Department of Plastic and Reconstructive Surgery
University of Helsinki

PRETIBIAL INJURIES

CLINICAL PRESENTATION, TREATMENT PATHS, AND HEALTH ECONOMIC BURDEN

TONI SEPPÄLÄ

DOCTORAL DISSERTATION

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Miksi minua näin rangaistaan? Mikä laiva tämä on? Laita uuni päälle.

ABSTRACT

Background. Pretibial injuries are universal traumas among the morbid and elderly population. The injuries present as two distinct clinical variations: *pretibial lacerations* (PL) and *pretibial hematomas* (PH). PLs and PHs affect the skin and subcutaneous tissue between the knee joint and ankle due to a low-energy trauma such as falling on flat ground. PLs constitute different types of open wounds e.g. linear lacerations, flap lacerations, and total skin loss. PHs form when closed subcutaneous bleeding occurs. Blood causes soft tissue bulging and pressure to the skin, which can lead to skin necrosis if the hematoma is not evacuated. Both injuries result in skin defects needing local wound care and/or split-thickness skin graft (STSG).

Pretibial injuries are common and cause indisputable pain and suffering. However, PHs and PLs are not recognized as distinct medical entities in clinical practice and are grouped together in the literature. Despite being known to heal slowly, pretibial injuries are not described in medical textbooks nor in chronic leg ulcer classifications. No previous studies on pretibial injuries exist in Finland, and thus, information on their clinical presentation, treatment paths, and wound healing is lacking. Further, the economic burden of pretibial injuries has not been investigated.

Aims. The study's first and second aim were to separately review ≥ 65-year-old patients diagnosed with PLs and PHs. The focus was on patient demographics, clinical presentation, treatment paths, wound healing, complications, and mortality of the injuries. With PHs, risk factors for skin necrosis were evaluated. The third aim was to examine whether healing of the STSG donor site of pretibial injury patients was associated with complications. The fourth aim was to calculate and compare the health economic burden of the treatment of PLs and PHs.

Methods. The study was a retrospective analysis of electronic patient history files. Patients were diagnosed at Kymenlaakso Central Hospital and its surrounding health care centers during 2015-2019. Study I included 116 PL patients and Study II 60 PH patients. In Study II, risk factors for skin necrosis were identified by comparing patients treated with PH evacuation with those treated without intervention. Study III included 12 pretibial injury patients treated with STSG. In Study IV, a calculation and comparison of costs of 109 PL and 60 PH patients were conducted via examining NordDRG products and their invoice data generated from patient treatment periods.

Results. The demographic data of PL and PH patients were similar, constituting morbid elderly patients with a mean age of 79 and 81 years. Of PL and PH patients, 67% and 72%, respectively, were female.

The median healing time for PLs was 53 days (mean 75, range 4–356 d); 32% became chronic wounds as they had not healed at 90 days. The infection rate was 30%.

In PH patients, two different treatment paths were distinguished. Thirty-five patients (58%) were treated conservatively without any specific intervention, as they did not develop skin necrosis. Twenty-five patients (42%) needed surgical treatment (PH evacuation) due to skin necrosis; 60% of the skin defects after PH evacuation were left for local wound care with a median healing time of 82 days (mean 90, range 14-181 d).

Risk factors for skin necrosis comprised chronic skin fragility i.e. dermatoporosis ($p<0.0001$), a higher Charlson Comorbidity Index ($p=0.005$), and compromised patient independence ($p=0.033$).

The median time for STSG donor site healing was 23 days (mean 35, range 13–97 d).

Treatment of PLs and PHs generated 401 and 219 NordDRG invoices. The median total treatment cost among PLs was 240 € (mean 1800 €, range 132 € – 22 581 €). With PHs, the median of total treatment cost was 1100 € (mean 3300 €, range 132 € – 20 078 €).

The total costs, emergency room costs, cost of surgical treatment, and cost of inpatient care were higher in PHs than in PLs ($p=0.0486$, $p=0.0002$, $p=0.0058$, $p=0.6526$). PLs generated more costs from the outpatient clinic but this was not statistically significant ($p=0.6533$).

Conclusions. Pretibial injuries have characteristic features that must be recognized when diagnosing and treating patients. Skin defects caused by PLs and PHs frequently results in chronic wounds. Thus, pretibial injuries should be considered an independent etiological pathology for chronic leg ulcers.

PHs among morbid dermatoporotic patients require prompt surgical intervention to ease pain and prevent skin necrosis. However, PHs seem to not be recognized in time. Further, the infection rate of 30% among PLs and long treatment periods also suggests failures in current treatment.

Only 15 patients of all pretibial injury patients were treated with STSG. Using STSG was safe and did not result in significant complications, although prolonged donor site healing did occur. Thus, early STSG application should not be avoided.

Compared with PLs, PHs generate higher costs in healthcare mainly from emergency room visits and from operative treatment. PLs cause more burden in the outpatient wound clinic. Improved diagnosis and treatment are critical to cut costs and reduce patient suffering.

Keywords: Pretibial injuries, pretibial lacerations, pretibial hematomas, health economics, lower extremity wounds, skin grafts, donor site healing, DRG system, chronic leg ulcers, traumatic wounds

SUOMENKIELINEN TIIVISTELMÄ

Tausta. Pretibiaaliset vammat ovat yleisiä monisairailla vanhuksilla. Vammoja on kahta tyyppiä: *pretibiaaliset laseraatiot* (PL) ja *pretibiaaliset hematoomat* (PH). Molemmat syntyvät iholle polven ja nilkan väliselle alueelle pienienergisen vamman, kuten kaatumisen seurauksena. PL:t ovat ihon haavoja, palkeenkieliä ja puutoksia. PH muodostuu, kun ihonalaisrasvassa verisuoni katkeaa ja syntyy suljettu verenvuoto. Verimassa kohdistaa iholle painetta, joka voi aiheuttaa ihon kuolion. Molemmat vammat johtavat tyypillisesti haavanhoidon ja/tai ihonsiirreleikkauksen tarpeeseen.

Pretibiaaliset vammat aiheuttavat kipua ja inhimillistä kärsimystä. Vammat voivat johtaa pitkäaikaisen säärihaavan muodostumiseen. Siitä huolimatta pretibiaalisia vammoja ei ole tunnistettu omaksi haavaryhmäkseen. Aikaisempaa tutkimusta pretibiaalisista vammoista ei ole tehty Suomessa, joten tietoa vammojen piirteistä, hoitopoluista ja paranemisesta ei ole kuvattu. Samalla kun pretibiaalisten vammojen ilmaantuvuus kasvaa väestön vanhenemisen myötä, ovat vammojen aiheuttamat kustannukset myös jääneet arvioimatta.

Tavoitteet. Tutkimuksen ensimmäisessä ja toisessa osatyössä tarkasteltiin erikseen ≥65-vuotiaiden PL- ja PH-potilaiden taustasairauksia, vammojen ulkoisia piirteitä, hoitopolkuja, haavojen paranemista, ongelmia ja kuolleisuutta. Lisäksi PH-potilaiden osalta tarkasteltiin ihokuolion kehittymisen riskitekijöitä. Kolmannessa osatyössä tutkittiin ihonsiirteellä hoidettujen potilaiden ihonottokohdan paranemista. Neljännessä osatyössä laskettiin ja vertailtiin PL- ja PH-potilaiden hoitojaksojen kustannuksia.

Menetelmät. Kyseessä oli takautuva tutkimus, jossa tarkasteltiin pretibiaalisten vammapotilaiden sähköisiä potilasasiakirjamerkintöjä. Potilaat diagnosoitiin Kymenlaakson keskussairaalassa tai sen lähiterveyskeskuksissa vuosina 2015–2019. Ensimmäisessä osatyössä tutkittiin 116:n PL-potilaan taustatietoja, hoitoa ja paranemista. Toisessa osatyössä tutkittiin 60:n PH-potilaan hoitopolkuja ja ihon kuolion riskitekijöitä vertailemalla verihyytymän poistotoimenpiteellä hoidettuja potilaita niihin, jotka eivät tarvinneet verihyytymän kirurgista poistoa. Kolmannessa osatyössä tutkittiin 12 potilaan ihonottokohdan paranemista ihonsiirreleikkauksen jälkeen. Neljännen osatyön kustannuslaskelma ja -vertailu tehtiin 60:n PH-potilaan ja 109:n PL-potilaan NordDRG-tuotteiden laskutustiedoista potilaiden hoitojaksojen eri vaiheista.

Tulokset. PL -ja PH-potilaat olivat valtaosin monisairaita vanhuksia. Keski-ikä ryhmissä oli 79 ja 81 vuotta. Naisten osuus oli 67% ja 72%.

PL-potilaiden haavojen paranemisen mediaani oli 53 päivää (keskiarvo 75, vaihteluväli 4–356 päivää). PL:t muuttuivat kroonisiksi haavoiksi 32%:lla potilaista, kun paraneminen kesti yli 90 päivää. PL-potilaiden haavoista 30% tulehtui seurannassa.

PH-potilaiden kesken havaittiin kaksi toisistaan poikkeavaa hoitopolkua. Ilman leikkausta hoidettiin 35 (58%) potilasta, joilla PH ei aiheuttanut ihon kuoliota. Ihon kuolion vuoksi 25 (42%) potilasta hoidettiin kirurgisesti poistamalla verihyytymä. Hyytymän poiston jälkeen 60% ihopuutoksista jätettiin paranemaan paikallishoidolla. Haavan paranemisen mediaani oli 82 päivää (keskiarvo 90, vaihteluväli 14–181 päivää). Riskitekijöitä ihokuolion kehittymiselle olivat hauras iho eli dermatoporoosi ($p<0,0001$), korkeampi Charlson Comorbidity Index ($p=0,005$) ja alentunut kotona selviytyminen ($p=0,033$).

Ihonsiirteellä hoidettujen potilaiden ihonottokohdan paranemisen mediaani oli 23 päivää (keskiarvo 35, vaihteluväli 13–97 päivää).

PL- ja PH-potilaiden hoito johti kuntien laskutukseen yhteensä 401:llä ja 219:llä NordDRG-tuotteella. PL-potilaiden hoitokustannusten mediaani oli 240 € (keskiarvo 1800 €, vaihteluväli 132 € – 22 581 €). PH-potilaiden hoitokustannusten mediaani oli 1100 € (keskiarvo 3300 €, vaihteluväli 132 € – 20 078 €).

PH-potilaiden aiheuttamat kokonaiskustannukset olivat suurempia kuin PL-potilaiden ($p=0.0486$). Erikseen tarkasteltuna päivystys- ja leikkaushoidon kokonaiskustannukset olivat PH-potilailla merkitsevästi suurempia ($p=0.0002$ ja $p=0.0058$). Vuodeosastokulut olivat myös suuremmat, mutta ei merkitsevästi ($p=0.6526$). Kokonaiskustannukset haavanhoitoon liittyen olivat suurempia kuin PH-potilaiden, mutta ei merkitsevästi ($p=0.6533$).

Johtopäätökset. Pretibiaalisten vammojen erityispiirteet tulisi ottaa huomioon diagnosoitaessa ja hoitaessa potilaita. Paikallishoidolle jätettynä haavat paranevat hitaasti ja muuttuvat herkästi kroonisiksi säärihaavoiksi. Pretibiaaliset vammat tulisikin hyväksyä osaksi pitkäaikaisten säärihaavojen syiden kirjoa.

PH:t tulisi hoitaa verihyytymän poistolla varhaisessa vaiheessa haurasihoisilla ja monisairailla potilailla kivun helpottamiseksi sekä ihon kuolion estämiseksi. Diagnoosiin päästään kuitenkin liian myöhään. PL-potilaiden korkea tulehdusten määrä ja hidas paraneminen viittaa sekin puutteeseen hoidossa.

Vain 15 potilasta koko aineistosta hoidettiin ihonsiirteellä, vaikka ihonottokohta parani useimmilla komplikaatioitta. Varhaista ihonsiirteen käyttöä ei tulisi välttää.

Kustannuslaskelmien perusteella PH:t aiheuttavat enemmän sairastavuutta ja kuormittavat terveydenhuoltoa enemmän kuin PL:t. Diagnosoinnin ja hoidon parantaminen on tärkeää kustannusten laskemiseksi sekä inhimillisen kärsimyksen vähentämiseksi.

Avainsanat: Pretibiaaliset vammat, pretibiaaliset laseraatiot, pretibiaaliset hematoomat, terveystaloustiede, krooniset säärihaavat, ihonsiirre, ihonottokohdan paraneminen, DRG

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications:

I Seppälä T, Grünthal V, Koljonen V. Pretibial lacerations among elderly patients – A province-wide study from Kymenlaakso, Finland, 2015–2019. *J Plast Reconstr Aesthet Surg*. 2021; 74(9):2244–2250.

II Seppälä T, Grünthal V, Koljonen V. Pretibial hematomas – A real-world single-center study. *JPRAS Open*. 2022; 32:79–87.

III Seppälä T, Grünthal V, Koljonen V. Skin Graft Donor Site Healing among Elderly Patients with Dermatoporosis – A Case Series. *The Int J Low Extrem Wounds*. 2022;0(0).

IV Seppälä T, Grünthal V, Koljonen V. Bumping to a rollator walker: How pretibial hematomas create more costs than pretibial lacerations. *Int Wound J*. 2023;1–7.

The publications are referred to in the text by their Roman numerals and have been reprinted with the permission of their copyright holders. In addition, some unpublished material from Study IV is presented.

ABBREVIATIONS

CCI	Charlson Comorbidity Index
CLU	Chronic leg ulcer
DFU	Diabetic foot ulcer
DRG	Diagnosis-related group
DVT	Deep vein thrombosis
ER	Emergency room
FTSG	Full-thickness skin graft
ICD-10	International Classification of Diseases, 10th revision
LMWH	Low-molecular-weight heparin
LOS	Length of stay
MLL	Morel-Lavallée lesion
NPWT	Negative-pressure wound therapy
PG	Pyoderma Gangrenosum
PH	Pretibial hematoma
PIC	Personal identification code
PL	Pretibial laceration
POAD	Peripheral occlusive arterial disease
RBC	Red blood cell
STSG	Split-thickness skin graft
TBSA	Total body surface area
UV	Ultraviolet

1 INTRODUCTION

Morbid and polymedicated elderly patients, especially women, frequently present to the hospital and emergency rooms (ERs) due to a pretibial injury, comprising a unique group of traumatic wounds.[1–6] Pretibial injury can occur anywhere between the knee joint and ankle, typically on the medial-lateral-anterior aspect.[2–4] Despite the estimated incidence being high, 5.2/1000 (0.5%) of all ER visits[2,6], previous literature and knowledge are sparse.

Patients usually suffer a chronic cutaneous fragility syndrome, *dermatoporosis*, which among other comorbidities constitute the genesis and complications of pretibial injuries.[7–14] A significant complication is the development of chronic leg ulcers (CLUs) due to prolonged wound healing and large tissue defects.[4,15,16] CLUs are a worldwide problem affecting millions annually, representing a significant health risk and a substantial burden to patients and society.[17–19]

CLUs exist with various etiologies affecting over 5% of those aged 80 years or more.[18,20] The etiology and classification of CLUs can be divided into venous, arterial, mixed venous and arterial, and a varying set of atypical wounds.[17–21] Traumatic leg wounds are commonly left out of CLU classifications or addressed as one large group, regardless of differences in patient demographics, trauma etiology, and clinical presentation.

Pretibial injuries result from low-energy trauma e.g. falling on flat ground or hitting a household object.[3,6] The injuries quintessentially present as either *pretibial lacerations* (PLs) or *pretibial hematomas* (PHs), forming two distinct taxonomies within traumatic leg wounds.[2,22,23] Since patients' demographics and trauma etiology in both groups are uniform, not all previous literature uses this distinction.[6,24–26] Instead, PLs and PHs have been grouped together, despite differing clinical presentation and treatment.[3,4,6,22,27]

PLs manifest as open skin wounds, which can be categorized into five types according to the Modified Dunkin Classification, proposed by Lo et al in 2012.[3] Type I is a simple linear laceration and type II a flap laceration with an intact blood supply.[3] Type III is also a flap laceration but with a compromised blood supply, i.e. flap necrosis.[3] Type IV PL constitutes total skin loss.[3] A type V PL comprises an open skin laceration with an accompanying hematoma.[3] Skin defects caused by PLs are usually managed with local wound care, when under 1%TBSA (total body surface area).[3] Larger defects are generally treated with revision and a STSG.[3]

PHs typically manifest usually among patients with anticoagulants.[16,22,23,28] Minor shearing forces cause bleeding in the subcutaneous plane, separating the skin and subcutaneous tissue from muscle fascia.[16,22,23,28] A closed blood-

filled cavity is formed, and pressure in the cavity can exceed the blood pressure of dermal and subdermal capillaries.[16,22,23,28] This leads to ischemic pain and ultimately skin necrosis if the hematoma is not surgically evacuated in time.[23,29] A necrotic skin defect results in the need for surgical debridement. In such cases, STSG can be applied to cover the exposed soft tissue, or the wound can be left to heal by secondary intention.[24,30]

Pretibial injuries can result in CLUs and extensive mortality, can cause pain and suffering, and are estimated to have a significant financial impact.[1,22] As only a rough estimate of the costs of PHs has been published[22], the factors contributing to the healthcare costs related to pretibial injuries remain largely unknown. Further, pretibial injuries are frequently left unattended and practice gaps are seen.[15,24] Some studies advocate conservative treatment and others prefer early skin grafting.[25,31] Surgeons may avoid the use of STSGs, since donor site healing has been shown to be prolonged among the elderly.[32]

This series of studies approaches PLs and PHs separately due to differences in their pathogenesis. The thesis provides new information on the clinical presentation, patient demographics, risk factors, current treatment paths, wound healing, STSG donor site healing, and health economic burden of the injuries. Pretibial injuries are shown to represent a distinct CLU etiology and a new classification is proposed for their diagnosis and treatment.

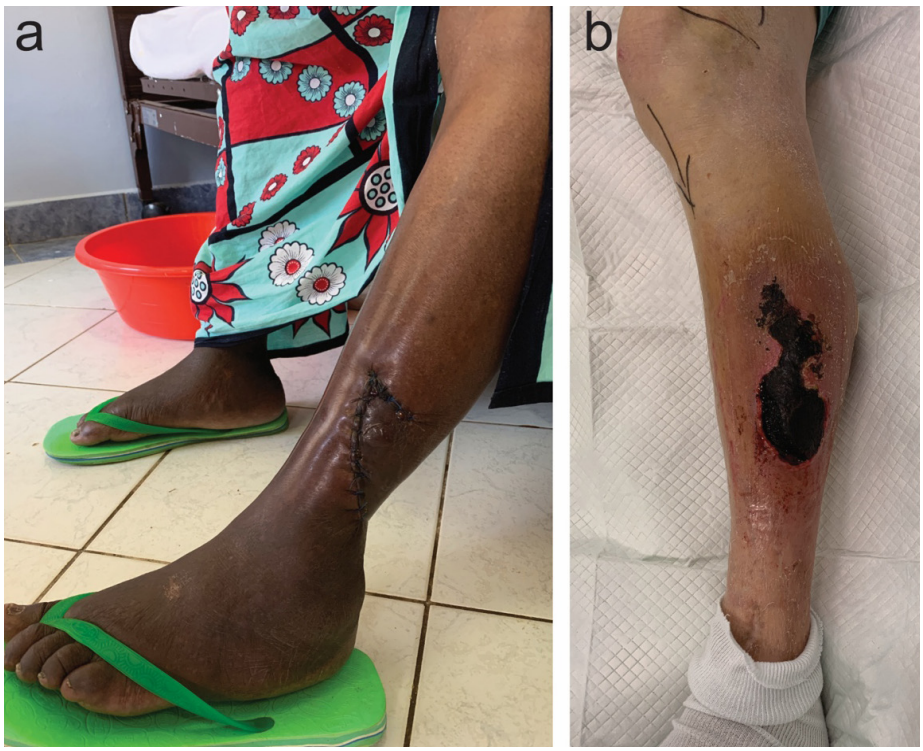


Image 1: A Modified Dunkin type II PL (a) and a PH with skin necrosis (b). © T. Seppälä

2 REVIEW OF THE LITERATURE

2.1 Wound healing

The skin is the largest organ system in the human body.[33,34] Serving as a physical, chemical and microbial barrier, the skin is also a sensate organ that communicates sensory information such as pain and heat from the external environment.[33] The skin is responsible for multiple physiological and humoral functions including thermal regulation, fluid balance, and vitamin D synthesis.[33] Thus, the integrity of skin plays a crucial role in human life.[33]

Wounds represent a disruption of the anatomic and physiologic continuity of the skin, while wound healing is a natural physiological reaction to this disruption.[34,35] Wound healing is a tremendously complex process involving interactions between numerous cell types, cytokines and other diverse mediators.[35,36] Many underlying physiological processes in wound healing remain unknown.[33,36] In normal physiological conditions, wound healing happens through four overlapping phases: hemostasis, inflammation, proliferation and remodeling.[19,33–36]

Hemostasis occurs after injury via vasoconstriction and blood clotting, which provides a matrix for cell migration.[33,34,36] Platelets secrete growth factors while cytokines attract a multitude of cells including fibroblasts, endothelial cells, and immune cells to initiate healing.[33,34,36] The following inflammatory phase, which typically lasts up to 7 days, consists predominantly of phagocytic cells cleaning the wound and initiating the proliferative phase.[33,34,36,37] The proliferative phase is primarily characterized by granulation tissue formation, angiogenesis, and epithelialization of the wound.[33,34,36] Finally, remodeling of the provisional matrix into organized collagen – a scar – begins and may last for years.[18,34,36]

The severity of a wound depends on its surface area and depth, as these affect the mechanisms of wound healing.[38] Partial-thickness wounds that involve the most superficial layer of the skin, the epidermis, and partly the underlying dermis, heal by primary intention via intact skin appendages such as hair follicles and sweat glands.[34,36]

In full-thickness wounds the dermis is destroyed exposing deeper layers of tissue.[35] This results in healing by secondary intention, as repair of tissue loss happens through the formation of granulation tissue before epithelial covering from wound margins occurs.[35] Healing by third intention is related to more complex wounds that are closed in a delayed fashion e.g. by plastic surgical reconstruction with flaps or using skin grafts.[35]

The art of using skin grafts as autografts to reconstruct skin defects is centuries old.[39] Skin grafts are thought to have originated from India over 2500 years ago.[39] Nowadays, STSGs have remained one of the most profound methods especially for more superficial defects.[38,40] A graft can only integrate on a vital wound beds or tissues capable of generating granulation tissue.[40] Harvesting STSGs results in a donor site wound, which is a partial-thickness wound that heals via primary intention.[34,36] Thicker grafts contract less and result in better functional and esthetic appearance.[41] However, the prognosis of skin graft integration on the wound bed can depend on graft thickness since it lacks an autonomous blood supply.[40] Therefore, thicker grafts result in more frequent graft failure and prolonged healing of the donor site.[41]

Histologically the process of graft integration is identical to that of wound healing.[40] However, skin graft integration has an initial phase of diffusion – imbibition – that lasts for 24–48 hours before the inflammation and revascularization phase begins.[40] During imbibition, the adherence between the graft and recipient wound bed happens via a fibrin network, whereas tissue nourishment is maintained by exudate.[40] After imbibition, capillaries from the wound edges and the wound bed move towards the graft and inhabit its vascular network in a process termed inosculation, typically occurring within 5–7 days.[40] Restoration of lymphatic circulation also occurs within 7 days.[39] The adjustment phase follows revascularization causing the graft to retract.[40] Finally, 2–4 weeks after grafting, innervation begins and modifications of pigmentation occur.[40] However, gaining full sensation may require several months or even years.[39]

Treatment with STSGs aims to fasten wound closure and epithelization of larger skin defects. However, a clinician must first treat the patients systemic diseases (e.g stabilize blood sugar levels among diabetics) and optimize local factors of the wound bed to attain the best possible outcome in surgery.

Many systemic disorders, such as peripheral vascular disease which results in hypoxia and ischemia, diabetes mellitus, smoking, and malnutrition can impair the normal wound healing process and also the skin graft integration.[11,13,33,40] Local factors that impair wound healing and graft integration are pressure, edema, infection, bacterial biofilm, maceration, and dehydration.[37,40] Taken together, disruption in these systemic and local factors can cause a wound to fail to proceed through the normal phases of healing, resulting in chronic wounds such as CLUs.[19] Addressing these factors usually provides an optimal environment for wound healing to proceed.

