esim. maataessa, istuessa)?**

Toistuvasti, aina |-----| Ei koskaan, harvoin

**3. Kuinka voimakasta jalkakipua on levossa?**

Äärimmäisen kova kipua |-----| Ei kipua

**4. Kuinka usein jalkakipua esiintyy rasituksessa (esim. kävellessä, urheillessa)?**

Toistuvasti, aina |-----| Ei koskaan, harvoin

**5. Kuinka voimakasta jalkakipua on rasituksessa?**

Äärimmäisen kova kipua |-----| Ei kipua

**6. Onko vammautunut jalkanne heikompi kuin toinen?**

Merkittävästi heikompi |-----| Ei puolieroa

**7. Onko jaloissanne kovettumia?**

Kivuliaita / laajoja kovettumia |-----| Ei kovettumia

**8. Onko nilkan tai jalkaterän liikkuvuus rajoittunut?**

Nilkka / jalkaterä on jatkuvasti jäykkä |-----| Ei liikerajoitusta

Tutkimusnumero \_\_\_\_\_



**9. Kuinka paljon jalkaongelmat haittaavat portaissa liikkumista?**

Ei onnistu lainkaan | \_\_\_\_\_ | Ei ongelmia

**10. Kuinka paljon jalkaongelmat haittaavat työntekoa?**

Estävät täysin | \_\_\_\_\_ | Eivät rajoita  
työnteon | \_\_\_\_\_ | työntekoa

**11. Kuinka paljon jalkaongelmat haittaavat autolla ajamista (esim. polkimien käyttöä)?**

Estävät täysin | \_\_\_\_\_ | Eivät rajoita ajamista  
ajamisen | \_\_\_\_\_ |

**12. Kuinka kauan pystytte seisomaan ilman jalkaongelmia?**

Ei onnistu / lyhyen aikaa, | \_\_\_\_\_ | Tunteja, ilman  
keppiin tukien | \_\_\_\_\_ | rajoitusta

**13. Pystyttekö seisomaan yhdellä (vammutuneella) jalalla?**

Ei onnistu lainkaan | \_\_\_\_\_ | Ei rajoituksia

**14. Kuinka kauan pystytte kävelemään ilman jalkaongelmia?**

Ei onnistu / lyhyen aikaa, | \_\_\_\_\_ | Tunteja, ilman  
keppiin tukien | \_\_\_\_\_ | rajoitusta

**15. Pystyttekö juoksemaan jalkaongelmasta huolimatta (esim. pehmeällä tai epätasaisella alustalla)?**

Ei onnistu lainkaan | \_\_\_\_\_ | Ei rajoituksia

**16. Haittaavatko jalkaongelmat päivittäisiä toimintoja (esimerkiksi pukeutumista, syömistä, peseytymistä)?**

Eivät onnistu, | \_\_\_\_\_ | Ei rajoituksia  
jatkuva avuntarve | \_\_\_\_\_ |

**17. Rajoittaako jalkaongelma matkustamista joukkoliikennevälineillä?**

Ei onnistu lainkaan | \_\_\_\_\_ | Ei rajoituksia

**18. Onko teillä vaikeuksia löytää sopivia jalkineita jalkaongelmien takia (esim. korotettu tai leveämpi kenkä)?**

Vain erikoisvalmisteiset | \_\_\_\_\_ | Ei rajoituksia  
jalkineet sopivat | \_\_\_\_\_ |

**19. Estääkö jalkaongelma kävelyä epätasaisella alustalla?**

Estää täysin | \_\_\_\_\_ | Ei rajoita

**20. Onko jalassanne/jaloissanne tuntopuutoksia?**

Ei tuntoa lainkaan | \_\_\_\_\_ | Normaali tunto

**Appendix 6.** DASH main section. © 2006 Institute for work and health. Reprinted with permission.

## DISABILITIES OF THE ARM, SHOULDER AND HAND

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Write.	1	2	3	4	5
3. Turn a key.	1	2	3	4	5
4. Prepare a meal.	1	2	3	4	5
5. Push open a heavy door.	1	2	3	4	5
6. Place an object on a shelf above your head.	1	2	3	4	5
7. Do heavy household chores (e.g., wash walls, wash floors).	1	2	3	4	5
8. Garden or do yard work.	1	2	3	4	5
9. Make a bed.	1	2	3	4	5
10. Carry a shopping bag or briefcase.	1	2	3	4	5
11. Carry a heavy object (over 10 lbs).	1	2	3	4	5
12. Change a lightbulb overhead.	1	2	3	4	5
13. Wash or blow dry your hair.	1	2	3	4	5
14. Wash your back.	1	2	3	4	5
15. Put on a pullover sweater.	1	2	3	4	5
16. Use a knife to cut food.	1	2	3	4	5
17. Recreational activities which require little effort (e.g., cardplaying, knitting, etc.).	1	2	3	4	5
18. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5
19. Recreational activities in which you move your arm freely (e.g., playing frisbee, badminton, etc.).	1	2	3	4	5
20. Manage transportation needs (getting from one place to another).	1	2	3	4	5
21. Sexual activities.	1	2	3	4	5

