LUND UNIVERSITY

Lower Limb Amputation in Patients with Vascular Disease

Johannesson, Anton

2009

Link to publication

Citation for published version (APA):
Johannesson, A. (2009). *Lower Limb Amputation in Patients with Vascular Disease*. [Doctoral Thesis (compilation), Orthopaedics (Lund)]. Department of Clinical Sciences, Lund University.

Total number of authors:
1

General rights
Unless other specific re-use rights are stated the following general rights apply:
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.
• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal

Read more about Creative commons licenses: https://creativecommons.org/licenses/

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Contents

List of papers, 2

Abbreviations and definitions, 3

Thesis at a glance, 4

Description of contributions, 6

Introduction, 7

Definitions and incidence in lower limb amputation, 9
Trans-tibial amputation, 13
Postoperative treatment, 14
Rehabilitation, 16
Trans-tibial prosthesis, 17
Outcome assessment, 18
Mortality, 19
New standardised surgical rehabilitation program in trans-tibial amputation, 19

Analyses, 22

Objectives of the thesis, 24

Summary of papers with focus on material, method and results, 25

Study population, 25
Papers I–IV, 26

General discussion, 31

Incidence and mortality, 31
Outcome assessment, 32
Postoperative treatment after trans-tibial amputation, 32
Prosthetic fitting after trans-tibial amputation, 33

Conclusions, 36

Future perspectives, 37

Summary, 38

Summary in Swedish – Sammanfattning på svenska, 40

Acknowledgments, 42

Appendix, 43

References, 44

List of papers

This thesis is based on the following papers which will be referred to in the text by their Roman numerals:

I. Incidence of lower-limb amputation in the diabetic and nondiabetic general population: a 10-year population-based cohort study of initial unilateral and contralateral amputations and reamputations.
Anton Johannesson, Gert-Uno Larsson, Nerrolyn Ramstrand, Aleksandra Turkiewicz, Ann-Britt Wiréhn, Isam Atroshi
Diabetes Care 2009; 32: 275–80

II. The Locomotor Capabilities Index: validity and reliability of the Swedish version in adults with lower limb amputation.
Brita Larsson, Anton Johannesson, H. Ingemar Andersson, Isam Atroshi
Submitted

III. Comparison of vacuum-formed removable rigid dressing with conventional rigid dressing after trans-tibial amputation: similar outcome in a randomized controlled trial involving 27 patients.
Anton Johannesson, Gert-Uno Larsson, Tommy Öberg, Isam Atroshi
Acta Orthopaedica 2008; 79(3): 361–9

IV. Outcomes of a standardized surgical and rehabilitation program in trans-tibial amputation for peripheral vascular disease: a 10-year prospective cohort study.
Anton Johannesson, Gert-Uno Larsson, Nerrolyn Ramstrand, Henrik Lauge-Pedersen, Philippe Wagner, Isam Atroshi
Submitted

Abbreviations and definitions

CRD – conventional rigid dressing (plaster of Paris)
DM – diabetes mellitus
EQ-5D – is a measure of health-related quality of life composed of 5 items covering 5 dimensions (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression).
LCI – Locomotor Capabilities Index – a scoring system reporting outcome for lower limb amputees, consisting of 14 items (Appendix 1).
LLA – lower limb amputation
ICECAST® – a silicone casting instrument that is used to capture the shape of the stump either with plaster of Paris or in the manufacture of a laminated socket (see ICEX)
ICEX® – a prosthetic fitting technique in which the prosthetic socket is directly manufactured through pressure casting over a silicone liner that covers the stump.
ISO-8548-1 to 4: International Organization for Standardization; Standards referring to amputation and prosthesis
ORD® – vacuum-formed rigid dressing
TUG – timed "up-and-go" – an objective test to measure physical mobility in an elderly population
TSB – total-surface-bearing socket
PVD – peripheral vascular disease, refers to diseases of the blood vessels (arteries and veins) located outside the heart and brain
PTB – patellar-tendon-bearing socket

A. General Limb Amputation Terms

Lower limb amputation: Removal of the whole or part of a lower limb.
Level of amputation:
– transmetatarsal (TM)
– mid-foot (including tarsometatarsal joints) (MF)
– ankle disarticulation [a] (AD)
– trans-tibial [a] (TT)
– knee disarticulation [a] (KD)
– trans-femoral [a] (TF)
– hip disarticulation [a]
– trans-pelvic [a]