2.2 Chronic leg ulcers

Depending on the healing process, wounds can be regarded as acute or chronic.[35] Chronic wounds differ from acute ulcers in that they fail to progress through

a normal, orderly and timely sequence of tissue repair processes, resulting in a longer time to restore normal anatomical and functional integrity.[18,35] Often, chronic wounds stall in the inflammatory phase, which is characterized by excessive levels of proinflammatory cytokines and proteases leading to the destruction of the extracellular matrix.[36] This attracts more inflammatory cells and mediators amplifying the inflammation cycle.[19,36] A wound is considered chronic if healing does not occur within the expected period according to its etiology and size.[20] Normal healing happens in a time frame from four to six weeks to a maximum of three months.[20,42] Most chronic wounds are situated in the lower extremity, presenting as either CLUs or chronic foot ulcers.[17,19,20] Wounds in highly vascularized areas such as the head and neck area, and in the hands tend to heal with a good prognosis.[35,38]

CLUs affect 0.5-2% of the general population worldwide and are associated with increased mortality and morbidity and limitation in daily activities.[17–19,37,42] Psychosocial consequences are seen due to pain, infections, foul odor and discharge from the wound bed.[18] CLUs represent a clinical challenge for healthcare professionals and an unmet medical need for patients.[18] While improved wound care has occurred, malpractice still exists, and CLUs will continue as an even greater public health concern as the population ages and the incidence of risk factors for CLUs rises.[18] To fight against the growing number of patients with CLUs, more and better-trained clinicians are needed.[18]

Care for CLUs requires a multidisciplinary approach where the wound characteristics are modified towards that of an acute healing wound.[33,34,43] Making a correct wound diagnosis is paramount, which means addressing the etiologic cause, while not forgetting patient-dependent factors.[20,43] Hence, a simple stamp of "chronic leg ulcer" is not good practice, nor is it a sufficient diagnosis.[18–20,43] A comprehensive assessment of the patient, history, skin, vascular status, wound location, and ulcer characteristics is required to determine the correct etiology for planning adequate management.[18,20,37,43]

2.2.1 Etiology and classification

The etiology of CLUs is heterogeneous, with numerous different pathogeneses.[19,20,37,43] CLUs are typically divided into venous, arterial, mixed venous and arterial, and atypical wounds.[17,19,20,33] Atypical wounds constitute only 5%, despite multiple etiologies per se.[17,18,37] Atypical wounds include, but are not limited to, vasculitis, livedoid vasculopathy, pyoderma gangrenosum, hypertensive ischemic wound (Martorell's wound), calciphylaxis, infectious wounds (e.g. tuberculosis), dermatitis-based wounds, lymphedematic wounds, iatrogenic wounds (e.g. pharmaceuticals), and malignant wounds.[44–55]

In addition to CLUs, chronic foot ulcers belong to the discussion of chronic lower extremity wounds.[18] Foot ulcers manifest distally, close to bony

prominences and weight bearing areas contributing substantially to the total burden of chronic wounds.[18,56,57] Foot ulcers include and can be a combination of diabetic foot ulcers (DFU), ischemic ulcers due to peripheral occlusive arterial disease (POAD), pressure injuries, and more uncommonly tophaceous gout ulcers.[56–58] DFUs are the most common etiology for chronic foot ulcers.[18]

- ***Venous leg ulcers.*** Venous insufficiency is the most common etiology for CLU, with 50-80% of CLUs being of venous origin.[17,20,21,37,42] The prevalence of venous leg ulcers (VLUs) in individuals aged over 65 years is 4%.[17] Risk factors include age, female sex, obesity, immobilization and deep vein thrombosis.[21] VLUs occur, when malfunctioning vein valves cause reflux and venous hypertension.[20,21] Ulcers are superficial and moist, typically granulating.[20,21] The most common site is the distal crural region above the medial malleolus, but venous ulcers can be broad and circular as well.[20,21] Other skin findings of chronic venous insufficiency, such as lipodermatosclerosis, thrombophlebitis, edema, and pigmentation, are frequently observed.[20,21] Primary treatment is compression therapy and surgical treatment of venous insufficiency, e.g. by radio ablation therapy.

- ***Arterial leg ulcers.*** POAD contributes significantly to the etiology CLUs and foot ulcers. In 10% of CLUs, POAD is the only identifiable etiology.[52] Smoking, age, and diabetes are significant risk factors.[21,35,52] Clinically, leg ulcers are located at the lateral or pretibial area, or on the foot dorsum.[52] Foot pulses are usually absent, the extremities are cold, and wound pain is common.[52] An ankle-brachial index of under 0.9 indicates POAD.[21] In contrast to the distal necrosis of toes and forefoot in Fontaine stage IV POAD, the management of ischemic leg ulcers is less clearly defined.[52] POAD is underdiagnosed in patients with leg ulcers and suboptimal compression therapy using elastic bandages can result in iatrogenic damage.[52] Ulcers are typically dry, necrotic and deep.[52] Referral to a vascular surgeon for revascularization is key.

- ***Mixed venous and arterial leg ulcers.*** About 10% of CLUs are a result of both venous insufficiency and POAD.[21,52] The clinical presentation of these ulcers constitutes a varying combination of typical characteristics of both diseases.[21] Patients are referred to a vascular surgeon.

Atypical leg ulcers

- ***Cutaneous vasculitis.*** Vasculitis is a group of inflammatory diseases of the cutaneous small vessels, often responsible for skin ulcers.[50] Pathogenetically, two mechanisms are distinguished: inflammatory microangiopathy and

occlusive microangiopathy.[50] Focal ischemia explains the tissue necrosis and subsequent cutaneous ulceration. The skin is one of the target organs in vasculitis due to the anatomic features of postcapillary venules and the microcirculation physiology influenced by hydrostatic pressure.[50] Hence, the ulcers are typically located in the legs and feet. Lesional biopsy and histological examinations are mandatory for diagnosis. Treatment comprises anti-inflammatory and immunosuppressant therapy in the dermatology clinic.

- ***Vasculopathies.*** Livedoid vasculopathy is a chronic, recurrent, and painful skin condition, the pathogenesis of which is not understood.[51] The disease predominantly presents as bilaterally, affecting the lower extremities.[51] Livedoid vasculopathy is associated with a primary lesion of purpura progressing to shallow ulcerations and surrounding atrophie blanche.[51] Atrophie blanche presents as atrophic, stellate, white, scar-like plaques with teleangiectasia and hyperpigmentation.[51] Patients are referred to dermatologists for diagnosis and treatment.

- ***Pyoderma gangrenosum.*** Pyoderma gangrenosum (PG) is an uncommon ulcerative skin disease with unique clinical characteristics, predominantly affecting the lower extremities.[48,53] PG typically presents with painful, well-defined ulcers with violaceous borders.[45] It belongs to the neutrophilic dermatoses group of inflammatory dermatoses.[45] PG is frequently associated with other systemic diseases, especially inflammatory bowel diseases, rheumatoid arthritis, other autoimmune diseases, hematologic cancers and solid tumors.[45] PG has no infectious etiology or tissue-related vascular gangrene.[45] A biopsy of the wound can help rule out other diagnoses such as vasculitis. Depending on ulcer characteristics, PG can be treated topically, intralesionally, or with systemic corticosteroids and immunosuppressants.[45] Patients are referred to dermatologists for diagnosis and treatment.

- ***Martorell's hypertensive ulcer.*** Martorell's ulcer is a rare ischemic and extremely painful ulcer resulting from severe and poorly treated systemic hypertension.[46] Ulcers occur in the absence of peripheral arterial disease or venous insufficiency.[46] Obstruction of small arterioles cause lesions to the distal third of the leg, usually around the Achilles tendon region and anterolateral calf.[46] Classically the ulcer has variable depth, a necrotic base and violaceous edges.[46] The diagnosis is clinical and often delayed, following exclusion of other etiologies. A combination of several drugs accompanied by surgery may be required for healing. Skin grafting typically leads to a rapid improvement in pain.[46]

- ***Calciphylaxis.*** Also known as Calcific uremic arteriolopathy, calciphylaxis is a rare complication associated with end-stage renal disease.[47,53,54] However, the pathogenesis is complex and involves multiple factors. Intense deposition of calcium in small blood vessels, skin, and other organs is characteristic.[47,53,54] Calcification of arterioles leads to thrombotic occlusion resulting in painful necrotic ulcerations.[47,53,54] Subcutaneous indurated plaques are accompanied by livedo reticularis evolving towards a black eschar. Lesions can be located anywhere on the body.[47,53,54] The best way to confirm diagnosis is with skin biopsy. Drugs like sodium thiosulphate and bisphosphonates can be used in treatment.[47,53,54] One year mortality rates are estimated poor at 60-80%.[47,53,54]

- ***Lymphedema.*** Ulcer development in chronic lymphedema is less common than with venous insufficiency.[44] Lymphedema can present with lymphangiectasia, lymphorrhea (lymph drainage through the skin), inflammation and pustule formation, infection, papillomatosis, and hyperkeratosis.[44] These multiple skin changes result in deficient perfusion to the skin and the formation of ulcers.[44] Lymphorrhea causes maceration and tissue breakdown contributing significantly to ulcer formation.[44] Secondary pathological findings include pressure ulcerations due to heavy limbs or bandage misapplication, and venous ulceration from secondary venous stasis.[44] Lymphedema can be treated with pressure garments and/or surgery.

- ***Malignant ulcers.*** Skin cancers associated with CLUs are underrecognized.[18,49] They may result from a chronic ulcer undergoing malignant transformation (Marjolin ulcer) of prolonged duration or may arise de novo and mimic the appearance of CLUs.[18,49] The most common malignant ulcers arise from squamocellular carcinoma and basocellular carcinoma.[49] Metastases of cancers can arise on the skin presenting as a malignant ulcer.[49]

- ***Iatrogenic wounds.*** Iatrogenic injury refers to tissue damage caused by necessary medical treatment, pharmacotherapy, or the application of foreign medical devices[45,53]. Iatrogenic wounds include various acute wounds e.g. skin graft donor sites, injury due to laser, post-radiation therapy wounds, surgical site infections, wounds from immobilization devices such as casts[59], hospital-acquired pressure injuries, and wounds due to pharmacotherapy such as warfarin-induced necrosis.[45,55] Other wound-causing pharmaceuticals include chemotherapy, methotrexate and hydroxyurea.[45]

- ***Infectious wounds.*** Non-healing atypical wounds can be of infectious origin. When patient has recent travel history or is immunocompromised and presents with an atypical wound, infectious etiologies such as cutaneous

leishmaniasis, tuberculosis, Buruli ulcer, leprosy, and ecthyma gangrenosum should be considered. Acute fulminant and life-threatening conditions such as necrotizing fasciitis can result in CLUs due to various mechanisms.[60–62]

- ***Dermatitis.*** Various skin disorders can manifest as wounds. Such entities include necrobiosis lipoidica, ulcerative lichen ruber planus, epidermolysis bullosa and bullous pemphigoid.[53,60]

Chronic foot ulcers

- ***Diabetic foot ulcers (DFUs).*** Chronic hyperglycemia in diabetes results in multiple target-organ failures. DFU or diabetic foot syndrome affects 9-26 million diabetes patients annually worldwide.[56] More than half of DFUs become infected and approximately 20% of moderate to severe DFU infections lead to some level of amputation.[56] DFUs are typically seen in patients with diabetic neuropathy when repeating mechanical stress affects areas subject to pressure.[56] Also, a sudden minimal trauma to a diabetic foot can rapidly escalate to a DFU. POAD, when present, contributes to the formation of DFUs. Motor neuropathy leads to foot deformity, while sensory neuropathy results in the loss of protective sensation.[56] Finally, autonomic neuropathy decreases sweating resulting in dry skin. These three aspects of neuropathy lead to skin callus formation at pressure points of the foot.[56] The formed callus easily becomes hemorrhaged, and an ulcer is formed.[56] With appropriate therapy, surgical debridement and pressure off-loading DFUs heal in many patients.

- ***Pressure injuries.*** In individuals with normal sensation, mobility, and mental status, prolonged pressure prompts a change in body position through a feedback response. When the feedback response is lacking, sustained pressure ultimately leads to tissue ischemia, injury, and necrosis.[58,63] The National Pressure Injury Advisory Panel (NPIAP) defines pressure injuries as localized damage to the skin and its underlying tissue, usually over a bony prominence or related to a medical or other device because of intense or prolonged pressure in combination with shear.[58,63] The lower extremity is affected in 15–25% of cases, typically the posterior heel and lateral malleolus.[58,63] Pressure injuries are classified into six categories with the NPIAP staging system.[58,63] Stage I presents as nonblanchable erythema of intact skin. Stage II presents as partial-thickness skin loss with exposed dermis. Stage III presents as full-thickness skin loss and exposed adipose tissue. Stage IV presents as full-thickness skin and tissue loss exposing the fascia, muscle, tendon, ligament, cartilage or bone. Unstageable pressure injuries are obscured by eschar and cannot be staged. Removal of eschar

reveals a stage III or IV injury. Deep tissue pressure injury presents as persistent non-blanchable deep red, maroon or purple discoloration of intact or nonintact skin.[58,63] Treatment typically requires debridement and reconstruction of the tissue defect accompanied by strict restrictions in posture after surgery.

- ***Ulcerated tophaceous gout.*** Gout is the most common inflammatory arthropathy.[57,64] It is caused by accumulation of urate crystals typically in synovial fluid but also in other tissues such as skin.[57] While gout is more common in males, the development of tophaceous gout is more frequent in women.[57] Chronic gout with inadequate treatment is characterized by tophi formation and the presence of symptoms between acute attacks.[57,64] Breakdown of skin can happen, forming an ulcer with tophus discharge. When ulcers manifest on the feet at sites of joints and weight-bearing areas, delayed healing is common.[60] Compounding the problem, patients with gout often have other comorbidities contributing to prolonged healing.[60]

2.2.2 Traumatic wounds

Traumatic wounds are acute wounds characterized by sudden wound formation through a mechanical force. The etiology of the injuries varies from sharp penetrating injuries to blunt force, thermal injuries (burns), chemical injuries and animal bites.[35] Depending on the mechanism, traumatic wounds can present as clean iatrogenic surgical wounds, severe tissue loss with contamination, simple lacerations, contusions, abrasions or a combination of these. The mechanical force leading to a traumatic wound can be of high or low velocity, such as a gunshot wound or a simple fall on flat ground, affecting the clinical presentation and prognosis of the wound.

Traumatic wounds are seldomly included in chronic wound classifications due to their etiological diversity and typically good prognosis. Patients also report traumas differently. Many report CLUs to have progressed from a trivial trauma such as a scratch or a blister. These are not to be classified as traumatic wounds, as usually the wounds progress revealing the clinical appearance of a known CLU etiology such as POAD. Thus, when healing of a traumatic injury is halted and the wound appearance changes, clinical investigations are conducted to rule out CLU etiologies. Sometimes a clear physiological disorder is not found as an underlying cause for the prolonged healing.

Pretibial injuries are a recursive traumatic wound etiology with distinct clinical features. Already in 1965 Dr. Rozner stated that traumatic wounds below the knee heal more slowly than similar wounds elsewhere.[65] Suggested reasons for this were a vicious cycle of poor blood supply of the pretibial region, use of tight sutures, wound edge necrosis and infection.[65] Hence, a hypothesis that

pretibial injuries are an independent cause for CLUs is justifiable. Obviously, underlying medical conditions (which are evident among pretibial injury patients) as contributing factors to the slow healing should not be overlooked.

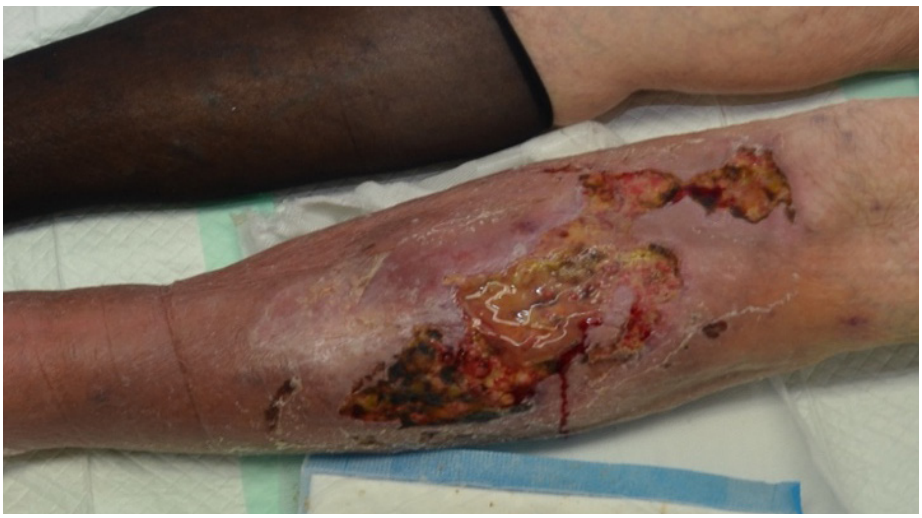


Image 2: Chronic leg ulcer caused by a traumatic pretibial hematoma. © T. Seppälä

2.3 Pretibial injuries

Pretibial injuries include PLs and PHs, which are common traumatic wound entities in the morbid and elderly population, especially among women.[1–3,5,15,24–27,66] PLs and PHs occur typically from minor low-energy traumas such as falling on flat ground, ascending stairs, or hitting an object.[2,66] PHs form their own pathology in pretibial injuries with a distinct clinical presentation and symptoms.[22,23] However in some literature, e.g. classifications from Dunkin[5] and Lo et al. [3], PHs seem to be partly included with PLs.[3,5,25,27] Also Tuboku-Metzger et al., Vasdeki et al., and Hili et al., group PHs and PLs together in their studies.[1,25,31]

Despite pretibial injuries being common, scientific literature on these injuries is sparse. From the handful of papers many are either decades old[65,67–72], literature reviews[2,3,5,66], case reports[28–30,70,73–76], or retrospective studies.[1,2,4,6,16,22–25,27,28,77,78] A few randomized prospective studies on the treatment of PLs have been conducted, but they have limitations in cohort sizes and patient heterogeneity.[67–69,77,79] These studies are discussed in Sections 2.4 and 2.5. Since pretibial injuries mostly occur in the frailest, elderly patients in community health care settings, they traditionally have not been considered an interesting research subject.

2.3.1 Incidence

In New Zealand, the estimated incidence of pretibial injuries is 40–70 per 100 000 annually.[6] They account for 5.2 per 1000 (0.5%) of all ER attendances in the United Kingdom.[2,27] One of every 36 ER trauma admissions is estimated to be due to a pretibial injury.[1,2,27] In the USA, the risk of developing a PL in the institutionalized elderly is estimated at 0.0-2.5 % per patient per year.[2] Since the patient population and trauma mechanisms of PHs and PLs are the same, current estimates of the incidence of pretibial injuries is a mixture of PLs and PHs, resulting in a bias. Further, not all pretibial injury patients seek help from the ER making the estimates of the incidence unreliable. The incidence of pretibial injuries in Finland is unknown. However, as seen in Figure 1, the population is rapidly aging.[80] It is safe to say that the incidence of pretibial injuries is on the rise.

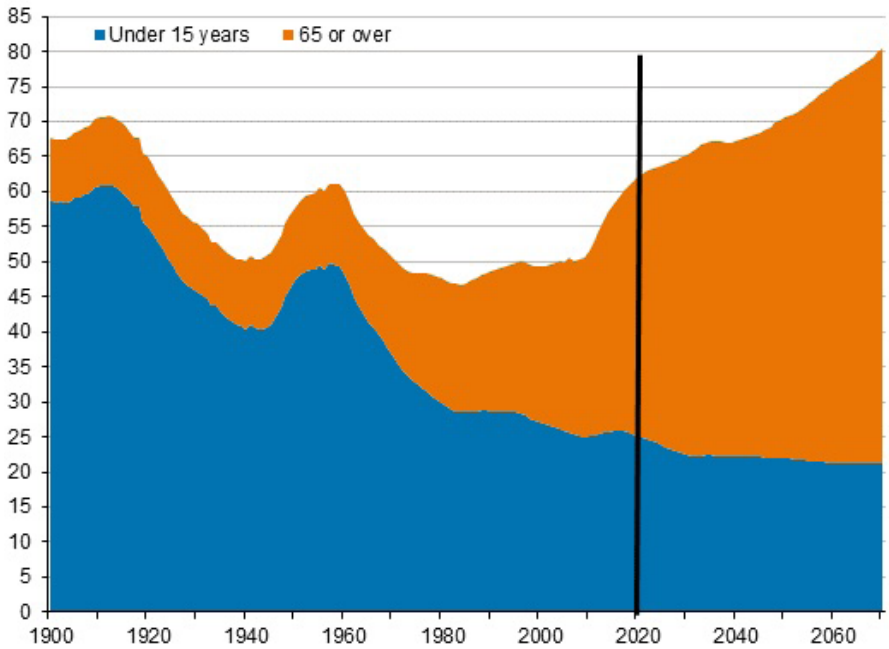


Figure 1: The Demographic dependency ratio. The number of those aged 15 or under and 65 or over per 100 working age persons in 1900 to 2020 and projection until 2070. © Tilastokeskus

2.3.2 Risk factors

Age, multimorbidity, and polymedication pose significant risk factors for pretibial injuries.[66] The number of capillaries in the skin decreases with age, leading to less oxygen and nutrients delivered, slowing down healing.[14] In addition, aging and corticosteroids lead to a chronic skin fragility syndrome, *dermatoporosis*, which can be considered the most important risk factor for pretibial injuries.[7–10,14] This age- and sex-related skin fragility leads to a decrease in the skin's viscoelastic properties, resulting easily in full-thickness wounds that heal slowly via granulation compared with epithelization, as no residual epithelial cells are adjacent.[35,38] Dermatoporosis is discussed thoroughly in Section 2.3.4.

Other underlying chronic diseases such as diabetes, peripheral vascular disease, and lower limb edema are common among pretibial injury patients, contributing to impaired wound healing, and thus can be considered risk factors.[42,52,60] Further, poor eyesight and challenges in everyday activities through compromised physical ability increase the risk for traumas.[2]

Among medication, especially corticosteroids and anticoagulants are important risk factors for pretibial injuries, as corticosteroids slow down wound healing and cause secondary dermatoporosis.[9] Anticoagulants are risk factors especially for developing PHs.[22,23] Female sex has been identified as a clear risk factor because of earlier development and higher prevalence of dermatoporosis.[1,4,7–9] In addition, females wear skirts and other clothing that provides less protection for the pretibial area.[6,81]

Often pretibial injuries occur in healthcare settings such as hospital wards or long-term care institutions.[16] Studies on the prevention of pretibial injuries have advocated creating safe environments for minimizing trauma, maintaining good skin care by using moisturizing creams, and using protective Kevlar socks for injury prevention.[12,13,81]

2.3.3 Anatomy

The lower leg between the knee joint and ankle constitutes of two long bones, the tibia and the fibula. The muscles, blood vessels and nerves adjacent to these bones are enveloped by fascia into four compartments: the anterior, lateral, superficial posterior and deep posterior compartment. Each compartment constitutes specific anatomic structures (see Table 1). The skin and subcutaneous tissue overlay circularly on top of the muscle fascia, and anteromedially on the periosteum of the tibia.

Table 1: Compartments of the leg.

	Muscles	**Main vessels**	**Nerves**
Anterior compartment	Tibialis anterior, extensor hallucis longus, digitorum longus	Anterior tibial artery and vein	Deep peroneal nerve
Lateral compartment	Peroneus longus and brevis	-	Superficial peroneal nerve
Superficial posterior compartment	Gastrocnemius and soleus	-	-
Deep posterior compartment	Tibialis posterior, flexor hallucis longus, flexor digitorum	Posterior tibial artery and vein, fibular artery and vein	Tibial nerve

The pretibial region constitutes the circumferential area of skin between the knee joint and ankle. Especially the anterior, lateral, and medial portions of the skin are prone to injuries, because only a thin layer of poorly vascularized skin and soft tissue cover the prominent triangular margo of the tibia, leaving the attached skin vulnerable to shearing forces. However, pretibial injuries can occur posteriorly as well. The vascular supply of the pretibial skin arises from the deep vessels of the compartments that perforate the deep fascia and branch into a small area of overlying skin. The most important vessels of the superficial venous system are the great saphenous vein and small saphenous vein. Injury to the perforating arteries, saphenous veins or their branches can result in PHs.

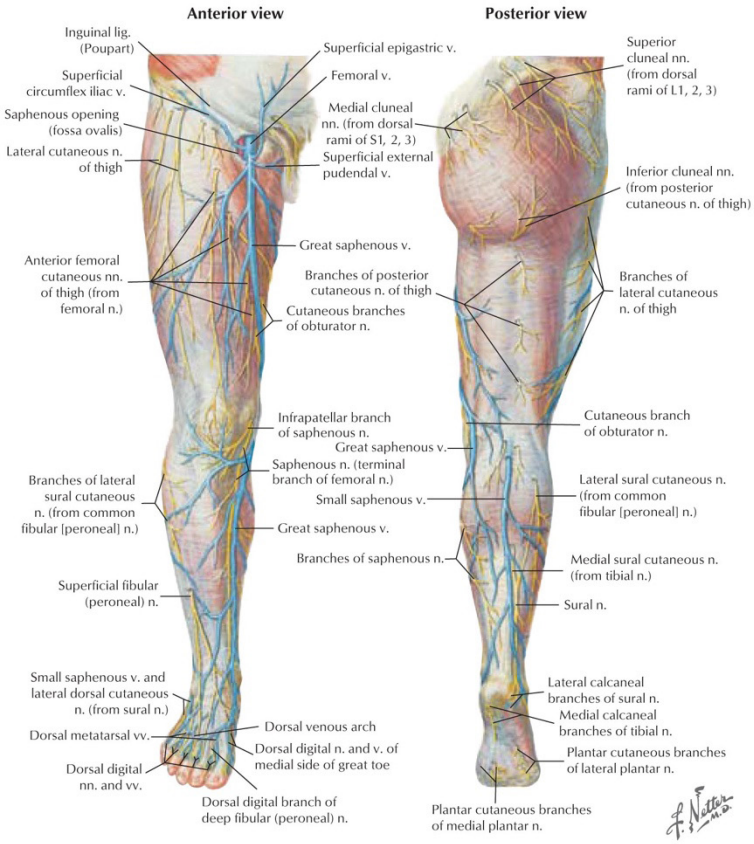


Figure 2: Illustration of the lower limb showing the superficial venous network. Netter illustration used with permission of ©Elsevier, Inc. All rights reserved.