## DISABILITIES OF THE ARM, SHOULDER AND HAND

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
22. During the past week, <i>to what extent</i> has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups? <i>(circle number)</i>	1	2	3	4	5
	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
23. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem? <i>(circle number)</i>	1	2	3	4	5
Please rate the severity of the following symptoms in the last week. <i>(circle number)</i>					
	NONE	MILD	MODERATE	SEVERE	EXTREME
24. Arm, shoulder or hand pain.	1	2	3	4	5
25. Arm, shoulder or hand pain when you performed any specific activity.	1	2	3	4	5
26. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5
27. Weakness in your arm, shoulder or hand.	1	2	3	4	5
28. Stiffness in your arm, shoulder or hand.	1	2	3	4	5
	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
29. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? <i>(circle number)</i>	1	2	3	4	5
	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. <i>(circle number)</i>	1	2	3	4	5

DASH DISABILITY/SYMPTOM SCORE =  $\frac{(\text{sum of } n \text{ responses})}{n} - 1 \times 25$ , where n is equal to the number of completed responses.

A DASH score may not be calculated if there are greater than 3 missing items.

**Appendix 7. QuickDASH main section.** © 2006 Institute for work and health.  
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**QuickDASH**

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Do heavy household chores (e.g., wash walls, floors).	1	2	3	4	5
3. Carry a shopping bag or briefcase.	1	2	3	4	5
4. Wash your back.	1	2	3	4	5
5. Use a knife to cut food.	1	2	3	4	5
6. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
7. During the past week, to what extent has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups?	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
8. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem?	1	2	3	4	5

**Please rate the severity of the following symptoms in the last week. (circle number)**

	NONE	MILD	MODERATE	SEVERE	EXTREME
9. Arm, shoulder or hand pain.	1	2	3	4	5
10. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
11. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? (circle number)	1	2	3	4	5

QuickDASH DISABILITY/SYMPТОM SCORE =  $\left( \left[ \frac{\text{sum of } n \text{ responses}}{n} \right] - 1 \right) \times 25$ , where n is equal to the number of completed responses.

A QuickDASH score may **not** be calculated if there is greater than 1 missing item.



**Appendix 8.** The Oswestry Disability Index (ODI). Reprinted with permission.

Oswestry Low Back Disability Questionnaire

## Oswestry Low Back Pain Disability Questionnaire

### Instructions

This questionnaire has been designed to give us information as to how your back or leg pain is affecting your ability to manage in everyday life. Please answer by checking ONE box in each section for the statement which best applies to you. We realise you may consider that two or more statements in any one section apply but please just shade out the spot that indicates the statement which most clearly describes your problem.

#### Section 1 – Pain intensity

- I have no pain at the moment
- The pain is very mild at the moment
- The pain is moderate at the moment
- The pain is fairly severe at the moment
- The pain is very severe at the moment
- The pain is the worst imaginable at the moment

#### Section 2 – Personal care (washing, dressing etc)

- I can look after myself normally without causing extra pain
- I can look after myself normally but it causes extra pain
- It is painful to look after myself and I am slow and careful
- I need some help but manage most of my personal care
- I need help every day in most aspects of self-care
- I do not get dressed, I wash with difficulty and stay in bed

#### Section 3 – Lifting

- I can lift heavy weights without extra pain
- I can lift heavy weights but it gives extra pain
- Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently placed eg. on a table
- Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned
- I can lift very light weights
- I cannot lift or carry anything at all

#### Section 4 – Walking\*

- Pain does not prevent me walking any distance
- Pain prevents me from walking more than 1 mile
- Pain prevents me from walking more than 1/2 mile
- Pain prevents me from walking more than 100 yards
- I can only walk using a stick or crutches
- I am in bed most of the time

**Section 5 – Sitting**

- I can sit in any chair as long as I like
- I can only sit in my favourite chair as long as I like
- Pain prevents me sitting more than one hour
- Pain prevents me from sitting more than 30 minutes
- Pain prevents me from sitting more than 10 minutes
- Pain prevents me from sitting at all

**Section 6 – Standing**

- I can stand as long as I want without extra pain
- I can stand as long as I want but it gives me extra pain
- Pain prevents me from standing for more than 1 hour
- Pain prevents me from standing for more than 30 minutes
- Pain prevents me from standing for more than 10 minutes
- Pain prevents me from standing at all

**Section 7 – Sleeping**

- My sleep is never disturbed by pain
- My sleep is occasionally disturbed by pain
- Because of pain I have less than 6 hours sleep
- Because of pain I have less than 4 hours sleep
- Because of pain I have less than 2 hours sleep
- Pain prevents me from sleeping at all