[a] A part of the ISO – standard 8548-2

B. Amputation procedures

Initial lower limb amputation: An individual's first lower limb amputation (including secondary closure or two-stage amputation).
Contralateral lower limb amputation: An amputation on the opposite lower limb in an individual who had undergone an initial unilateral amputation
Re-amputation: A surgical procedure on an amputated limb at a higher level than the previous level of amputation.
Revision amputation: A surgical procedure on a previously amputated limb without changing the level of amputation. This may involve removal of soft tissue, bony tissue or a combination of both.

C. The Person who has had an amputation

Amputee: A person who has had an amputation
Lower limb amputee: A person who has had a lower limb amputation
Unilateral lower limb amputee: A person who has had one lower limb amputation
Bilateral lower limb amputee: A person who has had an amputation of both lower limbs

Thesis at a glance

I. Incidence of LLA in the diabetic and nondiabetic general population

What is the incidence rate of initial LLA in the at-risk diabetic and nondiabetic general population and what are the incidence rates of contralateral and re-amputation in initial amputees?

Patients: 290 patients with LLA (at or above the transmetatarsal level)

Methods: All vascular LLA were registered and classified into initial amputation, re-amputation or contralateral amputation during a 10-year period (Table 1).

Conclusion: In the general population aged 45 years or older, the incidence of vascular lower limb amputation at or proximal to transmetatarsal level is 8 times higher in diabetic than in nondiabetic persons. One in four amputees may require a contralateral amputation and/or re-amputation.

II. The LCI: validity and reliability of the Swedish version

Is the Swedish version of the LCI a valid and reliable tool for use in persons who have undergone a lower limb amputation?

Participants: 144 lower limb amputees fitted with prostheses.

Methods: Construct validity was assessed by examining the relationship between the LCI and TUG test and LCI and EQ-5D. Discriminative validity was assessed by comparing scores in different age groups and in unilateral and bilateral amputees.

Conclusion: The Swedish LCI showed good construct convergent validity, with a high correlation with the TUG (r=–0.75) and the EQ-5D (r=0.84). Discriminative validity was supported by the finding of significantly lower mean LCI scores in older amputees than in younger amputees and in bilateral amputees than in unilateral amputees ($p<0.01$). High internal consistency was evident (Cronbach alpha 0.95).

III. ORD compared with CRD after trans-tibial amputation

Is a new, easily applicable and removable post-operative vacuum-formed rigid dressing (ORD) comparable to conventional plaster of Paris rigid dressing (CRD)?

Patients: 27 patients ranging in age from 43 to 91 years undergoing trans-tibial amputation.

Table 1. Incidence of LLA in the diabetic and nondiabetic general population

	Incidence in diabetic population			Incidence in non-diabetic population		
	Initial amputation [a]	Contralateral amputation [b]	Re-amputation [b]	Initial amputation [a]	Contralateral amputation [b]	Re-amputation [b]
Women		15 (7.0–26)	16 (8.0–28)		14 (7.2-24)	18 (10-28)
Population ≥45	192 (145–241)			22 (17–26)		
Total population	176 (134–221)			10 (8–12)		
Men		18 (10–29)	21 (12–32)		13 (6.3–22)	24 (15–35)
Population ≥45	197 (152–244)			24 (19–29)		
Total population	183 (142–226)			10 (8–12)		

[a] per 100,000 person-years, 95% confidence interval within parentheses
[b] per 100 amputee-years, 95% confidence interval within parentheses