2.3.4 Dermatoporosis

The entity of dermatoporosis was proposed in 2007 by dermatologists Saurat and Kaya to cover the characteristics of aging skin beyond cosmetic features.[7] Dermatoporosis presents as a chronic cutaneous fragility syndrome or insufficiency.[7–10,14,82] The clinical features in fully developed dermatoporosis are skin atrophy, senile purpura and pseudoscars, which typically start to be seen at around 70 years of age.[7–10,14,82] However, the first clinical manifestations begin at around 40–60 years with wrinkles and changes in appearance.[8] A fully developed disease is seen between 70 and 90 years.[9] The overall prevalence of dermatoporosis is estimated to be around 37.5% in subjects aged over 65 years (27.5% in males and 43.9% in females).[9,82]

Dermatoporosis occurs predominantly on sun-exposed areas such as the dorsal side of the forearms, dorsum of the hands, presternal area, scalp and pretibial regions.[8,9] Primary dermatoporosis is the most common type of dermatoporosis

resulting from chronological aging and long-term exposure to UV radiation from the sun.[8,9] Secondary, iatrogenic, dermatoporosis results from the long-term use of topical and systemic corticosteroids.[7–9] The mechanisms in the pathogenesis of dermatoporosis are linked to various signaling pathways, including the Wnt/beta-catenin pathway and the p16INK4a pathway, and most importantly to the decrease in skin hyaluronate and its receptor CD44.[9] Further, hyalurosomes, which essentially serve as hyaluronic acid factories in the keratinocytes, become deficient in dermatoporosis.[9] Treatment and prevention of dermatoporosis with pharmaceutical agents are currently under investigation.[9] By targeting the potential role of hyaluronosome deficiency, topical administration of hyaluronic acid fragments to activate the CD44-mediated signaling pathways for epidermal hyperplasia has been successful in mice.[9] Protecting the skin from cumulative exposure to UV radiation is critical in prevention. Oral nutrition supplements containing collagen peptides might reduce skin vulnerability in older adults.[83] However, using a twice-daily moisturizing ointment protocol seemed not to have an effect in decreasing the amount of excoriations.[84]

Saurat and Kaya proposes to staging the extent of dermatoporosis into four categories.[8–10] Stage I constitutes skin atrophy, senile purpura, pseudoscars and superficial excoriations.[8,9] Stages IIa and IIb constitute small and large skin lacerations.[8–10] Stages IIIa, IIIb and IV constitute superficial (subepidermal) hematomas and deep hematomas (subdermal) with or without skin necrosis.[8–10] Saurat and Kaya use the term deep dissecting hematoma, which can be considered uniform with PHs, except for the anatomical location not being limited to the pretibial region. In the literature on PHs, other terms, such as deep dissecting hematomas, tension subcutaneous hematomas, superficial hematomas and lower extremity hematomas are used.[23,28,73,74]

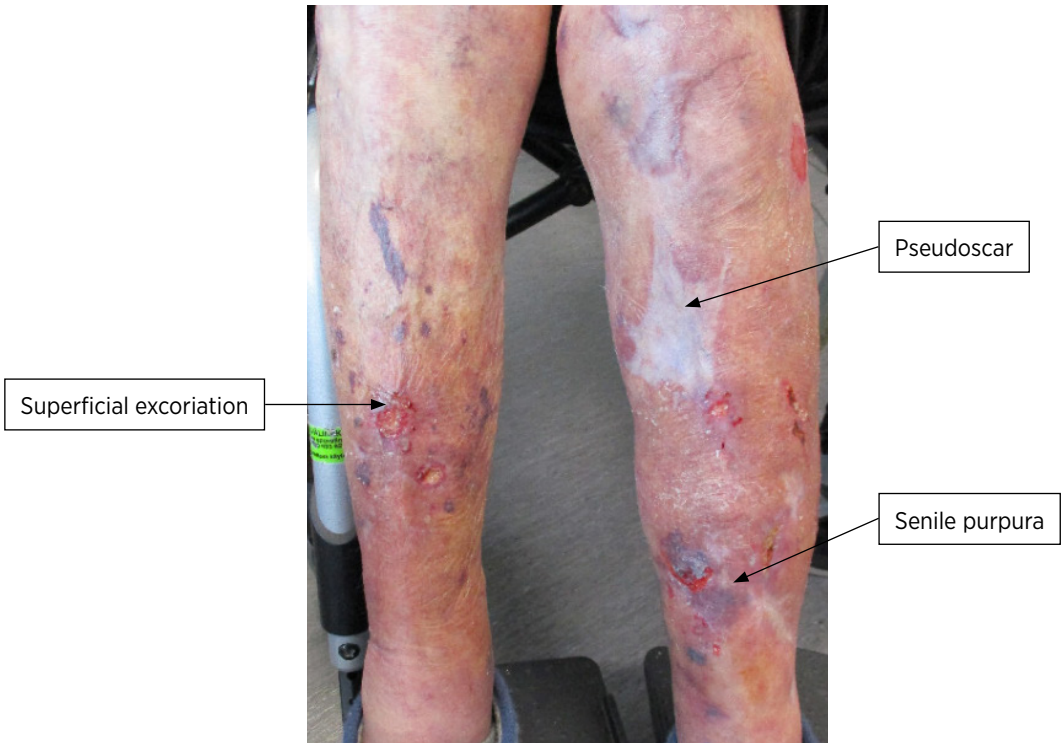


Image 3: Dermatoporosis showing atrophy of the skin, pseudoscars, superficial excoriations and senile purpura. © T. Seppälä

Complications of dermatoporosis are increasingly observed in the growing population of the elderly and infirm.[2,9] PLs and PHs result easily in a dermatoporosis-affected lower limb due to impairment of the viscoelastic properties of the skin.[7–9] Healing is delayed because of a diminished blood supply to dermatoporotic skin, as the number of capillaries is smaller in the ageing skin.[1] In the approach of Saurat and Kaya, pretibial injuries can be seen as direct complications of dermatoporosis in the lower leg.

2.4 Pretibial lacerations

Low-energy shearing forces have caused PLs in the elderly and the infirm for decades. In patients suffering severe dermatoporosis, removal of wound dressings or even grasping a limb can cause PLs or excoriations of the epidermis.[85] PLs constitute five different types of full-thickness wounds with known directional treatment recommendations.[3] Typically, treatment is carried in community healthcare settings, while larger skin defects are usually referred for evaluation of surgical treatment.

2.4.1 History of treatment

The earliest publications in the scientific literature of PLs can be found in the 1970's.[70] Tandon et al. and Crawford et al. documented different treatment methods of PLs, expressing concern over the slow healing.[68,70]

Already for decades, avoiding the use of sutures in treating PLs has been advised.[70,71] Tandon et al. reported the use of sutures to be "doomed to failure".[70] Dr. Sutton also advocated avoiding sutures after conducting a randomized prospective study in 1985, where he compared wound closure with sutures and adhesive tapes.[72] Sutured PLs generated skin edge necrosis and healed slower.[72] Slow healing is caused by the tight sutures promoting ischemia to fragile wound edges, especially in a situation where trauma has caused elevation of flap lacerations tearing the underlying vessels, making the skin flap ischemic to start with.[71,72] Thus, avoiding sutures has remained the common consensus to this day. However, debate on whether to treat PLs via early debridement and skin grafting, or with conservative wound management by closing the initial laceration/flap continues.[31]

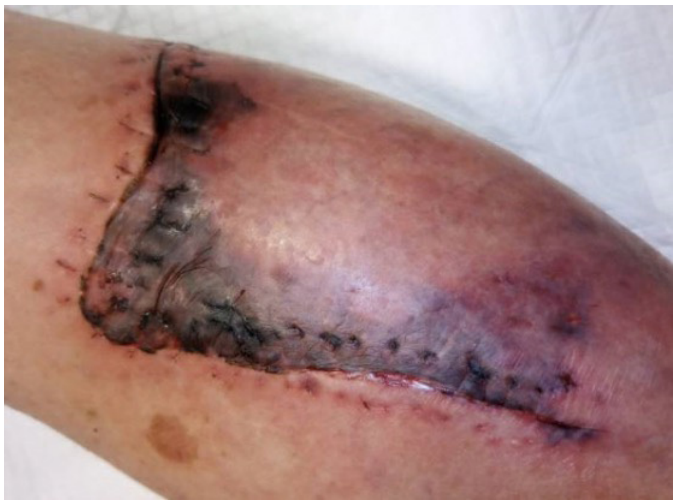


Image 4: A pretibial laceration showing skin edge necrosis after suture removal © T. Seppälä

Different treatment methods especially regarding PLs have been utilized throughout history. In 1973 Tandon et al. reported a study comparing two groups (A and B) of patients.[70] Group A was treated immediately with STSG after excision of the non-vital skin flap. Group B was treated with STSG after 10-44 days of conservative treatment. The healing time was 23 and 53 days in average, and patients were hospitalized for treatment.[70] Ramnani et al. repeated the intervention of immediate application of STSG in 1981.[69] Patients were treated under regional anesthesia (lateral femoral cutaneous nerve block), without the

need for hospitalization resulting in a healing time of 15 days.[69] A few years later in 1987 Shankar et al. reported harvesting STSG under local anesthesia with immediate mobilization also with good results of wound healing in 21 days.[86]

Crawford et al. in 1977 presented in a prospective setting a more conservative method of immediate excision of the flap of the PL and using the excised flap as a skin graft after defatting it.[68] This meant that STSG was not harvested invasively from the thigh. Forty-eight patients were treated in an outpatient setting, no hospitalization was needed, but the average healing time was quite long, 65 days.[68]

In 1990, Haiart et al. compared using a STSG to defatting the PL flap in a randomized prospective trial of 25 patients.[67] Primary excision and using a STSG from the ipsilateral thigh proved to have a much faster healing rate than defatting the flap, 13 vs. 41 days, again advocating for operative treatment.[67]

Defatting the traumatic skin flap and using it as a primary full-thickness skin graft rarely covers the whole defect since the traumatic flap shrinks, and wound edges frequently undergo ischemia. Dr. Grant reported a case series of three patients in 1993, where he demonstrated excision of the flap laceration and cutting it into small pieces.[87] These small pieces of graft were laid on the wound bed after irrigation and all patients healed within 5 weeks.[87] Later, in 2018, Ikeda et al. modified this method, calling it mini patch grafting.[85] Only the edge of the flap was trimmed with scissors to get small pieces of skin to patch graft the areas that would normally be out of reach of the primary flap. With Ikeda's method, healing time was not reported.[85]

In 2001, Silk et al. presented a technique of using deep enforcing sutures of vital flap PLs (group 1) and linear PLs (group 2).[77] In this prospective study, PLs were sutured after careful irrigation and revision of wound edges through adhesive tapes that were placed parallel to wound edges. Suturing through adhesive tape material prevented tension on wound edges. In addition, deep fascial bites were taken to provide stability. None of the patients needed skin grafting and patients in groups 1 and 2 healed on average in 26 and 16 days, respectively.[77]

Dionyssiou et al. repeated a prospective study of defatting the flap in 2011 with better results than Haiart et al. Dionyssiou reported a healing time of 21 days on average supporting conservative treatment.[79]

To conclude, during the past decades PLs have been understood to present in different clinical forms (skin flaps, linear lacerations, and total skin defects) with different treatment options. The number of studies on treatment is small, and all studies have limitations. Consensus on an optimal treatment has not been established to date, as some studies advocate early debridement and STSG over conservative treatment, and others vice versa.[25,31] Thus, little has changed in the management of PLs during 50 years despite improvement in wound management science and surgical applications. Based on the small retrospective

and prospective studies by Tandon, Ramnani, Shankar and Haiart, treating PLs with early STSG in an outpatient setting seems to be the best method of management.[67,69,70,86]

Table 2: Studies on the treatment of pretibial lacerations.

Author	Published	Study method	Cohort size, n	Healing time in days	Treatment recommendation
Tandon et al.	1973	Retrospective: early STSG vs delayed STSG	26 + 11	23 and 53	Early debridement and STSG heal faster than delayed STSG
Crawford et al.	1977	Prospective	48	65	Revision of wound edges and tensionless steri-strip closure of the flap
Ramnani et al.	1981	Retrospective	40	15	Early debridement and STSG
Shankar et al.	1987	Prospective	25	21	Early debridement and STSG
Haiart et al.	1990	Random control trial: defatting the flap vs STSG	14 + 11	41 and 13	STSG healed faster than defatting the flap
Grant	1993	Case report	3	35	Using the elevated flap as a small patched full-thickness graft is possible
Ikeda et al.	2017	Case report	1	not reported	Using the elevated flap as a small patched full thickness graft is possible
Silk et al.	2001	Prospective: Enforced sutures in flap PLs and linear PLs	112 + 35	26 and 16	Using enforced sutures resulted in good healing in both flap lacerations and linear lacerations
Dionyssiou et al.	2011	Prospective	27	21 (n=6, 60)	Conservative treatment with defatting the flap and suturing through adhesive tapes

2.4.2 Classifications

The first classification for skin tears was described by Payne and Martin in 1990, further updated by the same authors in 1993.[88,89] In principle, skin tears can be regarded similar to PLs. However, their anatomical location is not limited to the pretibial region. Further, the classification by Payne and Martin is poorly applicable to PLs. Payne and Martin only focused on defining skin tears based on the extent of epidermal loss from the dermis. Thus, full-thickness skin lacerations were not included, which are seen among PLs. The Payne and Martin classification for skin tears was used mainly in nursing medicine. Later, in 2007, the Australian STAR (Skin Tear Audit Research) classification system was introduced, which is very similar to that of Payne and Martin, differing only by focusing on the quality of the skin flap and its edges.[13] STAR is also used in the field of nursing medicine.[13]

Payne and Martin Classification 1993

Category IA	Linear skin tear with separated epidermis and dermis, without tissue loss
Category IB	Epidermal flap laceration that completely covers the dermis within one millimeter of the wound margin
Category IIA	Scant tissue loss, <25% of the epidermal flap
Category IIB	Tissue loss, >25% of the epidermal flap
Category III	Complete tissue loss, absent epidermal flap

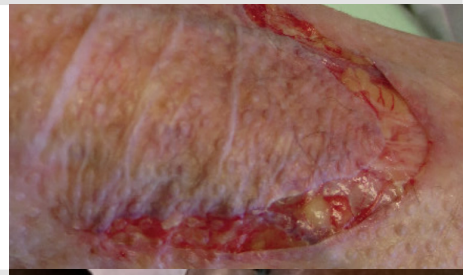
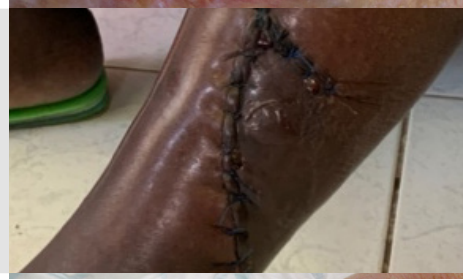
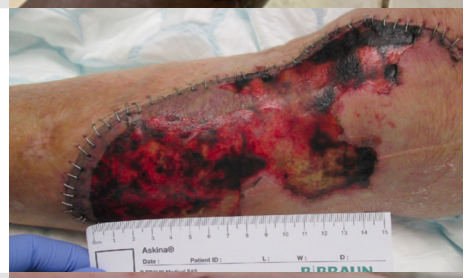
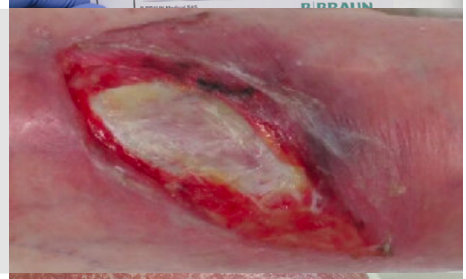
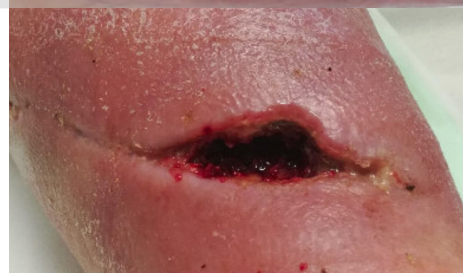
In 2003, Dunkin et al. proposed a more systematic classification for PLs based on an extensive review of the literature.[5] The classification aimed to unify communication between healthcare professionals and provide guidance in management.[5] A noticeable discrepancy in the Dunkin classification is the major open degloving injury (Type IV). Degloving injuries result from high-velocity traumas, and thus, might not be relevant for inclusion in PL classifications.

Dunkin Classification 2003

Type I	Linear PL optimal for conservative treatment by closure with adhesive tapes without tension.
Type II	Linear laceration or flap laceration with minimal skin edge necrosis, also suitable for conservative treatment via adhesive tapes after debridement of the skin edges and wound bed.
Type III	A larger lacerated skin defect with necrosis and a subcutaneous hematoma, with a treatment recommendation of early debridement and STSG.
Type IV	A major degloving injury needing debridement and further reconstruction.

Almost another ten years passed before modifications were made to the Dunkin classification. In 2012, Lo et al. provided another extensive review of the literature on pretibial injuries.[3] Based on this, Lo discouraged the use of the Payne and Martin classification and made modifications to the Dunkin classification. Hence, the Modified Dunkin classification was proposed. Separating linear lacerations from flap lacerations and considering flap vitality were key. Lo also included a type V PL, which constitutes a laceration with a subcutaneous hematoma. Degloving injuries were not included in the Modified Dunkin Classification. However, open degloving injuries can result in Type IV defects. Skin grafting is suggested when defect size exceeds 1% of the total body surface area (TBSA).

Modified Dunkin Classification 2012 by Lo et al.

	Clinical presentation	Treatment recommendation	Image
Type I	Linear laceration	Conservative treatment with adhesive tapes, no sutures.	
Type II	Vital flap laceration	Conservative treatment with adhesive tapes, no sutures.	
Type III	Non-vital flap laceration	Debridement of non-vital skin, STSG on larger defects (>1%TBSA)	
Type IV	Total skin loss	Debridement and STSG on larger defects (>1%TBSA)	
Type V	Laceration with an accompanying hematoma	Revision, hematoma evacuation, STSG if necessary	

Different classification systems have been introduced, with the Modified Dunkin classification remaining thus far. However, both the Modified Dunkin classification and the original Dunkin classification can cause confusion in distinguishing PLs from PHs. A Modified Dunkin Type V PL is an open laceration accompanied by a subcutaneous hematoma.[3] Thus, it clinically resembles that of a PH. The same can be concluded with a Dunkin Type III PL. Further, PHs can rupture spontaneously due to pressure, meaning that a PH can precede the formation of a Modified Dunkin Type V / Dunkin Type III PL. For the reasons mentioned, it could be justifiable to exclude the Type V / Type III PL from future classifications. The open degloving injuries described in the original Dunkin classification can be considered equivalent with a Modified Dunkin Type IV injury.

2.5 Pretibial hematomas

The trauma mechanism of PHs is uniform with PLs.[1,22,23,28] However, some PHs form spontaneously without apparent trauma.[28] Why some patients develop PHs instead of PLs remain unknown. Anticoagulant medication seem to be associated with the injuries.[22,28] Cutaneous complications of anticoagulants have been undervalued relative to intracranial and gastrointestinal bleedings despite PHs often fulfilling the criteria of serious bleeding.[23] PHs continue to be considered a trivial pathology that does not require treatment.[23]

PHs form when minor shearing forces causes a rupture to the superficial pretibial vessels.[28] Bleeding separates skin and subcutaneous tissue from muscle fascia forming a cavity that is filled with blood. When the pressure in the blood-accumulated cavity overcomes the blood pressure of dermal and subdermal capillaries, ischemia and ultimately skin necrosis occur.[28] PHs can be severe acute conditions, where prompt action needs to be taken to stop bleeding, ease the ischemic pain, and reduce the extent of skin loss.[16,23,28,29]

2.5.1 Risk factors

The most important risk factors for PHs are skin aging, dermatoporosis, and anticoagulant medication.[10,16,23] Usually, individuals with healthy skin and no anticoagulant medication get a bruise from a low-energy pretibial trauma. However, in dermatoporotic skin the viscoelastic properties are lost, and anticoagulant medication slows coagulation, leading to the development of a PH.[10,14,22,28] Anticoagulants are associated with PHs, although not all patients use anticoagulant medication. Given the association, PHs can be considered partly iatrogenic in origin.[22,23]

2.5.2 Diagnosis

The symptoms first manifest as bulging, erythema, epidermal blistering and intensive pain of the leg (see Image 5). The classical *rubor, tumor, pallor* and *dolor*, can mislead the clinician to suspecting, for instance, erysipelas or deep vein thrombosis (DVT). This can delay treatment and worsen the prognosis. At the latest, a necrotic skin eschar reveals the correct diagnosis (see Image 5).

Other rare but important differential diagnostic options for nonspecific bulging of the leg are soft tissue tumors such as sarcomas. When there is a discrepancy in patient history and clinical presentation, malignancy must be kept in mind. In ambiguous cases, magnetic resonance imaging or computer tomography will provide sufficient information.

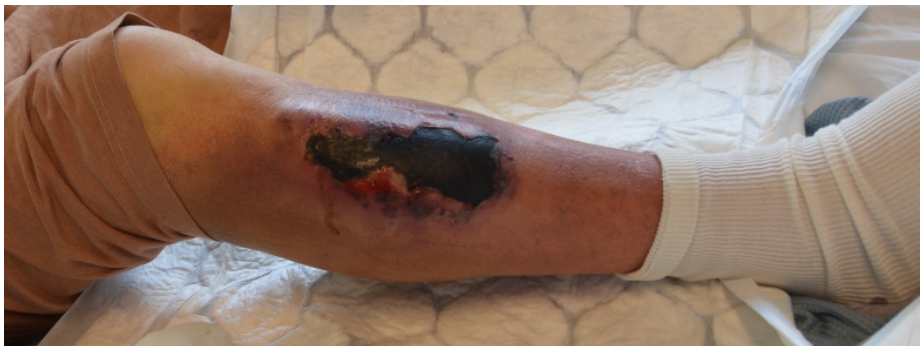


Image 5: An untreated pretibial hematoma has resulted in a necrotic skin eschar. © T. Seppälä

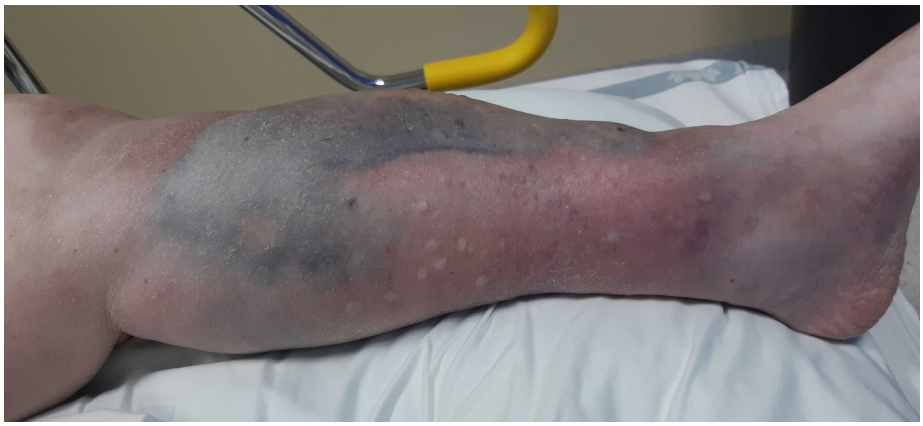


Image 6: A pretibial hematoma at an early stage with vital skin and symptoms resembling, for instance, erysipelas. © T. Seppälä

2.5.3 Treatment

Treatment of PHs should be prompt to stop bleeding, ease pain and reduce the extent of potential skin loss.[29] If evacuation of the PH is delayed and skin necrosis occurs, the eschar needs surgical debridement. This leaves a defect that can either be left for conservative wound management or proceed to reconstruction with STSG. Both treatments can be complicated due to comorbidities such as dementia, which pose risks for anesthesia, surgery, postoperative management, and patient compliance in wound care.[2] See Image 7 for treatment with STSG after debridement.

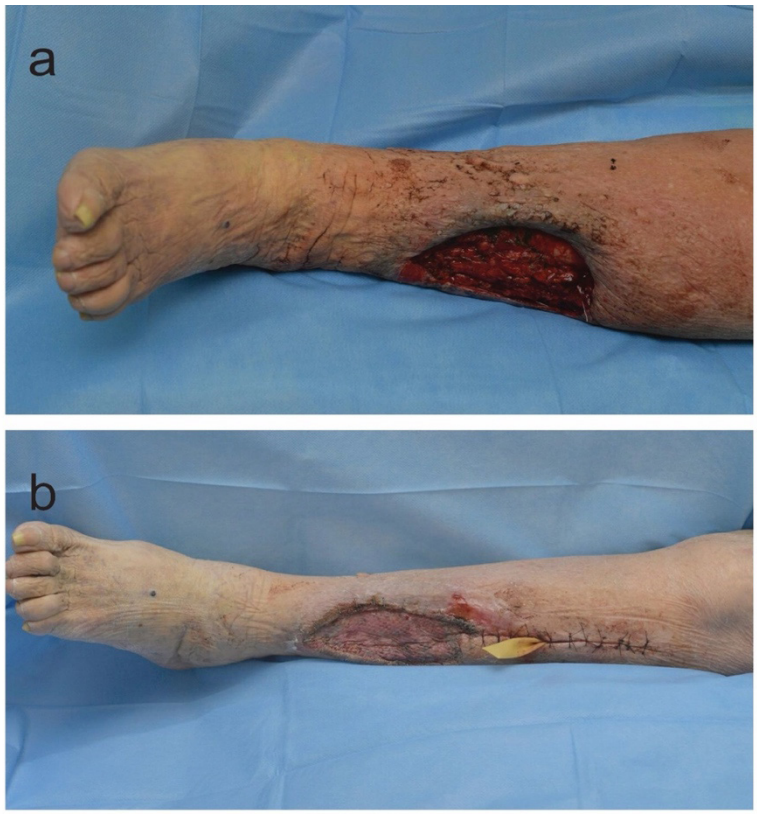


Image 7a: Tissue defect after PH evacuation and debridement of necrotic skin.

Image 7b: The defect treated with STSG at 5 days post op.

Patients are usually treated under general or regional anesthesia for PH evacuation and wound debridement. Small PHs can be evacuated under local anesthesia. Compression therapy after using a large caliper Yankauer suction cannula for PH evacuation has been reported to be a successful treatment method.[29] Due to coagulation of the hematoma, traditional needle aspiration with a 18G needle is unsuccessful.[75] If the PH has an accompanying open laceration, the wound can be used as a port for the sucker or the finger to evacuate the clotted blood.[29]

Optimally, after diagnosing a PH, a stab incision is made in the skin overlying the hematoma to proceed to evacuation. After evacuation, the PH cavity is irrigated thoroughly with saline, hemostasis is acquired, and the incision is closed loosely for free drainage. Compressive bindings from the distal foot to the knee are applied. See Figure 3.