**Section 8 – Sex life (if applicable)**

- My sex life is normal and causes no extra pain
- My sex life is normal but causes some extra pain
- My sex life is nearly normal but is very painful
- My sex life is severely restricted by pain
- My sex life is nearly absent because of pain
- Pain prevents any sex life at all

**Section 9 – Social life**

- My social life is normal and gives me no extra pain
- My social life is normal but increases the degree of pain
- Pain has no significant effect on my social life apart from limiting my more energetic interests eg, sport
- Pain has restricted my social life and I do not go out as often
- Pain has restricted my social life to my home
- I have no social life because of pain

**Section 10 – Travelling**

- I can travel anywhere without pain
- I can travel anywhere but it gives me extra pain
- Pain is bad but I manage journeys over two hours
- Pain restricts me to journeys of less than one hour
- Pain restricts me to short necessary journeys under 30 minutes
- Pain prevents me from travelling except to receive treatment

**References**

1. Fairbank JC, Pynsent PB. The Oswestry Disability Index. Spine 2000 Nov 15;25(22):2940-52; discussion 52.

**Appendix 9.** Pre-information form.

Perhesuhde:  naimisissa/avoliitossa  leski  eronnut  naimaton

**TERVEYDENTILA** Pituus \_\_\_\_\_ cm Paino \_\_\_\_\_ kg

Lääkärin diagnosoimat sairaudet: \_\_\_\_\_

Lääkitys (nimi ja annos) \_\_\_\_\_

Leikkaukset \_\_\_\_\_

Ahtauttava valtimonkovettumistauti  ei  kyllä

Verenpainetauti (RR >140 / >90)  ei  kyllä

Diabetes  ei  kyllä

Tupakointi  ei  kyllä, keskimäärin \_\_\_\_\_ savuketta/päivä

Alkoholin käyttö  ei  kyllä, keskimäärin \_\_\_\_\_ pnä/viikko, \_\_\_\_\_ annosta /käyttökerta

(Yksi alkoholiannos vastaa yhtä ns. ravintola-annosta = pullo keskiolutta, 12 cl mietoa viiniä tai 4cl väkeviä).

**TOIMEENTULO**

työssä

vuorotteluvapaa

osaeläke

sairauspäiväraha  
eläke

opiskelija

kuntoutusraha

työtön

äitysloma/vanhempainloma

muu, mikä? \_\_\_\_\_

Ammatti \_\_\_\_\_

Koulutus: Peruskoulu  Ammattikoulu  Lukio  Yliopisto

Koulutusvuodet peruskoulun jälkeen (merkitse vuosimäärä X vuotta): \_\_\_\_\_

Sairausloman pituus viimeisten 12 kk aikana yhteensä \_\_\_\_\_ kk \_\_\_\_\_ päivää

Jos olette sairauspäivärahalla / eläkkeellä, johtuuko se pääosin tästä tutkittavasta sairaudesta?

Kyllä  Ei

Olitteko ennen sairauttanne töissä? Kyllä  Ei

Palasitteko saman alan töihin leikkauksen jälkeen? Kyllä  Ei

Merkitkää janalle poikkiviivalla viimeisen viikon aikainen kokemuksenne yleisestä terveydentilastanne.

täysin terve huonoin mahdollinen

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**Appendix 10.** FIT index.

<b>Liikunnan määrä</b>	<b>Kuinka usein harrastatte liikuntaa?</b>	<b>Pisteet</b>
	Vähintään 6 kertaa viikossa	5
	3-5 kertaa viikossa	4
	1-2 kertaa viikossa	3
	Muutaman kerran kuukaudessa	2
	Kerran kuukaudessa tai vähemmän	1
<b>Liikunnan teho</b>	<b>Kuinka rasittavaa liikuntaa harrastatte?</b>	
	Erittäin rasittavaa, kovatehoista liikuntaa. Hengästyminen ja hikoilu on runsasta, esim. kilpaurheilu	5
	Selvästi rasittavaa liikuntaa, joka aiheuttaa hengästymistä ja hikoilua	4
	Kohtalaisen rasittavaa liikuntaa esim. reipas kävely	3
	Kevyttä liikuntaa	2
	Hyvin kevyttä liikuntaa	1
<b>Liikunnan aika</b>	<b>Kuinka kauan liikuntasuorituksenne tavallisesti kestää?</b>	
	Pidempään kuin 30 minuuttia	4
	20-30 minuuttia	3
	10-19 minuuttia	2
	Alle 10 minuuttia	1

Mitkä ovat tyypillisimmät liikuntalajit, joita harrastat? Mainitse kolme.

1. \_\_\_\_\_

2. \_\_\_\_\_

3. \_\_\_\_\_