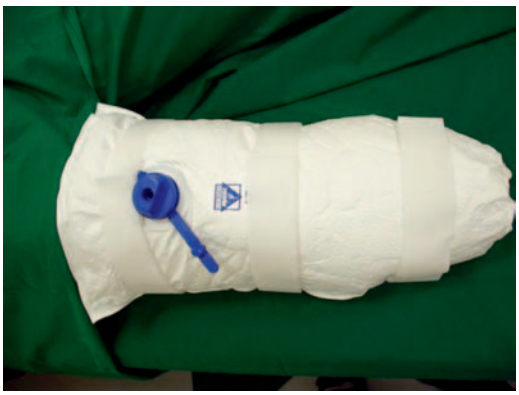

Figure 1. ORD

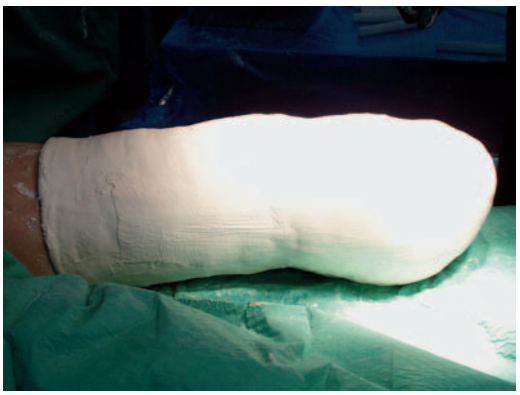

Figure 2. CRD

Methods: Patients were randomly assigned immediately after amputation to receive either ORD (Figure 1) or CRD (Figure 2). Both groups received compression therapy using silicone liner and were provided with an ICEX socket as a part of their prosthesis. Three months after the amputation functional outcome with prosthesis was measured using LCI and TUG.

Conclusion: The ORD appears to yield results similar to those of the CRD regarding time to prosthetic fitting and function with prosthesis.

IV. Outcomes of a standardized surgical and rehabilitation program in trans-tibial amputation for peripheral vascular disease: A 10-year prospective cohort study

What are the outcomes after implementation of a new treatment program in trans-tibial amputees?

Patients: 217 patients undergoing trans-tibial amputation for vascular disease.

Methods: The new treatment program consisted of the use of a sagittal incision, rigid dressing, compression therapy with silicon liner (Figure 3) and a direct manufactured prosthetic system (Figure 4).

Conclusion: 55% were fitted with prostheses. The median time from amputation to prosthetic fitting was 41 (range 12–147) days, with no differences between diabetic and nondiabetic patients ($p = 0.65$). More than half of all amputees and more than 80% of those who could walk prior to the amputation and who survived at least 90 days after amputation were fitted with prosthesis after a median time of six weeks. Almost two-thirds of prosthetic recipients obtained good function defined as wearing the prosthesis daily and able to walk alone or with assistance outdoors or alone indoors.

Figure 3. Silicon compression liner.

Figure 4. Direct manufactured prosthetic socket in process.

Description of contributions

Paper I

Study design: Anton Johannesson, Isam Atroshi
Data collection: Anton Johannesson, Gert-Uno Larsson, Ann-Britt Wiréhn
Data analysis: Anton Johannesson, Alexandra Turkiewicz, Isam Atroshi
Manuscript writing: Anton Johannesson, Isam Atroshi, Nerrolyn Ramstrand
Manuscript revision: Anton Johannesson, Isam Atroshi

Paper II

Study design: Brita Larsson, Anton Johannesson, Ingemar Andersson
Data collection: Brita Larsson, Anton Johannesson
Data analysis: Anton Johannesson, Isam Atroshi, Brita Larsson
Manuscript writing: Brita Larsson, Anton Johannesson, Isam Atroshi
Manuscript revision: Anton Johannesson, Brita Larsson, Isam Atrosh

Paper III

Study design: Anton Johannesson, Tommy Öberg, Gert-Uno Larsson
Data collection: Anton Johannesson, Gert-Uno Larsson
Data analysis: Anton Johannesson, Isam Atroshi
Manuscript writing: Anton Johannesson, Gert-Uno Larsson, Isam Atroshi
Manuscript revision: Anton Johannesson, Isam Atroshi

Paper IV

Study design: Anton Johannesson, Isam Atroshi
Data collection: Anton Johannesson, Gert-Uno Larsson
Data analysis: Anton Johannesson, Philippe Wagner, Isam Atroshi
Manuscript writing: Anton Johannesson, Isam Atroshi, Nerrolyn Ramstrand, Henrik Lauge-Pedersen
Manuscript revision: Anton Johannesson, Isam Atroshi

Introduction

The word "amputation" has no official definition although an attempt was made by Rang & Thompson: "In the English language the word amputation is derived from the Latin, *"amputatio,"* meaning "cutting around" and was originally used for describing the removal of a limb or portion of limbs with a knife. The term was also used for describing the removal of other parts of the body, such as breast or testicle" (Kostuik and Gillespie 1981). The English word *"dismember,"* a derivative of the French *"désmembrer,"* from the original Latin *"membrum"* a limb, was also commonly used in the context of limb excision (Kirkup 2007). Today, a more specific description of someone losing a limb through accident or surgery is *"limb amputation"* and consequently a distinction can be made between limbs as *"lower limb amputation"* (LLA) or *"upper limb amputation"* (ULA) (Bowker et al. 1992).