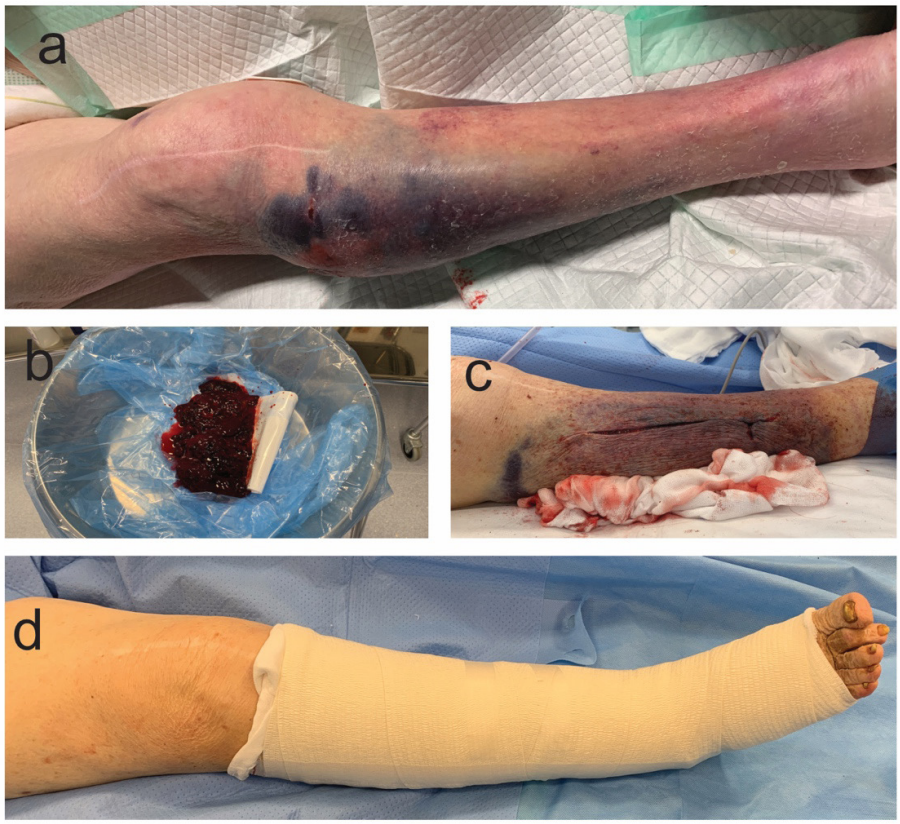


Figure 3: Evacuation of a PH.

a: Acute PH needing evacuation

b: Coagulated blood after evacuation

c: Loose closure of skin flaps after stab incision, evacuation, and irrigation

d: Compressive bindings applied

When a PH defect is managed with local wound care, the aim is to debride the hematoma as non-traumatically as possible to prepare the wound bed for secondary healing.[16] Local wound care of PHs has been described by using hydrogels for hematoma softening and larval therapy (use of sterile maggots) for debriding the wound from the hematoma.[16,30] However, multimorbid patients sustaining PHs can end up with CLUs from large PH defects left to heal by secondary intention.

2.5.4 The Morel-Lavallée lesion

The Morel-Lavallée lesion (MLL) is a closed degloving injury that usually results from high-velocity trauma.[90,91] It was first described by French surgeon Maurice Morel-Lavallée in 1863.[90,91] The MLL is important to discuss alongside PHs since there are similarities in the pathogenesis of the injuries. However, several important differences need to be addressed.

MLLs result from devastating traumas and are often accompanied with polytraumas such as pelvic fractures.[90,91] By contrast, PHs form due to low-velocity trauma or occur even spontaneously, being isolated injuries. Thus, the clinical history is quite different between the two pathologies. Further, the site of occurrence is different. MLLs frequently occur in the peri trochanteric or lumbosacral region; only 1.5% have been reported to occur in the lower leg.[90]

MLLs, as PHs, are characterized by separation of the subcutaneous plane from the deep fascia. However, in MLLs the tangential force disrupts the perforating lymphatic and vascular structure resulting in a collection of hemolymphatic fluid and necrotic fat.[90,91] The dermis and epidermis remain vital. Inflammatory and metabolic products potentiate cellular permeability and further leakage from the vessels and lymphatics into the created space.[90] Thus, a seroma-like collection is formed. Often, especially when unnoticed, the MLL forms a capsule or pseudocyst, which can mimic soft tissue tumors clinically and radiologically.[91]

MLLs can be managed by percutaneous drainage or open debridement and irrigation. Presence of a capsule indicates the choice of surgery.[91] Alternative interventions such as using liposuction and administration of sclerosing agents have been suggested.[90]

In contrast to PHs, skin necrosis or eschar formation is not typical among MLLs. Despite ultimately being different injuries, MLL pathogenesis is important to understand. In rare cases the clinical appearance of a MLL and a PH can resemble each other. Ultimately, PHs are not degloving injuries, as the pathogenesis and mechanism of trauma are different.

2.6 Split-thickness skin grafts

Various techniques for wound closure can be used by reconstructive surgeons. When primary closure and healing by secondary intention is not possible, using split-thickness skin grafts (STSGs) is one of the most indispensable methods.[92,93] Hence, STSGs are considered the third step in the reconstructive ladder of plastic surgery.[94] STSGs serve a fundamental role in various clinical situations such as treating burns, traumatic wounds, chronic wounds and defects after oncologic resections.[92,94,95] However, avascular recipient beds such as exposed bone, cartilage without perichondrium, tendon, and nerve will not support a STSG.[39]

STSGs are generally taken using a pneumatic or an electric dermatome.[92] An electric dermatome can be seen in Image 14. Harvesting a STSG leads to a sheet of skin consisting of the epidermis and a varying thickness of dermis, leaving sufficient dermis on the donor site for secondary healing to occur via re-epithelization.[92] STSGs lack their innate vasculature and adnexal structures.[39] Thus, STSGs need a vascular or granulating wound bed to integrate.[39] STSGs are generally smooth and semitransparent, and can be mechanically meshed with a hand-powered mesher to gain greater surface area coverage and to drain blood and exudate from the wound bed.[39] The STSG is the least durable form of wound closure.[39] Contraction, hypopigmentation, hyperpigmentation, or any combination of these can occur to both donor and recipient sites.[39]

Image 8: An electric Zimmer ® dermatome set. © T. Seppälä

Tissue texture matching should not be expected when using STSGs, as they mold closely to the floor of the recipient bed.[39] As a consequence, they are capable of only filling the most superficial volumetric defects.[39] Before attaching the STSG, the recipient bed must be carefully prepared.[39] Precise hemostasis minimizes the risk for hematoma and seroma beneath the STSG.[39] All non-vital tissue and fibrinous debris must be debrided from the wound bed.[39] Secure attachment of the STSG to the wound bed is essential to ensure survival since shearing movements to the graft can disrupt vascularization.[39] Traditionally, STSGs are secured to the wound edges with sutures or staples.[39] Shearing of the graft should be avoided for the first few days by using supportive dressings and preventing excessive ambulation or vigorous activities.[39] The optimal STSG dressing should maintain a moist wound healing environment and provide stable pressure on the graft to prevent shearing.[39]

2.6.1 Donor site healing

The treatment of the donor site wound after STSG harvesting is important since prolonged healing of the site causes pain, discomfort and poor cosmetic outcomes such as hypertrophic scarring.[93,96] Local treatment of the donor site aims to create an environment that facilitates re-epithelization, minimizes pain, decreases the risk for local infection and reduces hospital stay.[93,97] The STSG donor site is usually treated with a moist hydrofiber, occlusive dressing foam materials, or polyurethane with a silicone membrane.[98] However, the best dressing material to facilitate donor site healing is yet to be discovered.[96–98]

STSGs are commonly harvested from the thigh, but the abdomen, buttocks, back, and scalp are used as well.[92,95] The donor site is chosen based on the desired STSG size, method of harvest, and ability of the patient to care for the donor site wound.[39] Impact of the donor site in relation to the patients ability to ambulate, sit, and sleep must be considered.[39] Usually the thigh is used as a donor site since it is readily available for both the patient and the surgeon.[39]

In the thigh, a cadaveric study recommended using the anterolateral region since the epidermal and dermal thickness was the greatest.[41] An older study from 1985 stated that a graft thickness of 0.35mm (0.014 inch) is considered optimal when harvesting from the thigh.[99] Routine donor site healing generally happens between 7 and 21 days.[96,100] However, the graft thickness affects wound healing significantly.[100] Thicker grafts cause donor sites to heal slower.[100] Guogiené et al. compared donor site healing after harvesting of 0.2mm (0.0078 inch), 0.3mm (0.011 inch) and 0.4mm (0.015 inch) thickness grafts from the thigh.[100] Cohort sizes were n=28, n=26, and n= 30 patients with a mean patient age of 51-57 years.[100] Complete wound epithelialization was observed in 82% of patients in the 0.2mm cohort at 2 weeks.[100] However, only 53.8% in the 0.3mm group and

36.7% in the 0.4mm group had healed at this point.[100] The difference between the 0.2mm and 0.4mm transplant groups was statistically significant (p=0.004).[100]

Typically, healthy patients heal their STSG donor site without problems, while morbid elderly patients might have prolonged healing.[32,79] Pretibial injuries occur among the latter group and patients have comorbidities such as dermatoporosis, diabetes, chronic venous impairment, peripheral vascular disease, and malnutrition that can affect wound healing also above the knee.[32,101] Infections of donor sites are generally rare, though a valid consensus is difficult to ascertain since infections have been described in several patient cohorts with a varying incidence of 0-56% in a systematic literature review.[93]

Even though pretibial injuries have been treated with STSGs for decades, previous literature on donor site healing of the elderly is sparse. Studies involving pretibial injuries and skin grafting mainly focus on reporting the healing time of the grafted skin defect.[67,79] Further, donor site healing is usually investigated among burn patients or patients with pathologies other than pretibial injuries.[96,97]

Dionyssiou et al. in 2011 advocated for defatting a pretibial flap laceration and positioning it back on the wound bed to avoid a complicated STSG donor site.[79] However, no citations on complicated donor site healing were provided to back their claim. A handful of studies suggest immediate regrafting of the STSG donor site with remaining excess skin to facilitate healing among patients with a high risk for wound healing problems.[98,101,102]

A study from 1984 by Fatah et al. compared retrospectively the donor site healing of young and old patients.[32] Fatah concluded that elderly patients healed more slowly, but no statistical analysis was performed in the comparison. Further, a part of their study was conducted in a prospective setting where half of the donor sites of >60-year-old patients were regrafted with excess skin, resulting in faster healing than in the other half of donor sites, which were left for local treatment by dressings only.[32] In a retrospective study, Ki et al. repeated the observation of better results by regrafting the donor site with skin graft remnants.[98] Ki's study included observations on cosmetic appearance and patient satisfaction, both of which supported regrafting the donor site.[98]

In 2017 Bradow et al. examined donor site healing in elderly patients by conducting a prospective non-randomized study.[101] Group 1 consisted of elderly patients with an assumed risk of delayed donor site healing. Their donor sites were regrafted using skin graft remnants and placing them back on the donor site (n=204). The control group (n=113) comprised healthy patients whose donor sites were treated with regular dressings. The regrafted ''risk group'' healed in a mean time of 17.2 days, as opposed to 17.8 days in the control group, although the difference was not statistically significant.[101] In this study, conclusions on faster healing by regrafting the donor site are difficult to make since the control group had a different intervention.

Goverman et al. harvested another STSG adjacent to the primary donor site, meshed it 4:1 and back-grafted both the original donor site and the adjacent donor site.[102] However, patients were mostly burn victims with a mean age of only 65 years old, healing time was not reported, and a control group was lacking. This method also results in large surface areas of the donor sites. In Finland, meshed STSGs were reported to be over-meshed to gain a 1.25-fold surface area, thus leaving a smaller donor site.[103] Further, excess skin could be over-meshed and placed back on the donor site.

Taken together, it is difficult to conclude whether elderly patients' donor sites heal worse than those of healthy individuals. However, based on mainly Fatah's study[32], it seems that regrafting the donor site with excess skin is justified.

2.6.2 Skin grafting pretibial injuries

Since many pretibial injury patients suffer from dermatoporosis, care should be taken when harvesting STSGs with a dermatome. Using a meticulous technique and enough paraffin oil, not pressing too much, making sure a minimal thickness is chosen, and using an assistant are paramount to avoid deep iatrogenic wounds to the donor site.

Literature on treating pretibial injuries with STSGs is limited. According to a few small studies, treating PLs with early STSG in an out-patient setting results in the fastest healing of the injury.[67,86] Further, mobilizing pretibial injury patients after STSG application is important since previous studies have found no differences in STSG integration on the wound bed when comparing bed rest and early mobilization.[104–107] Bed rest for elderly patients is known to be dangerous, which also advocates early mobilization.[108,109]

Treating skin defects with STSGs due to a PH is known to be used after debridement of the hematoma and necrotic skin.[22,28] Further, a case report described the use of the PH skin flaps as an immediate FTSG to cover the defect after PH evacuation.[73] Regarding the use of STSGs in treating PHs, it remains unclear whether the grafts are applied in a single session immediately after debridement or later in a second session. Treatment of patients in a single session or in two sessions certainly could impact health economics, not to mention earlier ambulation, shorter rehabilitation, and less suffering for the patient.

2.7 Health economics in pretibial injuries

Healthcare costs are rising worldwide, especially due to multimorbidity in the aging population.[110–112] Hospital services comprise the largest share of total healthcare expenditures in all countries, regardless of income level.[113] In Finland,

healthcare expenditure was 22.0 billion (3983 € per capita), corresponding to 9.2% of the gross domestic product in 2019.[114]

Treatment of different etiology wounds constitutes a substantial share of the healthcare cost burden, from hundreds of millions to billions per year.[115,116] In Europe only, 1.5-2 million people are estimated to suffer from different types of wounds.[115] In the USA alone, chronic wounds affect an estimated 7 million patients annually, costing the healthcare system upwards of $25 billion each year.[117] Systematic calculations of the costs of pretibial injuries have not been conducted.

2.7.1 Diagnosis-related groups

Diagnosis-related groups (DRG) is the most frequently used system in healthcare worldwide for classifying and defining hospital costs.[113,118–123] DRGs were initially developed in the 1970s at the University of Yale and have since become the basis for product line management in most industrialized countries, particularly in Europe and USA.[118,121] Applications of DRG vary between countries and healthcare systems.[113,118,123] In Finland, financing and ownership of hospitals are public, and thus, DRG products aim to improve the control and comparison of hospital care-related costs and to standardize treatments.[123] In 1996, the Nordic countries of Finland, Sweden, Norway, and Denmark launched a modified DRG system, the NordDRG, based on the Nordic version of the International Classification of Diseases (ICD-10) and surgical procedures.[123,124] The publicly financed Association of Finnish Local and Regional Authorities (Suomen Kuntaliitto) and its subsidiary the Finnish Consulting Group (FCG) LLC own and manage the NordDRG system in Finland.[124]

DRG was introduced to increase the transparency and efficiency of costs by condensing individual patients treated by hospitals into a manageable number of clinically meaningful and economically homogeneous groups.[118,121] Thus, DRG enabled the comparisons of healthcare costs between different hospital districts and created the incentive to increase effectivity. The DRG classification system groups patients by diagnosis, comorbidities, surgical procedures, age, sex, and discharge status to obtain homogeneous resource groups.[123] Resource consumption of hospitals relying on DRG is calculated for each DRG group to reflect the average treatment costs in that group.[123]

DRG products seem to have been designed to facilitate the collection of treatment expenses from homogenous patient groups. For example elective hip replacement surgery, appendectomies, and other rather standard pathologies and treatments are easy to categorize under different DRG products. When studying the expenses of wound patients or wound patients with varying ICD-10 diagnoses, the DRG systems applicability weakens.

2.7.2 Health economic burden of pretibial injuries

Based on clinical experience and the previous literature, pretibial injury patients seem to consume a substantial amount of healthcare resources.[22,66] Pretibial injuries often lead to prolonged wound healing, lengthy hospitalization and rehabilitation, repeat surgery, multiple emergency room visits, and infection complication. Studies of the accurate costs of pretibial injuries are lacking, and DRG product invoicing from pretibial injury treatments has not earlier been investigated. In fact, pretibial injuries are not included in standardized DRG products. Rather, the treatment of patients generates a mixture of DRG product invoices from different phases of treatment making it more difficult to calculate costs.

In the United Kingdom by using the NHS data, Thomson et al. estimated a rough financial expenditure of around 4000 € per PH patient requiring a skin graft and with a length of stay of 11 days.[22] However, the method used for estimating the costs was not described. Further, the costs of PLs have not been studied or estimated previously. The price of revision surgery requiring a skin graft lies between 1500 € and 8300 € in Kymenlaakso, Finland. See Attachment 1 of this thesis.

3 AIMS OF THE STUDY

The aim of this thesis was to review pretibial injuries of ≥65-year-old patients treated in Kymenlaakso, Finland, during 2015–2019, regarding patient demographics, clinical presentation, treatment paths and outcome. Further, STSG donor site healing among dermatoporotic patients was examined. Finally, calculations and comparison of the health economic burden of treating PLs and PHs were conducted.

Specific aims were as follows:

I To review data on all ≥65-year-old patients treated for a PL in Kymenlaakso Central Hospital and its surrounding healthcare centers during 2015–2019 concerning patient demographics, clinical presentation, treatment paths and outcome.

II To review data on all ≥65-year-old patients treated for a PH in Kymenlaakso Central Hospital and its surrounding healthcare centers during 2015–2019 concerning patient demographics, clinical presentation, treatment paths, outcome and risk factors for skin necrosis.

III To review data on outcome and healing of skin graft donor sites in morbid elderly patients after treatment with a STSG for a pretibial injury.

IV To calculate and compare the health economic burden of the treatment of PLs and PHs to identify shortcomings in the current treatment.

4 MATERIALS AND METHODS

The Institutional Review Board of KYMSOTE approved the study protocol. Based on the Declaration of Helsinki, no ethics approval was required due to the retrospective nature of the studies.

4.1 Patients

An electronic search of patient files using the LifeCare® (TietoEvry, Espoo, Finland) patient database of Kymenlaakso Central Hospital was conducted. A retrospective investigation of the electronic patient files of ≥65-year old patients diagnosed for a pretibial injury (PL or PH) was done. Only patients diagnosed between 1 January 2015 and 31 December 2019 in the central hospital or its surrounding smaller health care centers were accepted. Patients were searched for using the following ICD-10 codes and procedural codes of surgical treatments presented in Table 3.

Table 3: Codes and descriptions for ICD10 diagnoses and surgical procedures.

ICD-10 code	Description
S80.1	Contusion of other and unspecified parts of lower leg
S81.8	Other superficial injuries of lower leg
S81.9	Open wound of lower leg, location unspecified
S85.8	Injury of other blood vessels at lower leg level
S85.9	Injury of unspecified blood vessel at lower leg level
S89.9	Unspecified injury of lower leg
T14.0	Superficial injury of unspecified body region
T14.5	Injury of blood vessel(s) of unspecified body region
T14.9	Injury, unspecified
Surgical procedure code	
QDB00	Lower limb wound suturation
QDB05	Lower limb wound revision
QDB10	Lower limb wound dressing change
QDB99	Other lower limb wound suturation/dressing change
QDG20	Lower limb chronic wound revision
QDA10	Lower limb skin incision
QWD00	Skin/subcutis revision, hematoma
ZZA00	Split skin graft, autograft
TQW11	Negative pressure wound therapy appliance

Length of stay (LOS) was extracted from the electronic patient files and the cause of death was determined from the patient's death certificates. Further, a three-month mortality rate from hospital admission was calculated. A Charlson Comorbidity Index (CCI) was calculated for each patient based on the diagnoses in the computerized medical records using the following internet calculator: https://www.mdcalc.com/charlson-comorbidity-index-cci. The CCI is designed to classify prognostic comorbidity in longitudinal studies.[125] For post-operative complications, the Clavien-Dindo classification was used.[126]

4.2 Study I

Based on electronic patient files, 116 patients were included in the study. Patients had a PL included in the Modified Dunkin classification. The anatomic location was defined as being in the pretibial region, between the knee and ankle anteriorly, medially, or laterally.

From the electronic medical records, the demographic data for each cohort patient were reviewed. Factors reviewed included age, gender, independency, physical ability, use of walking aid equipment, previous medical history, medication especially anticoagulation, per oral cortisone and immunosuppressants, mechanism of injury, wound length, surface area (cm/cm^2), LOS in the hospital plastic surgery ward and in a healthcare center ward, mortality, conservative or operative treatment, complications and outcome. If wound healing took over three months (90 days), the wound was deemed chronic.[20,42] The number of ER visits, follow-up visits with a physician or a nurse, and additional diagnosed traumatic lacerations and fractures were reviewed.

Based on medical record data and photographs of the wounds, a Modified Dunkin classification for each patient was established. The following description by Lo et al. [3] was used for the Modified Dunkin classification:

Type I	Simple linear laceration without skin loss
Type II	Laceration with a viable flap
Type III	Laceration with a non-viable flap
Type IV	Total skin loss
Type V	Laceration with a subcutaneous hematoma

4.3 Study II

Sixty patients who had a PH with or without accompanying skin necrosis in the pretibial region were included.

Patients were classified treatment-wise into two groups: *conservatively treated* and *evacuated* PHs. For each study cohort patient, data reviewed included age, gender, independency, physical ability (use of walking aid equipment), previous medical history, medication especially anticoagulation, per oral cortisone and immunosuppressants, mechanism of injury, associated injuries, skin blistering, dermatoporosis, mortality, cause of death, treatment (no evacuation, evacuation, aspiration), and outcome. The diagnosis of dermatoporosis was estimated based on patient photographs and descriptive text from medical history files. Descriptions such as "parchment skin", "cortisone skin", and "very thin skin" indicated dermatoporosis (see Image 3).

The involvement of compartment syndrome from patient history files was examined. The number of ER visits, time from injury to admission, and LOS were calculated. From the medical history, trauma-related PHs and spontaneous PHs were distinguished from each other.

Among patients who underwent PH evacuation, the time from injury to PH evacuation, time from PH evacuation to skin grafting (if done), LOS in the hospital plastic surgery ward and LOS in a healthcare center ward were calculated. In addition, the number of follow-up visits with a physician and or a nurse concerning skin defect or graft healing was recorded. If skin defect healing took over three months (90 days), the defect was deemed chronic.[20,42] Red blood cell (RBC) transfusions and hemoglobin (Hb) surveillance during the first seven days of hospitalization among patients who needed treatment due to the PH were investigated.

4.4 Study III

Fifteen patients from the cohorts of Studied I and II were included. Patients underwent STSG for the treatment of PL or PH after surgical debridement. The following patient factors were reviewed: age, gender, CCI, dermatoporosis, Clavien-Dindo[126] classification for postoperative complications, graft integration on the wound bed, donor site location, donor size area (%TBSA), donor site dressings, donor site infections, graft thickness (inch), mesh ratio, donor site follow-up visits, and donor site healing. Dermatoporosis was diagnosed from patient photographs and descriptive text from medical history files.

Prolonged healing of the STSG donor site was defined as being >21 days based on previous literature.[39,93] Donor site healing was reviewed from nurse

or physician recordings, and complete healing was accepted when no further dressing changes were needed.

4.5 Study IV

The health economic burdens of PLs and PHs were reviewed separately for comparison of costs. The cohorts included 109 PL patients and 60 PH patients from Studies I and II.

Information from two different databases were combined through record linkages of personal identification numbers (PICs). All citizens and permanent residents in Finland have a unique PIC, introduced in 1964-1967. The PIC used in all main registers in Finland allows reliable automatic record linkage. In detail, a Structured Query Language (SQL) search from the Effica® (TietoEvry, Espoo, Finland) patient database was conducted. NordDRG products used for municipality invoicing of patients treated during 2015-2018 were extracted from Effica®. The LifeCare® database was used for patients treated during 2019.

The NordDRG products were recorded from linkage to patient ICD-10 diagnoses of pretibial injuries and dates of each treatment contact needed in healthcare from the time of injury to the time of healing. Treatment included ER-related care, inpatient care, operative treatment and outpatient care.

NordDRG products were categorized according to each phase of treatment. Categorization helped to facilitate the cost distribution analysis of treatments. All NordDRG product invoices from ER visits, hospitalization periods in the acute wards and surgery wards, surgeries, and outpatient visits including wound care and phone call appointments were included. Secondary healthcare and primary healthcare expenses were calculated separately.

4.6 Statistical analysis

For Studies I–IV, the median, mean, and range of values for the different parameters were calculated directly from the obtained data.

In Study II, a comparison between conservatively treated and evacuated PHs was conducted using Pearson's Chi-square test for the following parameters: dermatoporosis, gender and patient independency. Fisher's exact test was used for comparing anticoagulant medication, use of walking aid equipment, and spontaneous hematomas. For continuous variables, CCI, and age, the Mann–Whitney U-test was used.

In Study IV, the costs of treatment were calculated directly from the obtained invoice data; the total amount of euros from the invoices was divided by the

number of patients in the cohort to get the mean cost per patient. The median costs were calculated accordingly.

Statistical analyses in Studies II and IV were conducted by using the NCSS 12 Statistical Software (2018) (NCSS, LLC. Kaysville, UT, USA, ncss.com/software/ncss) and SPSS Statistics version 19.0 (IBM Corporation, NY, USA). P-values of less than 0.05 were considered statistically significant.

To determine whether there was statistical significance in the costs between PLs and PHs, the non-parametric Mann–Whitney U -test (Wilcoxon Rank Sum Test) was used. The sum of ranks of each treatment phase from both cohorts (PH and PL) was compared. Parameters compared included the total costs of treatment, ER visits, inpatient care, operative care, and outpatient care.

5 RESULTS

In total, this series of studies consisted of 176 patients with a pretibial injury. The median age of all patients was 81 years (mean 79.9, range 65-99 y). Of patients, 69% were women and 49% used walking aid equipment. The median CCI was 6 (mean 5.8, range 2-13). The median score on the Mini Mental State Exam was 22 (n=66, mean 21.4, range 9-23).

The skin defects of 126 pretibial injury patients (89.4%) were left for local wound care (110 PL, 16 PH). Of these, the median healing time was 51 days (n=92, mean 76.7, range 4-559 d). The skin defects of 15 pretibial injury patients (8.5 %) were eventually treated with STSG (9 PH, 6 PL). The healing of 12 STSG donor sites was examined in Study III.

All STSGs were applied in a second session after PL debridement or PH evacuation. The median time from injury to PL revision or PH evacuation was 11 days (mean 12.7, range 0-30 d). The median total healing time among STSG treated patients was 69 days (mean 95.3, range 39-356 d).

5.1 Study I: Pretibial lacerations

5.1.1 Patient demographics of pretibial lacerations

The specific inclusion criteria resulted in 116 patients. Nine patients (8%) where from abroad or from other provinces and could not be followed. Thus, 107 patients were reviewed more thoroughly. Of the cohort patients, 67% were women. The median age of all patients was 79 years (range 65-97 y). Of the patients, 77 (66%) were self-acting or independent and 51 (44%) patients used walking aid equipment. Altogether 61 patients (53%) had at least one additional traumatic laceration in patient history files before or after the PL in question. None had fractures of the tibia or the fibula. See Table 4 for demographic data.

Table 4: Demographic data of 116 patients with a pretibial laceration.

Gender	**N (%)**
Female (%)	78 (67.2)
Male (%)	38 (32.8)
Mean age	**Years (range)**
All	79.3 (65–97)
Female	81.3 (65–97)
Male	75.2 (65–94)
Comorbidites	**N (%)**
Hypertension	88 (75.9)
Dermatoporosis	64 (55.2)
Lower limb edema	37 (31.9)
Cognitive impairment	35 (30.2)
Autoimmune disease	30 (25.9)
Asthma	27 (23.3)
Atherosclerosis	26 (22.4)
Congestive heart failure	25 (21.6)
Diabetes	20 (17.2)
Kidney insufficiency	16 (13.8)
Cancer	16 (13.8)
Hypothyreosis	15 (12.9)
Rheumatoid arthritis	12 (10.3)
Peripheral vascular disease	7 (6.0)
Chronic venous impairment	6 (5.2)
Chronic obstructive pulmonary disease	6 (5.2)
Polymyalgia rheumatica	5 (4.3)
Pacemaker	4 (3.5)
Epilepsy	4 (3.5)
Pulmonary fibrosis	3 (2.6)
Sarcoidosis	3 (2.6)
Liver cirrhosis	2 (1.7)
Cardiomyopathy	1 (0.9)
Polycythemia vera	1 (0.9)
Parkinson's disease	1 (0.9)
Laterality of injury	**N (%)**
Left	58 (50.0)
Right	56 (48.3)
Bilateral	2 (1.7)
Mean wound size	**cm/cm² (range)**
Length	8.9 (1–30)
Area	38 (1–200)

Anticoagulants, corticosteroids and dermatoporosis

Underlying conditions and medication known to affect the skin and subcutaneous tissue included anticoagulant medication in 67 (57.8%), per oral cortisone medication in 34 (29%), and dermatoporosis in 64 (55.2%) patients. See Figure 4 for distribution of anticoagulants.

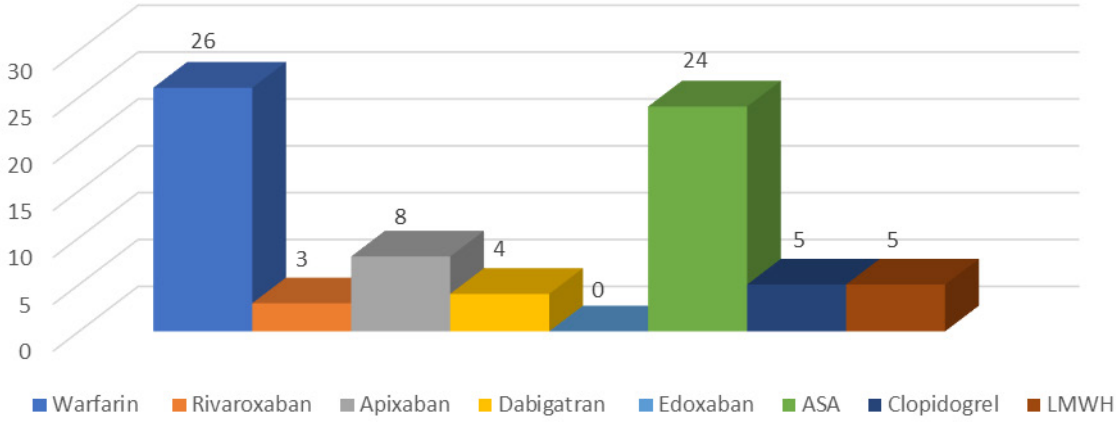


Figure 4: Distribution of anticoagulants among pretibial laceration patients.

Charlson Comorbidity Index

CCI was calculated based on data from medical records in 107 patients (92%). The median CCI was 5 (mean 5.64, range 2–11). See Figure 5 for distribution.

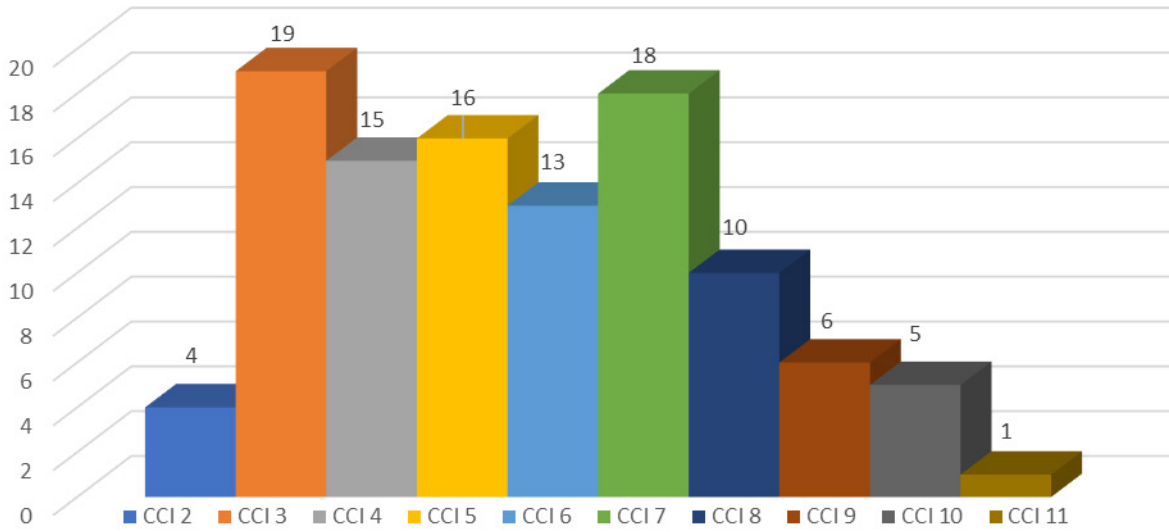


Figure 5: Charlson Comorbidity Index in 107 patients with a pretibial laceration.

5.1.2 Wound characteristics and classification

The distribution of the wounds was left 58 (50.0%), right 56 (48.3%) and both legs 2 (1.7%). Wound length was measured in 97 patients (83.6%). The median length was 7 cm (mean 8.1, range 1-30 cm). Wound surface area was estimated in 39 patients (33.6%). The median surface area was 20 cm^2 (mean 32, range 1-200 cm^2). Photographs were taken for the electronic files in 24 patients (20.7%).

The mechanism of injury was documented for 100 patients (86.2%). Falling on flat ground was the most common (25, 21.6%). See Figure 6 for stratification.

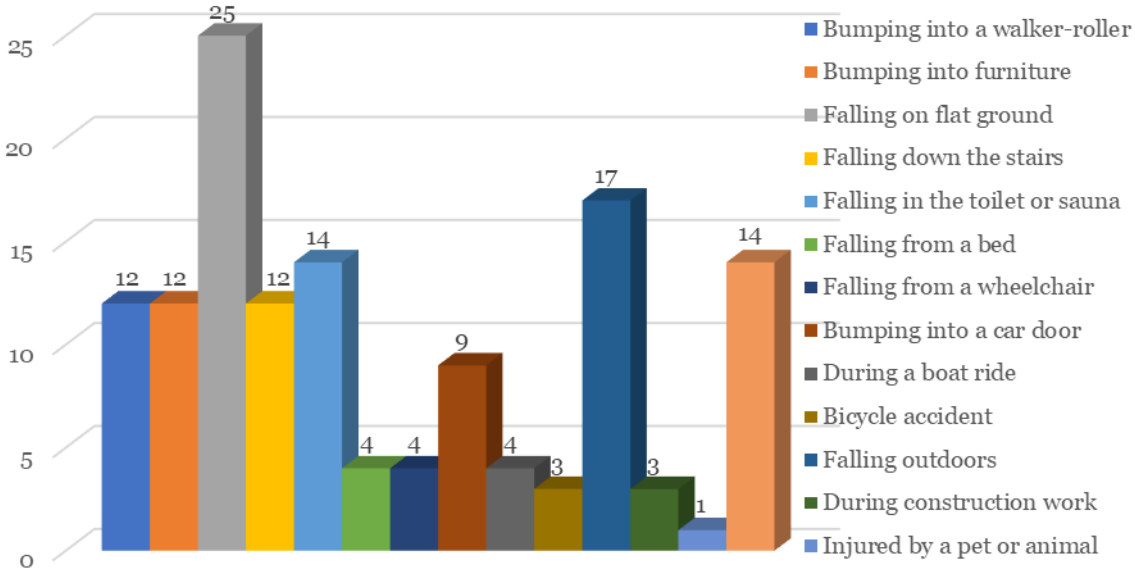


Figure 6: Mechanisms of injury.

Modified Dunkin classification

In the patient files, enough information to calculate the Modified Dunkin classification was found for 103 patients (88.8%).

The distribution of Modified Dunkin classifications was as follows: 36 patients (35.0%) had a type I linear laceration, 38 (36.9%) had a type 2 laceration, 8 (7.8%) had a type 3 laceration, 12 (11.7%) had a type IV laceration, and 9 (8.7%) had a type V laceration. The median Modified Dunkin classification was 2. See Figure 7 for distribution of Modified Dunkin classifications.

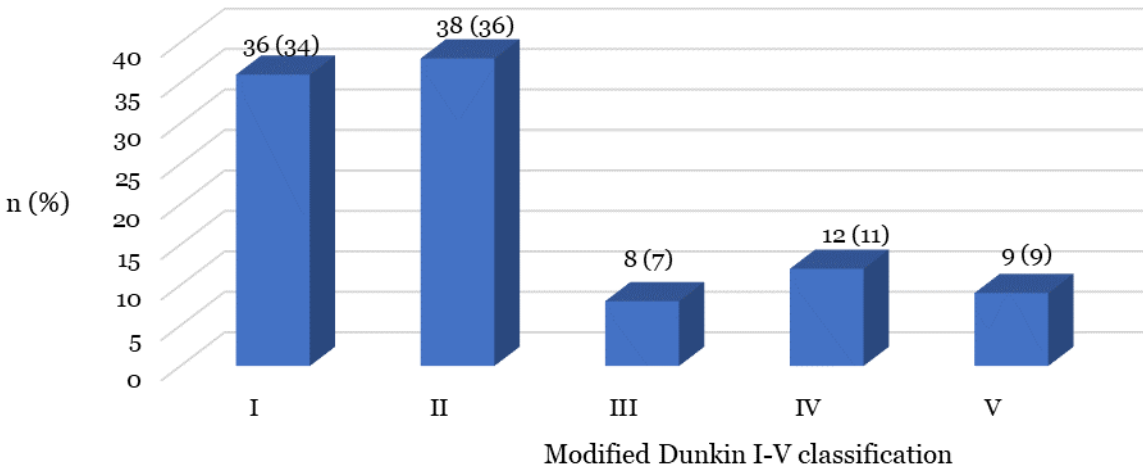


Figure 7: Modified Dunkin Classification in 103 patients with a pretibial laceration.

5.1.3 Emergency room visits and conservative treatment

The median latency of seeking treatment was 0 days (mean 4.3, range 0-120 d). Of the patients, 95 (81.9%) were discharged home from the hospital ER or from a health care center appointment. The median number of ER visits due to the same PL was 1 (mean 1.3, range 1–6) in 109 patients. Altogether, 21 patients (18.1%) had at least one re-admission to the ER in 30 days after the injury. Five (4.6%) had two ER re-admissions and one (0.9%) had three or more ER re-admissions.

Conservative treatment, e.g. local wound care, was established as a treatment path for 109 PLs (94.0%). Of the PLs, 36 (33.0%) were of type I, 38 (34.9%) type II, 8 (7.3%) type III, 10 (9.2%) type IV, and 5 (4.6%) type V PLs. For 15 patients (12.9%), conservative treatment involved the use of negative-pressure wound therapy (NPWT).

Sixty-six PLs (56.9%) were treated by primary suturation of the wound without a scheduled follow-up, except for suture removal. Of these, 26 (39.4%) were type I, 31 (47.0%) type II, 4 (6.0%) type III, 3 (4.5%) type IV, and 2 (3.0%) type V.

5.1.4 Operative treatment

Operative treatment constituting revision surgery or STSG was carried for 11 patients (9.5%). The median time from injury to revision surgery was 11 days (mean 21.8, range 2–70 d).

One PL (9.1%) was of Modified Dunkin type I, but needed a revision due to infection, one (9.1%) type II, none (0.0%) type III, four (36.4%) type IV, and five (45.5%) type V.

Six patients (54.5%) were treated with a STSG, of which two (33.3%) had a type IV and four (66.7%) a type V laceration. For nine patients (81.8%), NPWT was involved. Two patients did not consent to operative treatment despite recommendations and their wound classification was undetermined. See Figure 8 for treatments in relation to the Modified Dunkin classification.

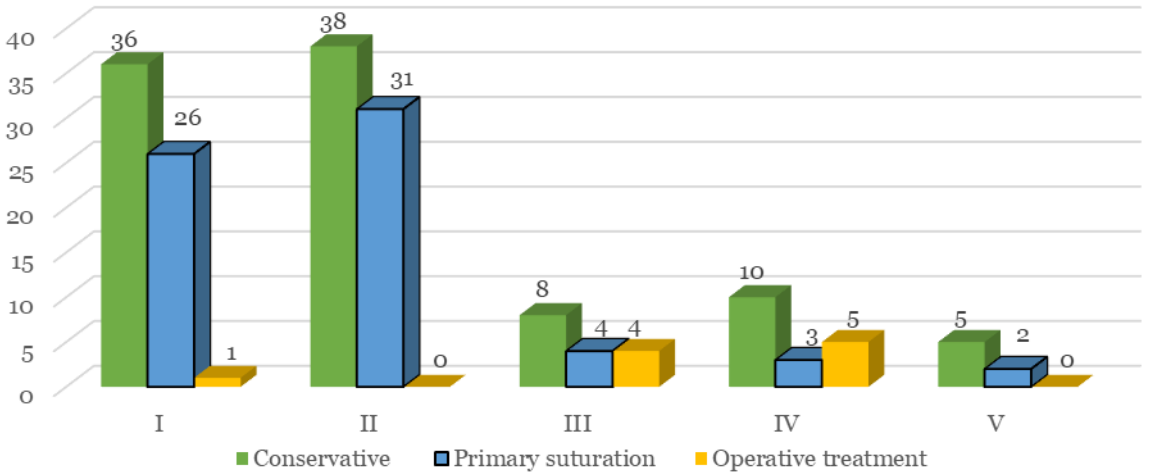


Figure 8: Treatment in relation with the Modified Dunkin classification of pretibial lacerations.

5.1.5 Outcome

The healing of the PLs, either conservatively or operatively treated, was tracked in 88 patients (75.9%). The median follow-up was 53 days (mean 75, range 4-356 d). Wound healing took more than 3 months in 37 patients (31.90%). Healing required a median of 3 (mean 3.4 range 0-13) physician appointments or consultations and a median of 11 (mean 19, range 0-200) nurse appointments including home visits. Wound healing was eventually successful in 89.7% of patients during a period of 0-356 days.

Twenty-five patients (21.6%) received treatment at the plastic surgery ward. The median LOS was 8 days (mean 9.6, range 1-51 d). After primary hospitalization 13 patients (11.2%) needed treatment and rehabilitation in a healthcare center ward. The median LOS stays in primary healthcare was 12 days (mean 21.1, range 0-86 d).

Complications

The complication rate in all patients was 35 (30.2%), with local wound infections accounting for 71.4%. Cellulitis or generalized infections were found among nine patients (7.7%).

Two patients with operative treatment had a minor infection complication, Clavien-Dindo class 1.

5.1.6 Mortality

Of the 107 patients, 13 died during the first three months after hospital admission. The median age for the deceased was 85 years (range 70-90). The 90-day mortality rate was thus 12.0%. Six patients (46.0%) died at home or at a retirement home and seven (54.0%) at a hospital ward. See Figure 9.

Cause of death was determined for 11 patients (85.0%). Four patients (30.7%) died of pneumonia, four (30.7%) of coronary artery disease, two (15.4%) of Alzheimer's disease, and one (7.7%) of kidney failure. All patients had suffered a PL 22-81 days earlier, and in 12 patients (92.3%) the wound healing was unsuccessful before death.

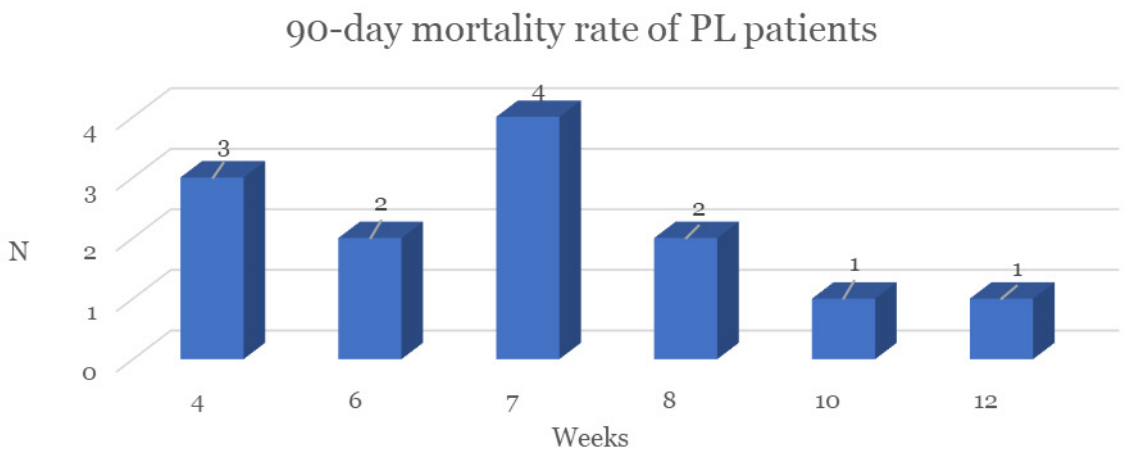


Figure 9: Ninety-day mortality, starting from the day of the admission

5.2 Study II: Pretibial hematomas

The specific inclusion criteria resulted in 60 patients, 71.7% of whom were women. Patients' demographic data are presented in Table 5.

Table 5: Demographic data of 60 PH patients.

Comorbidites	**N**	**%**
Hypertension	59	98.3
Diabetes	23	38.3
Cognitive impairment	23	38.3
Congestive heart failure	21	35.0
Atherosclerosis	20	33.3
Lower limb edema	18	30.0
Total knee arthroplasty	13	21.7
Hip arthroplasty	12	20.0
Hypothyreosis	12	20.0
Kidney insufficiency	10	16.7
Asthma	10	16.7
Autoimmune disorder	8	13.3
Pacemaker	7	11.7
Malignancy	7	11.7
Venous insufficiency	5	8.3
Compromised vision	5	8.3
Peripheral vascular disease	4	6.7
Polymyalgia rheumatica	4	6.7
Rheumatoid arthritis	3	5.0
Chronic obstructive pulmonary disease	3	5.0
Polycytemia vera	2	3.3
Epilepsy	2	3.3
Cardiomyopathy	1	1.7

5.2.1 Treatment paths

Patients were noted to have two distinct treatment paths: conservatively treated PHs with no specific management and surgically evacuated PHs.

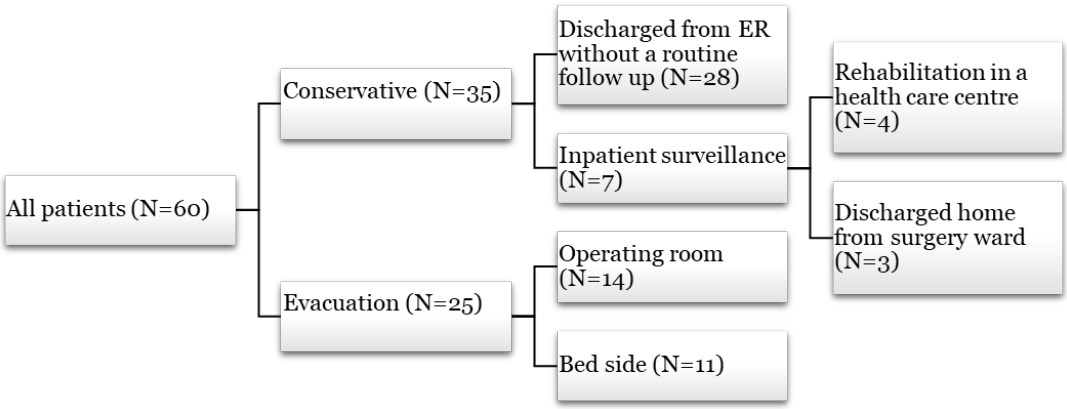


Figure 10: Treatments of patients with pretibial hematomas.

5.2.2 Conservatively treated pretibial hematomas

Altogether 35 patients (58.3%) were treated without hematoma evacuation. None developed skin necrosis nor needed blood transfusions. One patient developed skin blistering. The mean age was 80.6 years and 65.7% were women. Hitting an object was the most common trauma mechanism affecting 17 patients (48.6%). Spontaneous PHs were reported in four patients (11.4%). A conservatively treated PH is shown in Image 9.

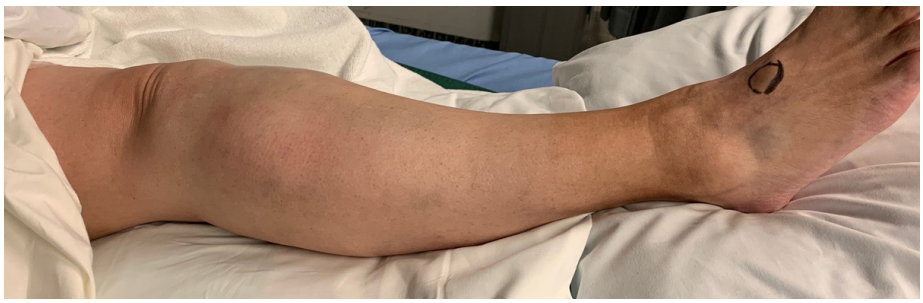


Image 9: A patient with good skin quality, no dermatoporosis, and no anticoagulant medication. The skin was vital, and the patient had only mild pain. The PH was treated conservatively without hematoma evacuation. © T. Seppälä

Charlson Comorbidity Index and patient independency

CCI was calculable in all patients, the median being 5 (mean 5.4, range 2-13). Altogether 25 patients (71.4%) were self-acting or independent and 14 (42.9%) used walking aids. Eight patients (22.9%) lived in a retirement home or in an assisted living facility.

Anticoagulant medication

Anticoagulant medication was used in 29 patients (82.9%). Thirteen patients (37.1%) used acetylsalicylic acid, seven (20.0%) warfarin, four (11.4%) rivaroxaban, three (8.6%) apixaban, three (8.6%) clopidogrel, and one (2.9%) dabigatran. One patient used acetylsalicylic acid and clopidogrel simultaneously. See Figure 11 for distribution of anticoagulants.

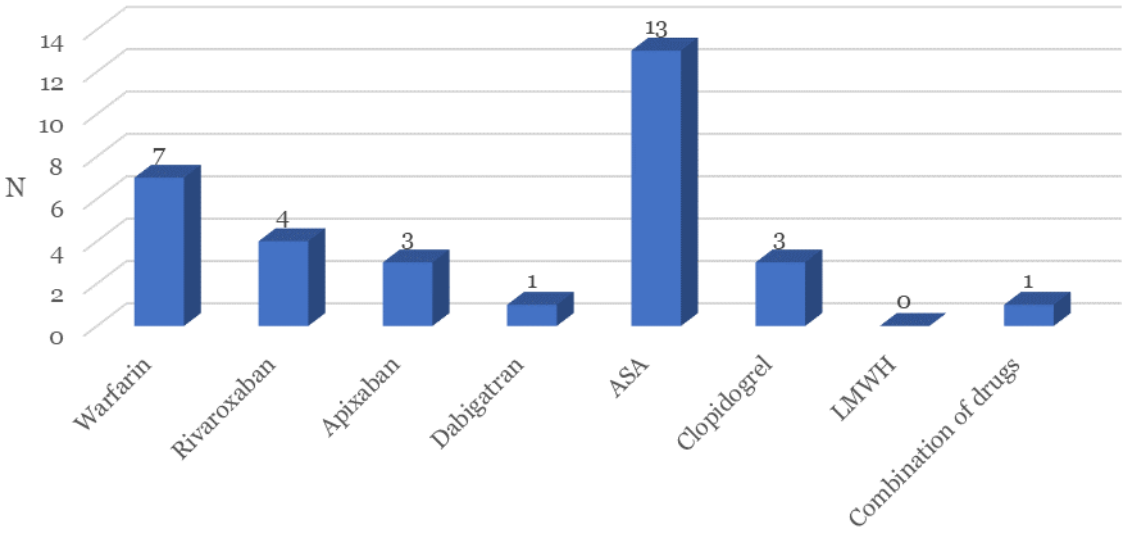


Figure 11: Anticoagulant medications of patients with a conservatively treated PH.

Dermatoporosis and corticosteroid medication

Five patients (14.3%) had dermatoporosis based on medical records. One patient was on systemic corticosteroid medication, and one patient received other immunosuppressant therapy.

Emergency room visits and diagnosis

The median latency in seeking treatment from the accident was 2 days (mean 4.8, range 0-16 d). One ER visit was found for, 24 patients (68.6%). Seven patients (20%) had one, two (5.7%) had two and two (5.7%) had three ER re-admissions concerning the PH. Twenty-eight patients (80.0%) were discharged from the ER with no further treatment or follow-up.

One patient was primarily misdiagnosed as having erysipelas, and in four patients DVT was suspected. None had fractures of the tibia or fibula. None of the patients were diagnosed with soft tissue tumors. Needle aspiration (18G) was attempted in one patient but was unsuccessful due to hematoma coagulation.

Length of stay

Seven patients (20.0%) were treated as in-hospital patients, five of whom needed further rehabilitative treatment. The median LOS at the surgery ward was two days (mean 2, range 0 d). Further, five patients needed a rehabilitative treatment period in a health care center ward where the median LOS was 10 days (mean 36.4, range 7-137d).

5.2.3 Surgically evacuated pretibial hematomas

The PH of 25 patients (41.7%) was evacuated surgically. Falling on flat ground was the most common trauma mechanism, affecting 10 patients (40.0%). Spontaneous PHs were reported in 10 patients (40.0%). Patients' skin defects were treated either with local wound care, with a STSG, or by direct closure with sutures. See Figure 12.

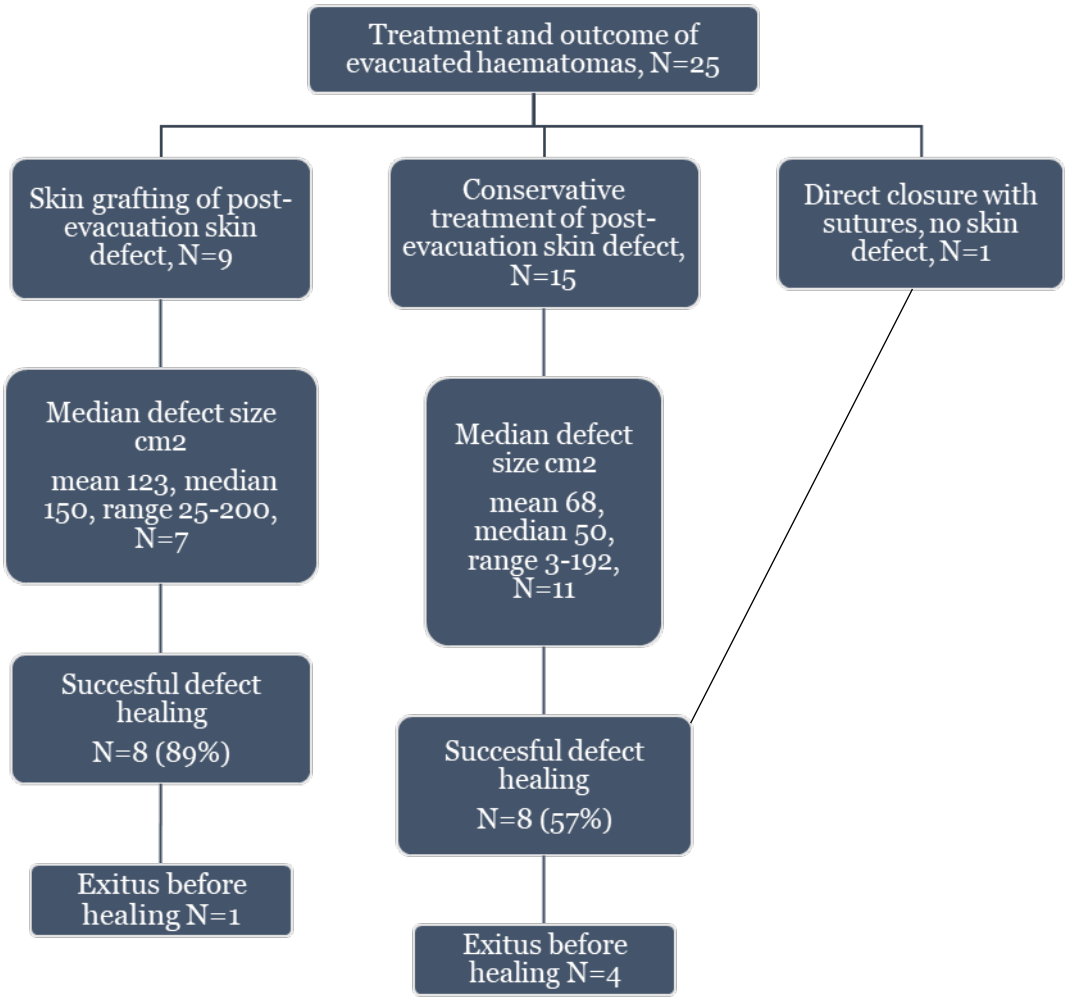


Figure 12: Evacuated PHs, further treatments, and outcome. © T. Seppälä

Charlson Comorbidity Index and independency

CCI was calculable in all patients, the median being 7 (mean 7.3, range 3-13). Nine patients (36.0%) were self-acting or independent and 22 (88.0%) used walking aids. Sixteen patients (64.0%) lived in a retirement home or at an assisted living facility.

Anticoagulant medication

Anticoagulants were used in 22 patients (88.0%). Thirteen patients (52.0%) used LMWH, 11 (44.0%) warfarin, seven (28.0%) acetylsalicylic acid, three (12.0%) apixaban, and one (4.0%) clopidogrel. Ten patients (40.0%) received two and one patient (4.0%) three anticoagulants simultaneously at the time of the PH. See Figure 13 for distribution of anticoagulants.

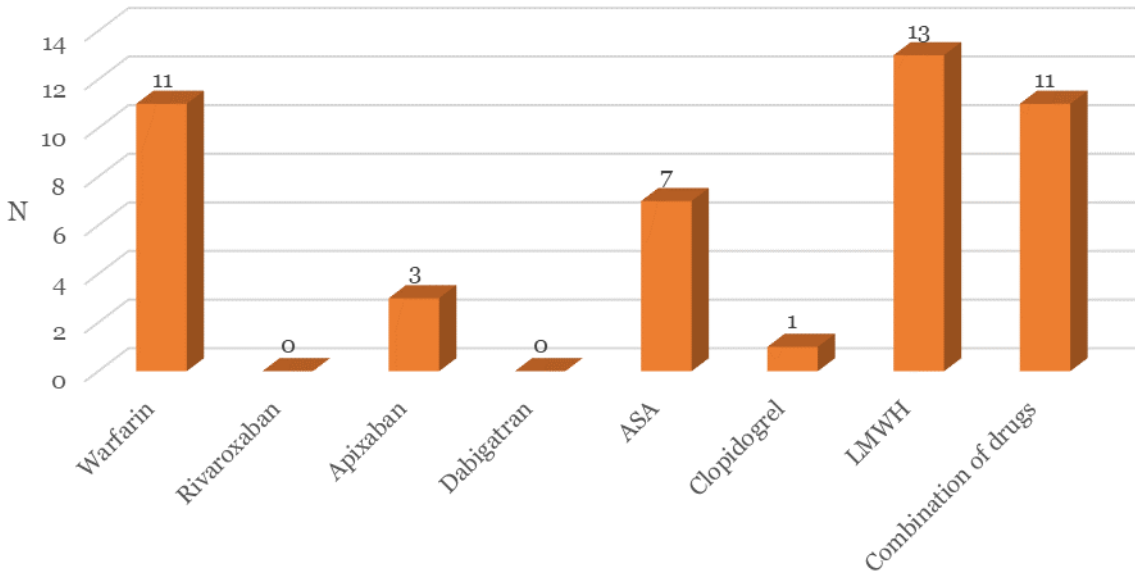


Figure 13: Anticoagulant medications of patients with an evacuated PH.

Dermatoporosis and corticosteroid medication

Dermatoporosis was observed in 20 patients (80.0%) based on clinical files. Seven patients (28.0%) were on systemic corticosteroid medication and two (8.0%) had other immunosuppressant medication.

Seeking treatment and length of stay

The median latency in seeking treatment from the injury was 0 days (mean 4.1, range 0-47 d). Two patients were mistakenly diagnosed with erysipelas. One patient had an accompanying femoral shaft fracture. None had fractures of the tibia or fibula. None of the patients were diagnosed with soft tissue tumors.

Twenty-four patients (96.0%) needed inpatient surveillance at the surgical ward. One was discharged from the ER after bedside evacuation. The median

LOS at the surgery ward was 4 days (range 0-30, mean 6.4 d). The median LOS after STSG was 5 days (mean 5.4, range 1-14 d).

Fifteen patients needed a rehabilitative treatment period in a health care center ward, where the median LOS was 9 days (mean 13.6, range 0-99 d).

Evacuations and skin grafting

PHs were evacuated either in the operating room (N=14, 56.0%) or bedside (N=11, 44.0%). STSG was used in nine cases (36.0%). Fifteen skin defects (60.0%) were treated with local wound care.

The median time from injury to evacuation was 3 days (mean 11, range 0-51 d). Evacuation was successful in 21 patients (84.0%). Three patients needed one re-evacuation, and one patient needed two re-evacuations, all of which were bedside evacuations.

Skin necrosis developed before PH evacuation in 18 cases (72.0%). Fourteen of these developed skin blistering. Blistering is evident in Image 10.

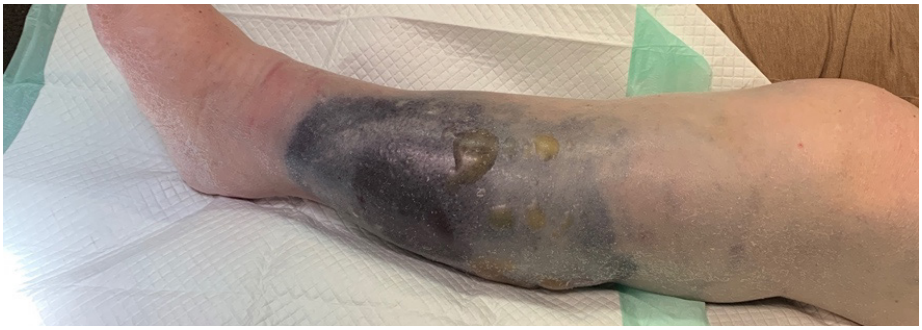


Image 10: A pretibial hematoma with epidermal blistering present. © T. Seppälä

All STSGs were applied in a second session after PH evacuation. The median time from injury to STSG was 31 days (mean 43, range 13-131 d), and the median time from PH evacuation to STSG was 24 days (mean 32.9, range 8-121 d). Three patients died waiting for a STSG. One patient did not consent to elective STSG despite recommendations. Graft integration was successful in all cases.

Instead of having a PH, one patient with LMWH medication had a subfascial, intramuscular hematoma that caused compartment syndrome. The patient was treated accordingly with fasciotomies and hematoma evacuation. Direct wound closure was successful.

Needle aspiration (18G) was attempted in four patients; all were unsuccessful and hematoma evacuation was utilized. NPWT was used for 14 patients (56.0%) after evacuation to facilitate granulation tissue formation. Nine of these were skin-grafted in a second session after a median of 25 days (mean 36, range 8-121 d).

Follow-up of healing and outcome

Wound healing was tracked in 23 patients (92.0%). The median number of physician visits/consultations after evacuation was 1 (mean 1.8, range 0-11). The median number of nurse visits, including home care, was 6 (mean 14.8, range 0-153).

In 17 patients (68.0%), the post-evacuation defect healed eventually. The median time from injury to healing was 82 days (mean 90.4, range 14-181 d). Four patients had to move to a nursing home after a long rehabilitative health care center ward period since patient independency became compromised permanently.

Blood transfusions

In 14 patients, red blood cell (RBC) transfusions were given from 1 to 5 single-unit transfusions; the median was 2 units. One patient received a single unit, 10 patients two units, 1 patient three units, 1 patient four units, and 1 patient five units of RBCs. The median decrease of hemoglobin during 2-7 days after hospital admittance was 23 g/dl (mean 26, range 13-53 g/dl).

5.2.4 Mortality

Of the 60 patients, five died during the first three months after hospital admission or ER visit, yielding a 90-day mortality of 7.9%. The median day of death was 20 (mean 29, range 7-65d). The mean age for deceased patients was 87.2 years (range 82-92 y). Three died in a healthcare center ward, one at a retirement home, and one at the Kymenlaakso Central Hospital plastic surgery ward. Cause of death was determined for all five patients; four died of heart disease and one of stroke. All five patients' death certificates included a description of a recent PH, which had been evacuated 4-51 days earlier. Healing was unsuccessful in these five patients.

5.2.5 Risk factors for skin necrosis

Age, gender, or use of anticoagulant medication did not significantly differ between the two groups. However, among the evacuated PH group, the incidence of dermatoporosis was significantly higher ($p<0.0001$). This group also had a higher median CCI ($p=0.005$), higher incidence of spontaneous PH formation ($p=0.014$), and greater need for walking aids ($p=0.0002$). Patient independency was significantly lower in the evacuated PH group ($p=0.033$). See Table 6 for stratification and P-values.

Table 6: Demographic data and risk factors for skin necrosis. P-values denote the correlation between conservatively treated and evacuated PHs. Pearson's Chi-square test was used for the following parameters: dermatoporosis, gender and patient independency. Fisher's exact test was used for comparing anticoagulant medication, use of walking aid equipment, and spontaneous hematomas. For continuous variables, CCI, and age, the Mann–Whitney U-test was used.

	All patients	**Conservative**	**Evacuated**	**P-value**
N (%)	60 (100)	35 (58.3)	25 (41.7)	0.22602
Female, n (%)	43 (71.7)	23 (65.7)	20 (80)	
Male, n (%)	17 (28.3)	12 (34.3)	5 (20)	
Mean age, years (range)				
All	81.1 (67–99)	80.6 (67–99)	81.6 (68–92)	0.80425
Female	83.8 (67–99)	84.6 (67–99)	82.9 (68–92)	
Male	74.1 (68–84)	73 (68–84)	76.6 (74–84)	
Charlson Comorbidity Index				
Median (range)	6 (2–13)	5 (2–13)	7 (3–12)	0.005 *
Mean	6.2	5.4	7.3	
Dermatoporosis				
Yes, n (%)	25 (41.7)	5 (14.3)	20 (84)	<0.0001*
No, n (%)	35 (58.3)	30 (85.7)	5 (16)	
Anticoagulant medication				
Yes, n (%)	51 (85)	29 (82.9)	22 (88)	0.72221
No, n (%)	9 (15)	6 (17.1)	3 (12)	
Living independently				
Yes, n (%)	36 (60)	25 (71.4)	11 (44)	0.033 *
No, n (%)	24 (40)	10 (28.6)	14 (56)	
Use of walking aid equipment				
Yes, n (%)	36 (60)	14 (40)	22 (88)	0.0002*
No, n (%)	24 (40)	21 (60)	3 (12)	
Spontaneous etiology				
Spontaneous (non-traumatic), n (%)	14 (23.3)	4 (11.4)	10 (40)	0.014*

*Indicates a statistically significant finding

5.3 Study III: Split-thickness skin graft donor site healing

The specific inclusion criteria resulted in 15 patients. Nine patients (60.0%) were treated for a PH and six (40.0%) for a PL. One patient died shortly after surgery due to unrelated heart failure, and two patients were treated postoperatively in nursing homes, and thus, further information on healing was not available.

The donor sites and wound beds of 12 patients were reviewed thoroughly. Nine patients (75%) were female. The median age was 81 years (mean 80.6, range 69-91 y). Eight patients (66.7%) had advanced dermatoporosis.

Median CCI was 7 (mean 7.1, range 4-12). All donor site areas were less than 2%TBSA. One minor donor site infection classified as a Clavien-Dindo 1 complication occurred (see Image 11). The patient's infectious donor site cultivated sensitive Staphylococcus aureus bacteria and was treated with per oral cephalosporins. No other postoperative complications were noted. Graft integration on the wound bed was successful in all cases.

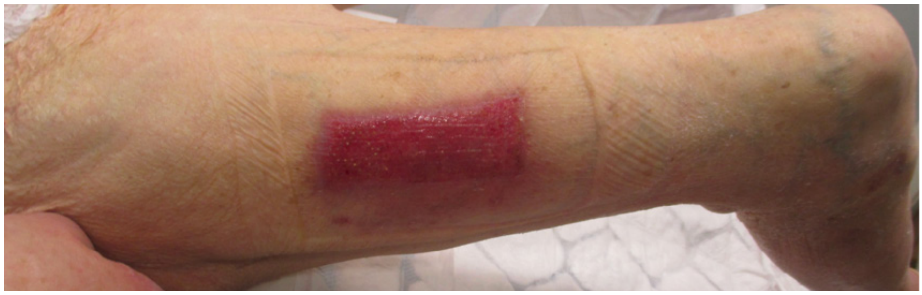


Image 11: Minor donor site infection with Staphylococcus aureus cultivated from discharge. An image of this dermatoporotic patient was taken after dressing change 30 days post-STSG. The infection healed with per oral cephalosporins and local wound care. © Reprinted with the permission of Sagepub Ltd.

5.3.1 Donor site healing

All STSGs were taken with a Zimmer™ (Zimmer Biomet, Warsaw, IN, USA) dermatome from the ipsilateral thigh and meshed 1:1.5. The specific anatomic location was the anterior thigh in eight patients and the lateral thigh in four patients. Graft thickness was 0.010 inches in one, 0.011 inches in one, 0.012 inches in seven, and 0.014 inches in one patient. In two patients, graft thickness was not reported.

Detailed use of donor site dressings was reported in nine patients. A hydrophilic polyurethane foam dressing Allevyn™ (Smith & Nephew, Kingston, UK) was used in all patients and advised to be removed at 14-21 days postoperatively. In addition, the skin substitute dressing Suprathel™ (Polymedics, Denkendorf,

Germany) was used in three patients, and Jelonet™ (Smith & Nephew, Kingston, UK) paraffin gauze was placed on the donor site before applying Allevyn™.

The median time of the first postoperative donor site dressing removal was 16 days (mean 15, range 6-25 d). The median overall healing time was 24 days (mean 34.7, range 13-97 d).

The median number of follow-up visits, including donor site dressing changes, was 6 (mean 11.3, range 1-60). In six patients, donor site healing took over 21 days (range 25-97 d). In two patients, healing took 25 days, and in four, 37-97 days. All donor sites healed via local wound care. None of the donor sites were regrafted immediately or later. See Table 7 for stratification of data.

Table 7: Demographics of 12 pretibial injury patients treated with a STSG in order of healing time.

Healing time	Patient no.	Age/ sex	CCI	Dermato-porosis	Location (R/L)	Dressing	Graft thickness, inch (mm)	Completely healed at, days	Number of follow up visits
≤21 days	1	71 F	7	Yes	Left, thigh, anterior	Allevyn Life	0.012 (0.30)	13	N/A
	2	89 F	5	Yes	Right, thigh, anterior	Suprathel, Jelonet, and Allevyn Life	0.012 (0.30)	15	3
	3	79 M	8	No	Right, thigh, lateral	Allevyn Life	0.011 (0.27)	18	3
	4	82 F	8	Yes	Right, thigh, anterior	N/A	0.010 (0.25)	18	7
	5	72 F	4	Yes	Right, thigh, anterior,	Allevyn Life	0.014 (0.35)	19	N/A
	6	84 F	5	Yes	Right, thigh, lateral	N/A	0.012 (0.30)	21	1
22–30 days	7	69 M	10	No	Right, thigh, anterior	N/A	0.012 (0.30)	25	2
	8	91 F	7	Yes	Right, thigh, anterior	Allevyn Life	0.012 (0.30)	25	15
>30 days	9	77 M	12	No	Right, thigh, lateral	Suprathel, Jelonet, and Allevyn Life	N/A	37	3
	10	90 F	5	Yes	Left, thigh, anterior	Jelonet and Allevyn Life	0.012 (0.30)	40	6
	11	84 F	4	Yes	Right, thigh, lateral	Suprathel, Jelonet, and Allevyn Life	0.012 (0.30)	87	13
	12	79 F	10	Yes	Right, thigh, anterior	N/A	N/A	97	60

N/A = not available, Allevyn®= Hydrophilic polyurethane foam dressing, Suprathel® = Absorbable, synthetic wound dressing / Skin Substitute Dressing, Jelonet® = Paraffin Gauze

5.4 Study IV: Health economic burden of pretibial injuries

Data of the treatment costs of 109 PL patients and 60 PH patients were obtained. For 7 PL patients, the NordDRG product invoices were not found.

Sixty-nine different NordDRG products were used in billing the municipalities for the treatment of pretibial injuries. All NordDRG products, their descriptions, prices, and contents are presented in the Attachments section of this thesis.

5.4.1 Treatment costs of pretibial hematomas

The total cost of all 60 PH patients was 199 749 €. The median total treatment cost was 1100 € (mean 3300 €, range 132 € - 20 078 €). The total costs were summed from a total of 219 invoices, which in turn, were based on combinations of 46 different NordDRG products. On average, the province municipalities were charged for 3.7 different NordDRG products (range 1 - 15) per treatment of a patient.

The breakdown of the mean total cost for each phase of treatment is presented in Figure 14.

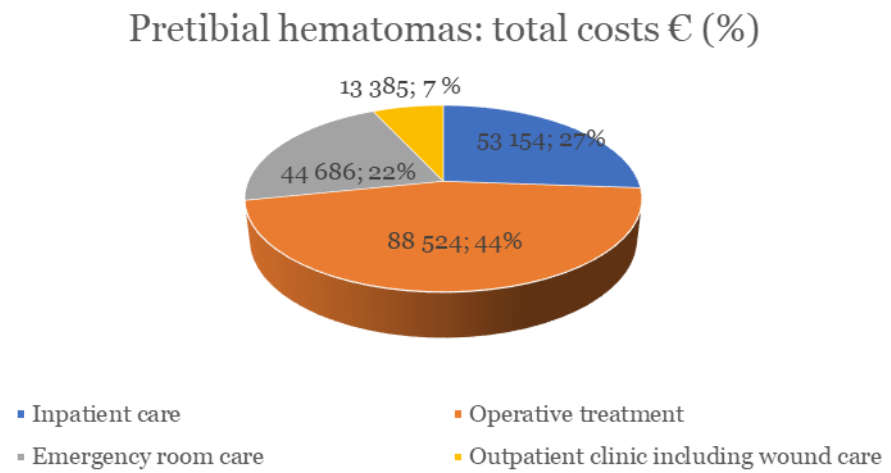


Figure 14: Distribution of the mean total cost of PHs (199 749 €) in each phase of treatment.

5.4.2 Treatment costs of pretibial lacerations

The total cost of all 109 PL patients was 199 003 €. The median total treatment cost was 240 € (mean 1800 €, range 132 € - 22 581 €). The total costs were summed from altogether 401 invoices, which, in turn, were based on combinations of 49 different NordDRG products. On average, the province municipalities were charged for 5.0 different NordDRG products (range 1 - 54) per patient.

The breakdown of the mean total cost for each phase of treatment is presented in Figure 15.

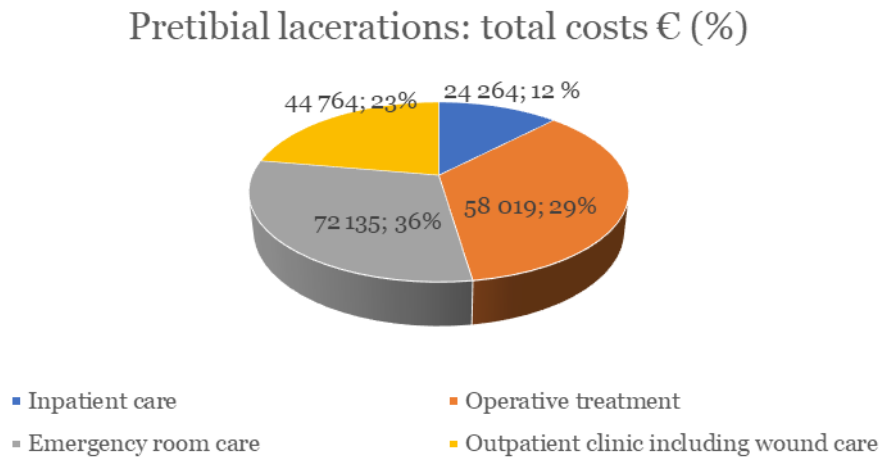


Figure 15: Distribution of the mean total cost of PLs (199 003 €) in each phase of treatment.

5.4.3 Comparing the costs of pretibial hematomas and pretibial lacerations

The costs, number of NordDRG products used, and number of invoices generated from the treatment of both PHs and PLs are categorized in Table 8.

Table 8: Stratification of patients, NordDRG products, invoices, and total costs.

	Pretibial hematomas	Pretibial lacerations
Patients	n=60	n=109
Different NordDRG products used in invoicing	n=46	n=49
Total number of NordDRG product invoices	n=219	n=401
Mean number of NordDRG product invoices per patient	3.7	5.0
NordDRG product price range	44–7780 €	44–10 152 €
Total costs of all patients (range)	199 749 € (132–20 078 €)	199 003 € (132–22 581 €)
Mean total cost per patient	3329 €	1826 €

Costs from the different phases of treatment in both patient cohorts are presented below in Table 9.

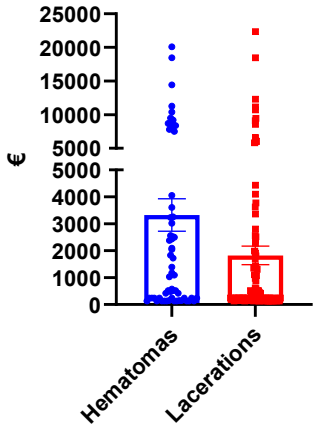
Table 9: DRG product costs and patient expenses of pretibial injuries stratified by treatment phase.

	Emergency room	Inpatient care	Operative care	Outpatient clinic
Pretibial hematomas				
Number of patients (%)	59 (98.3)	15 (25)	19 (30)	15 (25)
Total costs € (%)	44 686 (22)	53 154 (27)	88 524 (44)	13 385 (7)
Mean cost per patient € (range)	745 (0–3638)	886 (0–11 270)	1475 (0–10 152)	223 (0–2612)
Price range of DRG products €	44–1403	422–7780	168–10 152	44–566
Number of DRG products (%)	12 (26.1)	15 (32.6)	13 (28.2)	6 (13)
Number of DRG product invoices (%)	100 (45.7)	28 (12.8)	34 (15.5)	57 (26)
Mean number of DRG product invoices per patient (range)	1.7 (0–6)	0.47 (0–5)	0.57 (0–4)	0.95 (0–9)
Pretibial lacerations				
Number of patients (%)	103 (94.5)	14 (12.8)	12 (11)	29 (26.6)
Total costs € (%)	72 135 (36)	24 264 (12)	58 019 (29)	44 764 (23)
Mean cost per patient € (range)	662 (0–13 833)	223 (0–3710)	532 (0–7876)	411 (0–9078)
Price range per DRG product €	44–2500	22.5–3710	168–8345	11.4–558
Number of DRG products (%)	19 (29.2)	10 (15.4)	7 (10.8)	13 (20)
Number of DRG product invoices (%)	171 (42.6)	37 (9.2)	21 (5.2)	172 (42.9)
Mean number of DRG product invoices per patient (range)	1.57 (0–8)	0.33 (0–15)	0.19 (0–3)	1.58 (0–24)

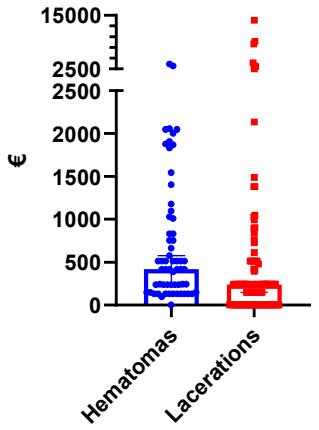
Statistical analysis of comparing costs

The total health economic burden of PHs and PLs in each phase of treatment was compared. The total costs of PHs were significantly higher than those of PLs. The higher costs of PHs arise mainly from ER visits and the need for operative care. Inpatient care was also more expensive albeit not significantly. PLs generate higher costs from the outpatient clinic. See Box plots 1–5 for distribution of costs and Table 10 for mean values, range of costs, and P-values.

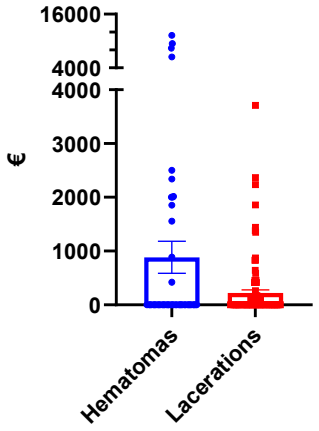
Box plot 1: Total costs



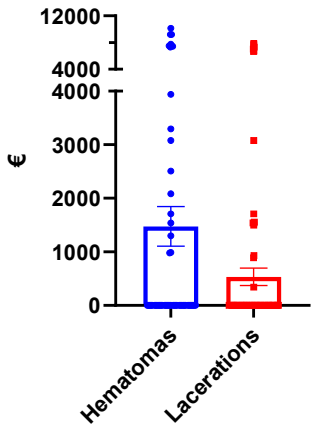
Box plot 2: ER costs



Box plot 3: Inpatient care



Box plot 4: Operative care



Box plot 5: Outpatient care

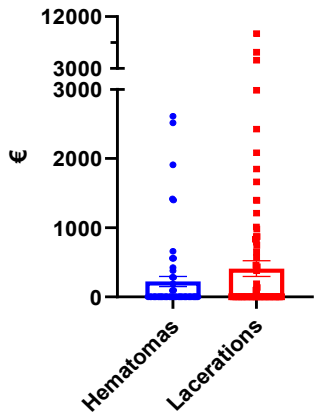


Table 10: Comparison of the costs of PLs and PHs.

		Pretibial lacerations (N=109)	Pretibial hematomas (N=60)	P-value
Total cost per patient (€)	Mean (range)	1826 (132–22 368)	3329 (132–20 078)	0.0486*
Cost of ER treatment per patient (€)	Mean (range)	662 (0–13 833)	745 (0–3638)	0.0002*
Cost of inpatient care per patient (€)	Mean (range)	223 (0–3710)	886 (0–11 270)	0.6526
Cost of operative care per patient (€)	Mean (range)	532 (0–7876)	1475 (0–10 152)	0.0058*
Cost of outpatient care per patient (€)	Mean (range)	411 (0–9078)	223 (0–2612)	0.6533

The non-parametric Mann-Whitney U-test (Wilcoxon Rank Sum Test) was used for statistical analysis. Groups were compared by their sum of ranks. The value zero (0 €) represents a patient who did not need treatment in the corresponding treatment phase/group. A P-value of <0.05 is considered statistically significant.

5.5 Unpublished data

Costs from primary healthcare were obtained for 30 PL patients treated during 2019. Costs included physician and nurse appointments, rehabilitative treatment at a healthcare center ward, and at-home wound care visits.

5.5.1 Primary healthcare costs of pretibial lacerations

The median cost per patient in the primary healthcare setting was 45.9 € (mean 148.5 €, range 10 € – 1739 €).

- Primary health care generated 143 invoices for 16 NordDRG products.
- NordDRG product prices ranged from 10 € to 442.46 €.
- Primary healthcare accounted for 2.2% (4455.33 €) of total expenses.
- The proportion of NordDRG invoices was 62.4%.
- Wound care treatment at home accounted for 45.5% of total primary healthcare invoicing, with a single visit cost of 12 €.

6 DISCUSSION

Pretibial injuries have been considered trivial or banal pathologies among the elderly and infirm patients. Despite being common, there is a lack of knowledge about pretibial injuries. In Finland, no terminology nor descriptions in medical textbooks exists on these injuries. However, clinical practice has shown that patients frequently require treatment in secondary healthcare settings, including multiple ER visits, surgeries, inpatient care, and wound care.

In this thesis, an overview of the current situation in treatment and outcome of pretibial injuries is presented. Further, parameters for recognizing patient- and wound-related factors, such as risks, clinical features, demographic data, and treatment costs, are disclosed. As most patients treated are frail, knowledge of these parameters is important to enable healthcare resources to be allocated in ways that best benefit the patients.

This thesis suggests that pretibial injuries are a unique traumatic wound entity that causes pain and suffering, as these injuries frequently result in chronic wounds. It was observed that most pretibial injury skin defects are left to heal with local wound care possibly contributing to CLU formation. The current state of diagnosis and treatment is non-standardized and favors a passive approach of prolonged local wound care.

6.1 Pretibial lacerations

Study I yields several important findings. It concludes that most PLs are superficial and small, mainly of the Modified Dunkin types I and II. In this study, the treatment decisions on conservative versus operative treatment correlated rather well with the Modified Dunkin classifications. However, the Modified Dunkin classification is not familiar to clinicians in Finland. Therefore, treatment decisions for PLs were not made with the help of the directional guidelines of the Modified Dunkin classification. Rather, ‘’clinical common sense” was used. The findings in patient history files indicated that these types of PLs are considered banal and easy to treat. PLs were sutured and patients were expected to heal normally.

Lack of knowledge resulted in treating the majority (56.9%) of PLs primarily by suturation against recommendations.[72,127,128] This included both linear and flap lacerations, and sometimes even necrotic flaps. PLs clearly have unmet outcomes compared with other traumatic wounds due to the nature of dermatoporotic skin. Frequent CLU formation, infection complications, and an associated decline in

patient independence are factors that need to be taken into consideration when treating patients. By disclosing these features, better practices can be utilized.

It is known that PLs frequently become chronic.[15,25,26] In Study I, 32% of patients' wound healing took more than 3 months, resulting in a hefty amount of CLUs. Further, the number of infection complications in Study I cohort was considerable, 30%. The high rate of complications may be iatrogenic in origin since PLs continue to be improperly treated with sutures in the ER and then patients are left circling in wound care clinics.

As the previous literature states and our study confirms, wound care after discharge from the ER mostly occurs in community-level healthcare centers by wound care nurses.[26] This leads to ER physicians not knowing the outcome of the primary treatment. It is difficult to change treatment habits when the outcome does not reach the primary caretaker. Furthermore, when the aftercare of PLs is left only to wound care nurses, other comorbidities affecting wound healing are not diagnosed and may go untreated. If wound healing is impaired, a physician must assess the vascular status and other wound healing conditions first.[19,20,60] Due to the multimorbidity of patients, seamless collaboration between wound care nurses and physicians is advised when treating PLs.

Study I revealed the long hospitalization periods of patients. As stated, patients were elderly and comorbidities were frequent in our cohort. The general subsidence of patient independency may be the reason why the LOS at the plastic surgery ward was relatively long, a mean of 9.6 days (range 0-51 d). Cahill et al. reported a similar LOS, 7.8 days, for patients undergoing surgery.[2]

Another reason for why LOS is so high, similar to the figure for hip fracture patients (11 days)[129,130], is that pretibial injury patients are often immobilized after STSG application. Prospective studies have shown that there is no difference in STSG integration whether patients are mobilized immediately or left to bed rest.[104–106] Also known is that delaying ambulation of morbid elderly patients can be fatal.[108] Further, our cohort patients needed rehabilitation in a health care center ward after treatment in the central hospital. In rehabilitation the mean LOS rose to 21 days indicating a significant decline in patients' overall well-being. Taken together, patients with PLs should be ambulated quickly since otherwise according to our results they are at risk for long hospitalization and a permanent decline in independency. Also, a geriatric evaluation could be utilized during their treatment periods, as with hip fracture patients.

Treatment, LOS, and follow-up of PLs requires excessive healthcare resources, as noted also in previous literature.[6] Recognizing the special features of PLs and educating healthcare professionals about these would result in improved treatment. Further, preventative measures could be utilized. Primary prevention is advisable and can be achieved by, for instance, wearing clothes with protective fabric around risk patients.[6,81] In Study I, a significant proportion of patients

(53%) had suffered at least one additional traumatic laceration during the period examined, emphasizing the need for preventive measures.

6.2 Pretibial hematomas and dermatoporosis

In Study II 60 patients with PHs diagnosed in a large central hospital during a five-year period were reviewed. Based on the clinical files, two distinct treatment paths were found: conservatively treated (58%) and evacuated (42%) PHs. The most noticeable indication for evacuation was a necrotic skin defect (72%) caused by cutaneous ischemia due to pressure in the PH cavity.

Previous literature states that evacuation of a PH should be done as soon as possible to reduce the risk of skin necrosis and infection.[16,23,29] Study II showed that 72% of the evacuated PHs were diagnosed only when skin necrosis had already occurred, i.e. after patients had suffered ischemic pain of the skin over a prolonged period. It seems that PH patients either receive treatment too late or are misdiagnosed. Patients do in fact seek treatment, as the median day for seeking treatment after injury was 0 in Study II. It is the treatment that is delayed. Therefore, descriptions of PHs should be included in medical textbooks to educate physicians.

The initial diagnosis of PHs can be difficult and differential diagnosis can mislead the clinician. PHs are characterized by phases including erythema, swelling, pain and temperature rise.[23] Because of these symptoms many cases are confused with, for instance, erysipelas or DVT, leading to unnecessary treatment with antibiotic therapy or LMWH, and delaying referral to surgical care. Confusing PHs with cellulitis or DVT can worsen the outcome not only by delaying hematoma evacuation but also because initiating anticoagulant therapy may provoke further bleeding. Elderly patients with anticoagulant medication should always be suspected of having a PH when presenting with acute leg pain and swelling.

The characteristics of those PHs that cause skin ischemia and necrosis seemed to be linked to dermatoporotic skin and morbidly fragile patients with a high CCI. Skin blistering was documented among 50% of the patients prior to necrosis. In dermatoporotic patients, it could be justified to proceed directly to evacuation even if the skin seems vital. Useful clinical criteria for prompt PH evacuation have not previously been suggested. Ischemic pain, dermatoporosis, and ultimately epidermal blistering are proposed criteria for expeditious evacuation to prevent skin necrosis.

When a patient with a PH has mild symptoms of slight pain, minor swelling and a visible capillary refill on the skin, invasive treatment seems unnecessary. Study II indicates that PHs among patients with healthy skin mostly heal without treatment or by applying a compression bandage since no further recordings of

these patients discharged from the ER were found. However, sometimes bleeding can proceed slowly and symptoms begin later, even several days after the injury. Especially in these cases, the diagnosis can be difficult. A routine follow-up for patients a few days after the injury might be advisable. Differential diagnosis becomes more important in ambiguous cases, and soft tissue tumors must be kept in mind.

Considering invasive treatment, traditional needle aspiration with a 18G needle was not a successful treatment method in any of the cases in Study II. Needle aspiration should not be utilized, as previous literature indicates as well.[72] Evacuation of a PH requires a stab incision and mechanical removal of the coagulated blood. Coagulated blood will not fit through a small needle. However, using a large caliper suction cannula has been reported to work.[29]

Of patients, 23% had a spontaneous PH or a PH without any noticed trauma history based on their patient files; 71% of these patients had dermatoporosis. Whether or not a spontaneous etiology for the PH is truly accurate remains unknown. Cognitive impairment was frequent among PH patients resulting in an unreliable medical history. Patients simply may have forgotten about a minor trauma. However, spontaneous PHs have been described in earlier literature.[28]

A high percentage of the PH patients in Study II had anticoagulant medication (85%). The link between anticoagulants and PHs is evident in previous studies.[16,22,23,28,29] It is safe to argue that PHs have a strong iatrogenic component and can be considered complications of anticoagulant medication (and cortisone-related dermatoporosis). Previous studies state that cutaneous complications of anticoagulant therapy are undervalued relative to intracranial and gastrointestinal bleeding.[23] In Study II the hemoglobin count was lowered acutely as much as 50 g/dl due to PHs. Given the need for RBC transfusions in several cases and PH involvements in five deaths, our study suggests that cutaneous bleeding among PH patients can be life-threatening.

The presence of compartment syndrome accompanying PHs was observed. Only one patient from the cohort had clinical compartment syndrome. However, this patient had intramuscular bleeding instead of a typical prefascially situated PH. Clinical practice has shown that patients with a PH are often referred to hospital from smaller healthcare center units by physicians for suspicion of compartment syndrome. This further indicates that the pathogenesis of PHs is not familiar to clinicians. PHs do not cause compartment syndrome since they occur in the prefascial plane within the subcutaneous tissue. Rather than causing compartment syndrome, the danger of PHs lies in the treacherous aging skin. However, PHs should be considered and treated with the same intensity as compartment syndrome since ischemic pain on the skin causes suffering and bleeding can be severe. Even though PHs do not lead to such drastic complications as compartment syndrome, patients should be treated promptly.

The overall incidence of dermatoporosis in Study II was 42%. The diagnosis of dermatoporosis was estimated from descriptive data in patient history files and photographs. The term "dermatoporosis" seems to be unknown among Finnish clinicians since it was not used once. Other descriptions were used such as "very thin skin", or "parchment-like skin" and "cortisone skin". It is likely that the incidence of dermatoporosis is much more frequent among this cohort. Given the findings of complications related to dermatoporosis in previous literature[7–10,14,131] and the results of our study, Finnish health care professionals should be educated more about dermatoporosis.

Finally, regarding long hospitalizations, prolonged wound care, and CLU formation, the same conclusions can be drawn as with the PL patients of Study I. Of the skin defects caused by PHs, 60% were left for local wound care causing considerable pain and suffering. Early decisions on treatment with STSG could result in faster healing.

6.3 Classification for pretibial injuries

In Studies I and II, a problem with the Modified Dunkin classification was noted since a type V laceration is accompanied by an underlying hematoma. This injury resembles that of a PH rather than a PL, as hematoma evacuation is needed. Thus, the Modified Dunkin Classification causes confusion in the distinction between PLs and PHs. See Image 12.

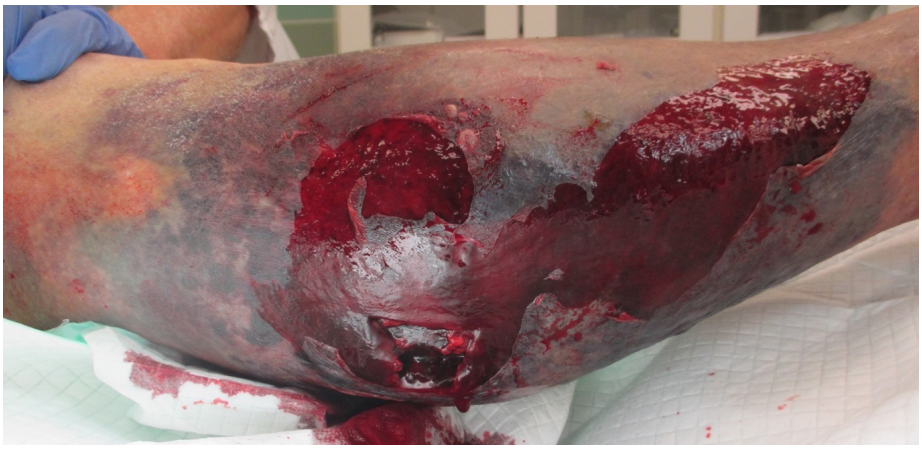


Image 12: An acute PH with spontaneous rupture of the skin. Is this a Modified Dunkin type V PL or a PH? © T. Seppälä

6.3.1 The Sinuhe classification

Since current classifications are somewhat confusing, a suggestion is made to help distinguish PLs from PHs. The Modified Dunkin V PL should not be included in the classification of PLs. In further studies, patients with a Modified Dunkin V injury should be included in PH cohorts to gain better patient homogeneity. Hence, the new Sinuhe classification for pretibial injuries is suggested. PLs should be categorized into linear lacerations, flap lacerations and total skin loss. PHs should be classified separately into open (ruptured), closed, and necrotic PHs. A clear distinction between PLs and PHs is important so clinicians can make the correct diagnosis and patients receive appropriate treatment. Table 11 presents the new *Sinuhe classification* for pretibial injuries:

Table 11: The Sinuhe classification for pretibial injuries with treatment recommendations.

Sinuhe classification of pretibial injuries	
Pretibial lacerations	**Pretibial hematomas**
Linear laceration	Open hematomas (ruptured hematomas)
• Oppose wound edges with adhesive tape	• Proceed to hematoma evacuation and wound closure, or debridement and STSG in a single session
Flap laceration	Closed hematomas
• Vital flap: oppose wound edges with adhesive tape • Non-vital flap: debride the wound and schedule STSG if defect is over 0.5–1%TBSA	• Proceed to prompt hematoma evacuation and wound closure if skin ischemia is present (pain, blisters, dermatoporosis)
Total skin loss	Necrotic hematomas
• Schedule STSG if defect is over 0.5–1%TBSA	• Proceed to escharectomy, hematoma evacuation, debridement and skin grafting in a single session

STSG = Split-thickness skin grafting
TBSA = Total body surface area

6.4 Using skin grafts for treatment of pretibial injuries

Study III examined donor site healing of pretibial injury patients treated with an STSG. The cohort consisted of 12 patients with a mean age of 81 years and unambiguous dermatoporosis in eight patients. Half of the patients' donor sites healed within the expected time range of 7-21 days.[93] The other half had prolonged donor site healing, but healing took over a month in only four patients. All donor sites healed with local wound care. One donor site infection occurred, contributing to prolonged healing.

Graft thickness in Study III was high when considering the frailty of patients and the high incidence of dermatoporosis. None of the grafts taken were 0.008 inches (0.2mm) thick, which in a previous study led to faster healing even in patients aged 50 years.[100] Further, immediate regrafting of the donor site was not used despite literature recommendations.[98,101,102] Thus, donor site healing time among frail patients could be shortened if a thin graft (e.g. 0.008 inch) was used and excess skin was grafted back immediately. Excess skin can also be over-meshed to increase its size before regrafting.[103]

Semi-occlusive wound-healing dressings should be used routinely on donor sites.[132] A Finnish study examined STSG donor site healing by comparing Suprathel® and Mepilex Transfer® when applied as donor site dressings.[133] The study concluded that Suprathel® causes less pain, bleeding, and scarring.[133] However, there were no differences in healing time.[133] In Study III, Suprathel® use on the donor site was reported in both ends of the healing time spectrum, supporting the claim that healing time is not improved with expensive dressings.

As Studies I and II present, among other literature, pretibial skin defects often become CLUs, requiring tens, even hundreds of wound care appointments.[15,25] Even though the cohort was small (n=12), there was no total graft losses in Study III. Despite donor site healing takin over 21 days in 50% of the patients, CLU formation from pretibial injuries can be considered a more unfavorable outcome. STSGs are typically used only when long conservative treatment is unfruitful, even though previous studies have shown that patients with CLUs benefit from STSGs in terms of health-related quality of life.[20,134] Tuboku-Metzger et al. demonstrated that with pretibial injuries debridement and reconstruction with STSG should take place within one week to improve healing.[25] Further, the earliest publications on pretibial injuries also advocate on early debridement and STSG.[69,70]

Primary operative treatment with STSG can be withheld gratuitously in fear of complications regarding the surgery and the donor site in a frail patient group.[68,79,85,87] Study III suggests that skin grafting is safe. Further, skin grafting can be considered mini-invasive, as small STSGs can be harvested under local anesthesia, e.g. infiltrating the subdermis with a 0.5-1% solution of lidocaine cum adrenalin.[86] Access to electric dermatomes should be alleviated in an outpatient

and ER settings to encourage early and mini-invasive treatment of pretibial skin defects. Further, prospective studies on treating small pretibial defects with FTSGs are needed, which would eliminate the creation of a donor site.

6.5 Pretibial injuries and their health economic burden

Study IV presents data on the medical cost burden of 109 PL and 60 PH patients aged ≥ 65 years treated in Finnish public healthcare during a five-year period. Costs were extracted and presented from NordDRG product invoices generated in the treatment of patients in secondary healthcare.

Per-patient generated invoices were traced accurately to estimate the costs of pretibial injuries to municipalities. In addition to calculating a reference point for pretibial injury-inflicted costs, a comparison of the health economic burden of PLs and PHs was conducted, indicating the importance of differentiating the two entities from each other. The examination of multiple invoices supports the previous notions that a significant proportion of pretibial injury patients needs repeat contacts in healthcare.[22]

In 2012, Thomson et al. estimated the mean cost of a PH to be around 3900 €.[22] The price consisted of a skin graft (1700 €) and a length of stay of 11 days (200 €/day).[22] Our average PH cost from a cohort of 60 patients was slightly lower, 3300 €. However, the treatment of over half of our cohort patients' was conservative, which reduces the total mean cost. Our study indicates that expenses have risen over the last decade, and the need for revisions and skin grafting has not declined.

The significantly higher costs of PHs relative to PLs can be argued to be caused by delayed diagnosis and treatment. Study II showed an incorrect primary diagnosis in 8% of patients and a latency of 4.8 days (range 0-16 d) in referral. Further, from the patients of Study II, 31% had repeat ER visits. Patients are frequently re-admitted after the primary symptoms of pain and swelling progress to skin necrosis. When skin necrosis occurs, the costs of PHs multiply due to the need for revision surgery and later skin grafting.

Early diagnosis and prompt PH evacuation are paramount and could cut costs by lessening the need for revision surgery, skin grafting, and hospitalization. Optimizing treatment requires knowledge of the unique clinical appearance of PHs. When a revision and skin graft are needed, this study suggests performing these in a single session to reduce costs and suffering. As our investigation of NordDRG products reveals, revision surgeries, skin grafting, and inpatient care have the highest fixed prices.

Study IV shows how PLs generate more expenses than PHs through prolonged local wound care. However, this difference was not statistically significant. Study I showed that the conservative healing of PLs takes around 75 days but can

exceed one year. Could early skin grafting shorten the need for local wound care? The high cost of surgical care seems to direct treatment towards the poorly resourced primary healthcare centers for local wound care, even if surgery could benefit the patients. Skin grafting can be done safely and cost-efficiently in an outpatient setting with faster results in healing.[69] Further, Study III implicates that donor site healing is relatively uneventful. Extensive prospective random-controlled trials on treating PLs with skin grafting in an outpatient setting to reduce the need for wound care are warranted.

6.5.1 Is the NordDRG system serving its function in wound medicine?

Eighty-five different NordDRG[124] products were used for billing municipalities for the treatment of pretibial injuries. The hundreds of different invoices in rather similar injuries and patients indicates an equivocal invoicing policy. Thus, the integration of NordDRG products into pretibial injury patient invoicing was found to be complex and irregular.

Assigning of NordDRG products was inconsistent even when patients had similar age, comorbidities, diagnosis, and treatment, thus affecting the variation in costs. This can be considered impractical when evaluating health economic cost burdens, in stark contrast to the presumably transparent and efficient DRG system.[118] Invoices in our study were generated through multiple patient contacts from different departments, resulting in a somewhat arbitrary selection of NordDRG products. The DRG product system seems unsatisfactory for acute and chronic wound patients needing several contacts in healthcare, even though the DRG system was built to increase the transparency and efficiency of hospital costs.[118,120,121]

Examining every invoiced NordDRG product enabled a calculation and grouping of pretibial injury costs. Further, potential problems in healthcare invoicing were highlighted. The NordDRG products seem to be constructed such that all possible treatment is directed towards primary healthcare. An example: A single wound care visit at the patient's home, including the re-application of NPWT dressings, generates a 12 € invoice for the municipality from primary healthcare. When the same treatment is provided in secondary healthcare, the price is 558 €. This creates inequality when patients are pushed for wound care to the poorly resourced primary healthcare with less wound care specialists.

Complicated NordDRG product invoicing plays a significant role in configuring the expenses of wounds and healthcare expenses. Alongside providing firsthand data on what constitutes the costs of pretibial injuries, some of the complex mechanisms associated with the NordDRG system were elucidated. Disclosing the economic burden of pretibial injuries and the diversity of NordDRG products to clinicians and policymakers is essential in a publicly financed healthcare system.

6.6 Limitations and strengths

A general limitation of Studies I, II, III and IV is the retrospective nature of the study designs. Data recorded for purposes other than research was used, and thus, reviewing and analyzing clinical diagnostic impressions from medical records can be considered a limitation of this thesis. All of the studies have limitations in cohort sizes, with Studies II and III affected the most. Despite the limitations and considering the age demographics of the population of Finland, this thesis is important and timely.

In Study I, the data related to Modified Dunkin classifications were not available because the classification is unknown in Finland. Thus, the classifications were estimated from descriptions or photographs of the PLs in patients' medical records, which can be considered a limitation. The CCI was used when evaluating patients' overall wellbeing. Because of the nature of the descriptive text in the patient files, the Rockwood Clinical Frailty Scale[135] was not calculable, even though it would have been more optimal considering the geriatric patient population.

The strengths of Study I include the larger cohort of patients (n=116) compared with previous studies in which the cohort sizes have varied between 24 and 73 patients.[67–70,72] Also, patient's rehabilitation periods were traced accurately for the first time, providing a realistic understanding of the complicated healing of PLs and their progression to CLUs. Thorough tracing of patients revealed the numerous follow-up visits and long rehabilitation hospitalization periods, indicating malpractice, which in turn can lead to a significant decline in patient independency and excessive use of resources.

Even though the cohort size of Study II is small, most previous research on PHs comprises case reports and descriptive studies.[29,54,73,74] Strengths of Study II include the statistically significant findings of the involvement of dermatoporosis, high CCI and poor physical ability among PH patients with skin ischemia and necrosis. By identifying risk factors, treatment decisions are easier to make and patients can receive faster and better treatment. Study II can be seen as an indicator of PHs not being recognized early in Finland. Further, STSG was seldom used and decisions on reconstruction were made after some weeks. All of this suggests that at present PH patients suffer prolonged discomfort due to unnecessarily long local wound care.

In addition to cohort size, the most important limitation of Study III was the diagnosis of dermatoporosis. The only possibility for diagnosis was to rely on descriptive text and some photographs from the patient history files. Dermatoporosis is an unknown term among Finnish clinicians and is currently not being taught in medical school. Finnish clinicians tend to use descriptive terminology such as "parchment skin", "cortisone skin", etc., to describe dermatoporosis, which had to be relied on during the study.

In Study III, data on donor site healing of the elderly were not compared with the data of younger patients. Further, data on postoperative pain and on the health-related quality of life could not be gathered. A previous study indicates that younger patients of <65 years describe significantly higher postoperative pain on donor sites than elderly patients.[134] Thus, the focus was kept on wound care-related issues rather than on health-related quality of life. Further, it is unlikely that any patients would have answered questionnaires since many had cognitive impairment or had died during the study. Study III is important since it provides information exclusively on dermatoporotic donor site healing. Using STSG is safe among frail patients, as no full-thickness donor site wounds were seen, and all donor sites healed.

The data of Study IV were scattered in two different databases, affecting the reliability of the search process when extracting NordDRG products. Some NordDRG product invoices were likely not found. Also, the ability to obtain expenses only partially from primary healthcare was a drawback. Further, retrospective analysis can result in a rather heterogenous patient selection contributing to difficulties when comparing treatment costs. The study cohort was not of Gaussian distribution, which caused limitations in statistical analysis.

Study IV is important because systematic calculations on the current economic impact of treating pretibial injuries have not been reported previously. The significance of distinguishing PHs and PLs was emphasized from a health economic perspective, further disclosing faults in their current treatment. Also, no examination of municipality invoicing via NordDRG products for wound care has been conducted earlier. Estimation of wound care costs is known to be difficult.[115] Several studies have been performed, but many have provided broad estimates from incidence and prevalence rates for all wound categories.[115,116] In this study, an accurate trace of per-patient generated invoices was conducted to reliably estimate the costs of pretibial injuries.

6.7 Future perspectives

This thesis provides in-depth findings on pretibial injuries. Clearly, there are defects in the current diagnosis and treatment of PLs and PHs. There is still no consensus as to whether to leave skin defects for local wound care or schedule an STSG. However, our study suggests the latter considering the high number of healthcare contacts needed with conservative healing. Unfortunately, using the operating room is expensive and has limited access, directing treatment into local wound care in the primary healthcare system. Many pretibial skin defects could be treated in an outpatient setting with STSGs.

Randomized prospective trials with homogeneous and large patient cohorts are needed to find evidence-based treatment methods for pretibial injuries.

Identifying an optimal treatment protocol would lessen CLU formation and the number of follow-up visits needed for wound care. The following trials would provide valuable information for planning treatment guidelines:

1. A prospective randomized trial on PLs comparing local wound care with early (< 7 days) or immediate STSG treatment in an outpatient setting.

2. A prospective trial comparing surgical treatments of PHs in a single session. Open PH evacuation, revision and skin grafting could be compared with a mini-invasive treatment using a large caliper suction cannula, e.g. a liposuction cannula, combined with a compression garment.
3. Randomized prospective trials on donor site healing among dermatoporotic patients are needed in larger cohorts to prove the safety of donor site healing.

4. The association between anticoagulants and PHs appears to be strong. This iatrogenic component should be investigated to determine which anticoagulants pose the greatest risk for PHs.

Currently, PHs in Helsinki University Hospital are treated in a single session including PH evacuation, debridement of necrotic skin, and immediate STSG without bed rest. This seems to lead to faster ambulation, a shorter need for wound care, and hopefully fewer CLUs. See Image 13.

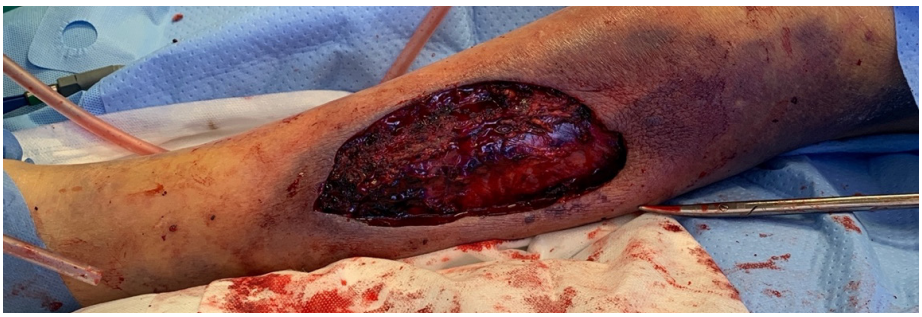


Image 13: An acute PH treated in a single session comprising evacuation, revision and STSG all at once. Image taken after evacuation of the PH and revision of the necrotic skin. © T. Seppälä

Cahill et al. presents a management approach for pretibial injuries used in Queen Victoria Hospital, England, UK, which could be implemented in Finland. In Queen Victoria Hospital, pretibial injury patients are discussed weekly in a multidisciplinary meeting.[2] Skin grafting is recommended if the wound is unlikely to heal in 4–6 weeks.[2]

Uniform terminology is paramount for communication and recognizing medical phenomena. Previous publications describe PHs in various terms such as deep dissecting hematomas, tension subcutaneous hematomas, superficial hematomas, contusion hematomas, traumatic hematomas, and lower extremity hematomas.[10,23,30,73,75,76,136,137] PLs are referred to as skin tears, excoriations, and abrasions.[7,13] To avoid confusion in clinical work and for use in research, *pretibial lacerations* and *pretibial hematomas* are suggested. In the study cohorts patient files, none of the terms above were used by clinicians, indicating a clear need for defining these injuries. Finally, the Sinuhe classification should be verified and adopted into clinical practice for improving diagnosis and treatment.

7 CONCLUSIONS

Based on the clinical publications, the following conclusions can be drawn:

I Patients treated for PLs are mostly multimorbid elderly females. The majority of PLs are of Modified Dunkin type I and II (72%), explaining why treatment is largely conservative (89%). Most PLs (57%) are treated primarily with sutures despite literature recommendations, indicating a lack of knowledge. Risk of CLU formation is high in patients with PL.

II PHs frequently cause skin ischemia and necrosis if not evacuated. Risk factors for skin necrosis are multimorbidity, dermatoporosis and compromised independence. Most PHs were diagnosed after skin necrosis was apparent. This indicates that patients receive treatment too late due to being misdiagnosed or not recognized early. Most skin defects after PH evacuation were left to local wound care. PHs can be treated conservatively without surgical evacuation when skin quality and the patient's overall health are satisfactory.

III Using STSGs to treat pretibial injuries among multimorbid dermatoporotic patients is safe and does not result in major complications, albeit prolonged donor site healing can occur. Donor sites heal via local wound care without the need for regrafting. Early treatment of pretibial injuries with STSG should not be avoided due to fear of complications with donor site healing.

IV PHs cause a significantly higher economic burden than PLs. Thus, PHs can be regarded as a more complicated injury. Costs arise from repeat ER visits and the need for revision surgeries due to delayed treatment. Patients with PLs have multiple contacts in the outpatient wound clinic. Improvement in diagnosis and treatment of both injuries is needed.

Pretibial injuries are important etiological factors in wound medicine and should be included in CLU classifications. Despite PLs and PHs having similar patient demographics, their clinical appearance is different. The two entities should not be mixed in classifications and in the literature. Under pretibial injuries, PLs should be categorized as linear lacerations, flap lacerations, or total skin loss. PHs should categorized as open (ruptured), closed, or necrotic PHs. Hence, The Sinuhe classification is suggested for guidance in diagnosis and treatment.

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This project, which commenced in Kymenlaakso Central Hospital, Kotka, and concluded in the Helsinki University Hospital, Department of Plastic and Reconstructive Surgery, was conducted between 2020 and 2023.

During the second year of my surgical residency in Kotka, at the beginning of 2020, COVID-19 hit the fan hard. Suddenly, normal life halted. During leisure I discovered some unusual thoughts circulating in my head. I found myself thinking about doing research. By then, I had treated several patients for pretibial injuries and was surprised that these injuries did not even have a name in Finland. I thought that this could be a topic that has remained under the radar. It could be something new that no one had truly grasped before. Obviously, it was not a matter of curing cancer, but it still felt important and interesting. Most of us get old and many will suffer pretibial injuries, of which too little is known.

I approached my mentor, plastic surgeon *Vahur Grünthal* with my ideas on the topic. He introduced me to *Virve Koljonen*, the current Professor of Plastic Surgery at the Helsinki University Hospital. A new world opened, as Virve became my supervisor and led me down the rabbit hole of science.

I warmly thank all of the people who made this project possible. My deepest and sincerest gratitude goes to my supervisor Virve. With Virve's endless energy, we formed a dynamic duo without even meeting for over a year. Virve taught me the fundamentals of doing science, teaching, learning, and questioning everything, as these are her hobbies. She thinks outside the box with an enthusiasm and efficiency I've never before witnessed. She continues to encourages me to be an academic surgeon.

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A special thanks goes to Vahur as he has taught me most of what I know about plastic surgery. He is the most systematic and patient teacher I know. Vahur is a virtuosic plastic surgeon, and I am lucky to be able to call him my friend.

Since continuing residency at HUS Musculoskeletal and Plastic Surgery, I have had the honor to work with and come to know some true masters. I thank

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No one understands the work of a resident surgeon quite like another resident. I'm lucky to be able to share thoughts, humor, and lessons with current resident colleagues in our department. Two years have flown by, hopefully, there are many more to come with all of you.

I thank plastic surgeon *Halfdan Wardemann* from Norway. He is proof that art, science and surgery go hand in hand. He managed to translate my allegories and visions into the perfect image on the cover of this thesis.

A good life requires more than work. My parents and big sisters have given me a privileged starting point in life. Thank you for the liberal upbringing of the youngest child. I've also been lucky in having plenty of true friends throughout my life. Many have stayed from early childhood. All are brilliant and kind, sharing their endless knowledge and enthusiasm with me. Finally, I humbly thank *Kia* for the love and support. Everything feels easy and light with you!

This book was written for the good of our frailest patients.

Helsinki 2023
Toni

ATTACHMENTS

ATTACHMENT 1: Breakdown of all 69 NordDRG products, with product names, original descriptions, product contents, quantity of products, and total expenses of the products in each group. Primary healthcare-related NordDRG products and expenses of the 29 PL patients are in the last section of the table.

NordDRG product name	Product description	PH or PL	Unit price €	Product invoices of 60 PHs (N)	Product invoices of 109 PLs (N)	Total sum of invoices per product PH €	Total sum of invoices per product PL €	Total sum of invoices per product PL + PH
ER products								
PAI/PKL	ER phone call	PH and PL	44	1	10	44	440	484
ENS22	Surgical ER patient	PL	322	0	2	0	644	644
PAIP	ER patient product	PH and PL	239 / 243	11	30	2629	7290	9919
PÄI02	ER patient needing routine examination (laboratory, x-ray), treatment time 13-24h. e.g. elderly patient with unspecified infection / falling on flat ground	PH and PL	337	2	3	674	1011	1685
PÄI03	ER patient needing a bed or demanding care with examinations. Treatment time 25-36h. e.g. elderly patient with unspecified infection	PH and PL	878	5	1	4390	878	5268
PÄI04	ER patient needing continuous monitoring and medication	PL	1533	0	1	0	1533	1533
PÄI05	Patient needing surgery	PL	2500	0	1	0	2500	2500
PÄI06	ER patients treatment in the ER exceeding 48h	PL	2000	0	2	0	4000	4000
PÄI07	Nurse appointment in the ER	PL	49	0	9	0	441	441
PÄI08	Short doctor's appointment in the ER	PL	79	0	1	0	79	79
PAI09	ER patient receiving a routine check-up from an MD with two laboratory / x-ray examinations, and a simple procedure e.g. wound suturation	PH and PL	148	7	14	1036	2072	3108
PAI10	ER patient needing monitor surveillance or demanding procedures or occupying staff. More than two laboratory / x-ray examinations	PH and PL	239	10	18	2390	4302	6692
PAI11	Fast track ER patient who gets discharged home without the need for surveillance, includes routine laboratory or x-ray examinations	PH and PL	98	1	1	98	98	196
PAI12	ER patient needing monitor surveillance or demanding procedures or occupying staff. More than two laboratory / x-ray examinations	PH and PL	515	29	23	14935	11845	26780
PAI13	Critically ill ER patient needing stabilizing care from an anesthesiologist, or 5h of continuous care	PH and PL	1382	1	3	1382	4146	5528

NordDRG product name	Product description	PH or PL	Unit price €	Product invoices of 60 PHs (N)	Product invoices of 109 PLs (N)	Total sum of invoices per product PH €	Total sum of invoices per product PL €	Total sum of invoices per product PL + PH
PÄI21	Nurse appointment in the ER	PL	61	0	4	0	244	244
PÄI22	Short doctor's appointment in the ER	PH and PL	132	13	20	1716	2640	4356
PÄI23	Long doctor's appointment in the ER	PH and PL	416	16	24	6656	9984	16640
PÄI24	Demanding patient	PH and PL	1403	4	4	5612	5612	11224
N (total)=19				**N (total) = 100**	**N (total) = 171**	**Total: 44 686 €**	**Total: 72 135 €**	**Total: 116 821 €**
Outpatient clinic products including wound care								
MON20	Regular 30-min wound care, including dressing changes	PH and PL	95 / 96	29	63	2755	5996	8751
MON21	Demanding 60-min wound care, including negative-pressure wound therapy	PH and PL	558 / 566	15	51	8490	28538	37028
MON26	Patient preparation and surveillance	PL	233	0	1	0	233	233
SAR	Fee for series of wound care treatments	PL	11,4	0	4	0	45,6	45,6
KIR0	Phone call from the surgery outpatient clinic	PL	718	0	1	0	718	718
KIR00	Digital consultation	PL	126	0	1	0	126	126
KIR01	Surgery outpatient clinic physicians 20-min appointment without examinations	PH and PL	93 / 94	3	5	279	470	749
KIR02	Doctor's appointment for 20 min with laboratory examinations	PL	134	0	1	0	134	134
KIR03	Doctors appointment for 30min with laboratory and x-ray examinations	PL	267 / 271	0	8	0	2164	2164
KIR04	Doctor's appointment for 30min with CT / MRI	PL	874	0	5	0	4370	4370
KIR05	Nurse wound care appointment 30min	PH and PL	45	2	2	90	90	180
KIR06	Nurse wound care appointment 60min	PL	70	0	1	0	70	70
KIRP	Surgery outpatient clinic appointment	PH	260	7	0	1820	0	1820
KIR / PKL	Phone call from the surgery outpatient clinic	PH and PL	41.2 / 43 / 44	1	29	43	1208.4	1251.4
N (total)=14				**N (total) = 57**	**N (total) = 172**	**Total: 13 385 €**	**Total: 44 764 €**	**Total: 58 149 €**

NordDRG product name	Product description	PH or PL	Unit price €	Product invoices of 60 PHs (N)	Product invoices of 109 PLs (N)	Total sum of invoices per product PH €	Total sum of invoices per product PL €	Total sum of invoices per product PL + PH
Operative treatment products								
Lei01	Nurse phone call for prepping to elective surgery, includes instructions for physiotherapy	PH and PL	168 / 171	5	3	855	510	1365
DR263	Skin revision or grafting due to other cause, uncomplicated	PL	8345	0	1	0	8345	8345
DR264	Skin revision or grafting due to other cause, uncomplicated	PL	3997	0	1	0	3997	3997
DR266	Skin revision or grafting due to other cause, uncomplicated	PH	1540	2	0	3080	0	3080
DR268	Plastic surgical intervention	PH	2083	1	0	2083	0	2083
DR269	Skin revision or grafting due to other cause, uncomplicated	PL	4779	0	1	0	4779	4779
DR271	Skin laceration / defect	PH	3938	1	0	3938	0	3938
DR280	Cutaneous / Subcutaneous injury, adult, complicated	PH	1298	1	0	1298	0	1298
DR281	Cutaneous / Subcutaneous injury, adult, uncomplicated	PH	966	4	0	3864	0	3864
DR415	Operative treatment of an infectious disease	PH	10152	1	0	10152	0	10152
DR439	Skin grafting due to injury	PH and PL	5795 / 5882	3	1	17385	5882	23267
DR442	Other procedure due to injury	PH and PL	7780	3	1	23340	7780	31120
DR443	Other procedure due to injury	PH	1563	1	0	1563	0	1563
DR444	Operation, adult, injury, complicated	PH	1540	1	0	1540	0	1540
DR445	Operation, adult, injury, uncomplicated	PH	1540	10	0	15400	0	15400
DR477	Unordinary combination of a procedure and diagnosis	PH	4195	1	0	4195	0	4195
DRGR-20E264	Other procedure performed due to injury	PL	966 / 1540 / 3938 / 5795 / 7665	0	13	0	38877	38877
N (total)=17				**N (total) = 34**	**N (total) = 21**	**Total: 88 524 €**	**Total: 58 019 €**	**Total: 146 543 €**

NordDRG product name	Product description	PH or PL	Unit price €	Product invoices of 60 PHs (N)	Product invoices of 109 PLs (N)	Total sum of invoices per product PH €	Total sum of invoices per product PL €	Total sum of invoices per product PL + PH
Inpatient care products								
LAI001	Primary day care	PH	2954	1	0	2954	0	2954
LAI002	Primary day care	PH	422	1	0	422	0	422
DR122	Ischemic heart attack without a complex health condition, patient alive on fourth day	PH	2341	1	0	2341	0	2341
PAI04	Treatment in the acute ward needing constant surveillance and expensive medications and/or examinations and/or treatment time exceeding 37-48h	PH	1533	2	0	3066	0	3066
PAI05	Treatment in the acute ward needing surgery	PH	2500	1	0	2500	0	2500
PAI06	Penalty product for being over 48h in the acute ward	PH	2000	3	0	6000	0	6000
PITDRG	Penalty product for a prolonged treatment period	PH	462 / 471 / 1413 / 3297	4	0	5643	0	5643
PTHT02	Physiotherapist / occupational therapist visit in the ward	PH	1276	1	0	1276	0	1276
POS02	Acute ward product, patient needing assistance, treatment time 13-24h	PL	352	0	1	0	352	352
POS03	Treatment in the acute ward needing demanding examinations (CT, MRI, etc.) or treatment time 25-36h, e.g. elderly patient with unspecified infection / falling on flat ground	PH and PL	891	1	1	891	891	1782
POS04	Treatment in the acute ward, needing constant surveillance and expensive medications and/or examinations (CT, MRI, endoscopy, etc.)	PH and PL	1556	2	2	3112	3112	6224
POSP	Acute ward treatment product, regular	PH and PL	831	3	2	2493	1662	4155
VOS1P	Ward 1	PH and PL	335 / 1340 / 2387 / 4092	2	2	6479	1675	8154
VOS2P	Ward 2	PL	2508	0	1	0	2508	2508

NordDRG product name	Product description	PH or PL	Unit price €	Product invoices of 60 PHs (N)	Product invoices of 109 PLs (N)	Total sum of invoices per product PH €	Total sum of invoices per product PL €	Total sum of invoices per product PL + PH
VOS3P	Ward 3	PH and PL	754 / 1131 / 2262 / 2597	2	3	5194	4147	9341
VOS4P	Ward 4	PH	2492	3	0	7476	0	7476
VOS5P	Ward 5	PH and PL	346 / 1038 / 1730 / 1023	1	4	1023	3450	4473
POKSOS3	POKS Ward 3, 10-day treatment period	PL	3710	0	1	0	3710	3710
LYH	Ward fee for short care	PL	22.5–391.2	0	20	0	2839.3	2839.3
N (total)=19				**N (total) = 28**	**N (total) = 37**	**Total: 53 154 €**	**Total: 24 264 €**	**Total: 77 418 €**
Primary health care products (PL, N=30)								
YLEPÄI	Doctors acute appointment, healthcare center	PL	20.6	0	5	0	103	103
YLPÄI2	Doctors acute appointment, healthcare center	PL	41.2	0	2	0	82.4	82.4
YLPÄI3	Doctors acute appointment between hours 8-20	PL	20.6	0	10	0	206	206
YLPÄI4	Doctors appointment during evening, night-time, or weekend	PL	28.3	0	6	0	169.8	169.8
KAYNT	Phone call from healthcare center	PL	20.6	0	5	0	103	103
TKH002	Nurse appointment, healthcare center	PL	59	0	4	0	236	236
SHMAK	Nurse appointment fee	PL	10	0	33	0	330	330
YLEHOI	Nurse appointment, healthcare center	PL	10	0	4	0	40	40
LYHYT	Rehabilitation period at a healthcare center ward	PL	5–391.2	0	9	0	1461.4	1461.4
ABKTI	Single visit of temporary home wound care	PL	12 / 15.7	0	58	0	699.7	699.7
GETURV	Geriatric security care product	PL	13.4	0	1	0	13.4	13.4
AAKSÄ2	Regular home wound care 4-11h/month	PL	122.17	0	1	0	122.17	122.17
AAKSÄ3	Regular home wound care 11-22h/ month	PL	39.67	0	1	0	39.67	39.67
AAKSÄ4	Regular home wound care 22-32h/ month	PL	268.02 / 442.46	0	2	0	710.48	710.48
AAKSÄ5	Regular home wound care over 32h/ month	PL	126.91	0	1	0	126.91	126.91
KFYS	Physiotherapist home visit	PL	11.4	0	1	0	11.4	11.4
N (total)=16					**N (total) = 143**		**Total: 4455.33 €**	**Total: 4455.33 €**

Attachment 2: Chronic leg ulcer and foot ulcer etiologies with pretibial injuries included.

Classification	Risk factors and associated conditions	Pathogenesis	Clinical features	Epidemiology
Venous leg ulcers	Obesity, age, low physical activity, female sex, deep vein thrombosis	Venous reflux causing venous hypertension and chronic inflammation	Wound location above ankle, irregular wound margins, superficial, can be circuclar, edema, exudate, lipodermatosclerosis, varicoses	51%-80% of CLUs
Arterial leg ulcers	Smoking, diabetes, coronary artery disease, hypertension, age	Atherosclerosis of peripheral arteries	Wound location typically in the foot, can be in the leg, painful, round, dry, necrotic, regular wound margins, claudication, absent pulses, abnormal ankle-brachial index (<0.9)	11% of CLUs
Mixed arterial and venous ulcers	Hypertension, obesity, smoking, diabetes, coronary artery disease	Combination of venous reflux and atherosclerosis of peripheral arteries	Irregular in shape, superficial, red wound bed, exudate, moderate pain, hemosiderin in surrounding skin	13% of CLUs
Pretibial injuries				
Pretibial lacerations	Dermatoporosis, multimorbidity, female sex, compromised independence	Low-energy trauma causes shearing of the thin skin in the pretibial region	Linear lacerations, vital flap lacerations, non-vital flap lacerations, total skin loss, laceration with subcutaneous hematoma	Incidence 40-70 /100 000 by population. % of CLUs unknown.
Pretibial hematomas	Anticoagulant medication, dermatoporosis, multimorbidity, female sex, compromised independence	Bleeding due to low-energy trauma, usually contributed to by anticoagulant medication, occurs in the subcutaneous tissue of the crus, causing bulging and pressure-induced skin necrosis	Bulging of skin, ultimately broad full-thickness skin necrosis, coagulated hematoma beneath the necrotic sheath	
Atypical wounds				
Vasculitis	Autoimmune diseases, Hepatitis B and C	Inflammation in the blood vessel walls	Painful, necrotic ulcers, blue-reddish outline, purpura, livedo racemose	4.5% of CLUs
Vasculopathies	Livedovasculopathy, connective tissue diseases, prothrombotic conditions, cholesterol emboli	Thrombo-occlusive cutaneous vasculopathy	Pain, hole-like round wounds, livedo racemosa, purpura, atrophie blanche, distal lower extremity	unknown
Pyoderma gangrenosum	Inflammatory bowel diseases, hematologic cancer, rheumatoid arthritis, solid tumors	Poorly understood, may involve neutrophol chemotaxis	Severe pain, typically starts from a blister-like papule advancing to an ulcer, creased edges	2.8% of CLUs

Classification	Risk factors and associated conditions	Pathogenesis	Clinical features	Epidemiology
Martorell's hypertensive ischemic ulcer	Continuous hypertension, type 2 diabetes mellitus, arteriosclerosis	Local skin infarction due to arteriosclerosis of the dermis and subcutis	Severe pain, proceeds fast, necrotic, involvement of the dorsolateral calf and Achilles tendon, normal ankle-brachial index	unknown
Calciphylaxis	End-stage renal insufficiency, Vitamin K deficiency, Warfarin, female sex, multimorbidity	Occlusion of dermal and subcutaneous arteries by calcification and fibrosis	Severe pain, painful plaques and ulcers in adipose tissue, livedo reticularis	1.1% of CLUs
Lymphedema	Lymphatic insufficiency	Excessive retention of lymphatic fluid in the interstitial compartment causing pressure	Edema, exudate, red wound bed	1.7% of CLUs
Malignant ulcers	Melanoma, squamocellular, basalioma, lymphoma, Marjolin ulcer	Malignant pathogenesis	Pigmentation or hypergranulation of the wound, bleeding, does not react to wound care, rolled out edges	1.0% of CLUs
Iatrogenic wounds	Surgical wounds, some pharmacologic agents	Iatrogenic	Post-surgical, pharmacologic	0.6% of CLUs
Infectious wounds	Tuberculosis, leishmaniasis, ecthyma gangrenosum; Travel history (tropics), immunosupression	Infectious pathogenesis	Atypical presentation of wound	unknown
Dermatitis-based wounds	Chronic dermatitis e.g. bullous pemphigoid	Multifactorial, involving elements of barrier dysfunction	Varies depending on the type of dermatitis	unknown
Chronic foot ulcers				
Diabetic foot ulcers (DFUs)	Diabetes, smoking, peripheral artery disease	Microangiopathic, neuropathic, and immunological components are caused by hyperglycemia. Neuropathy results in the lack of protective sensation leading to ulceration in areas of high pressure	Round, hollow, fistulas, high rates of infections, osteomyelitis, necrosis	Prevalence of DFUs in diabetics is 4–15%
Pressure ulcers	Immobilization, paraplegy, iatrogenic	Microvascular ischemia due to prolonged soft tissue compression between bony prominences and external surfaces	Staged I-IV in relation to the depth of the wound. Contains necrotic tissue before revision.	15% of pressure injuries occur in the foot
Ulcerated tophaceous gout	Diet, alcohol, diuretics, hyperuricemia, metabolic disorder, male sex	Hyperuricemia, accumulation of urate crystals in the joints causing inflammation	Tophus discharge from ulcer, usually joint-associated in the foot	unknown

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