Amputation due to arteriosclerosis or vessel calcification has been observed in mummies. However it is believed that in the prehistoric period most humans died younger and therefore fully developed arterial disease as a cause of amputation was probably rare (Kirkup 2007). Gangrene associated with diabetes was observed for the first time in the mid 19th century (Lyot 1896) and Treves was probably the first to recommend amputation in diabetic patients as a successful alternative treatment (Treves 1895).

The incidence of nontraumatic LLA has been found to be related to numerous factors including the age distribution in the study population, prevalence of peripheral vascular disease, the availability of health care (Global Lower Extremity Amputation Study Group 2000) and smoking habits (Harrison et al. 2002, Stewart 1987).

An increased incidence of LLA related to vascular disease was observed during the second half of the last century. This was attributed to a higher mean age of the population and the increasing prevalence of diabetes (Global Lower Extremity Amputation Study Group 2000). It has been estimated that during 2005, one in 190 Americans was living with the loss of a limb and that 38% had undergone an amputation secondary to dysvascular diseases with a comorbid diagnosis of diabetes mellitus (Ziegler-Graham et al. 2008). During the last decades however, the impact of increasing revascularisation procedures (Holstein et al. 2000) and special foot care programs for diabetic patients has been demonstrated to be effective in lowering the incidence of amputation (Larsson et al. 2008).

Incidence rates can be particularly useful in identifying patients who are at risk (e.g. those at an increased risk of requiring amputation surgery). However, most incidence reports on amputations are based on total populations and not the "at risk" population (for example population of people with diabetes) (Ephraim et al. 2003). This means that the risk population, standardized by age and gender, can be more specified than with conventional methods and thereby more efforts can theoretically be made to prevent amputation in an exposed group of patients with vascular disease.

The incidence of LLA is influenced by geographical region. In war affected regions like Africa the underlying cause of amputation is typically infection, trauma and tumor as compared to developed countries in which vascular cases account for 90% of all amputations and the mean age of amputees is twice as high (Persson 2001). The incidence of diabetes and vascular disease is also region specific (Ephraim et al. 2003). It has been suggested that the incidence of diabetes among adults in Sweden has not increased although the prevalence has increased mainly due to a higher median age of diabetic persons in the general population (Eliasson and Bostrom 2006). Conversely, in the United States for instance, diabetes is becoming more common. From 1980 through 2005, the number of Americans with diabetes increased from 5.6 million to 15.8 million (National Center for Chronic Disease Prevention and Health Promotion Division of Diabetes Translation 2008). People aged 65 years or older account for approximately 38% of the population with diabetes. Thus, age, obesity and a sedentary lifestyle are also significant risk

factors, especially in Type 2 diabetes (National Center for Chronic Disease Prevention and Health Promotion Division of Diabetes Translation 2008). The figure probably underestimates the true prevalence of diabetes as it is estimated that about one-third of persons with diabetes are unaware they have the disease because their diabetes has not been diagnosed (Cowie et al. 2006). According to the American Diabetes Association, the estimated cost of diabetes in the United States in 2007 was $174 billion (CDC 2008).

In patients with vascular disease, LLA can be done on different levels and there is no single non-invasive parameter that can reliably predict healing. A palpable pulse does not always indicate appropriate vascularity (Snyder 2007). However, higher levels of amputation in elderly persons are often related to immobility and social isolation (Cutson and Bongiorni 1996) since few of them are rehabilitated to near-normal mobility (Campbell et al. 1994).

The postoperative treatment of amputees has varied little since World War II. In the developing countries the most widely applied method is still the use of soft dressings (Choudhury et al. 2001, Dormandy et al. 1994). The main goal of soft dressing is to absorb fluid from the wound and to prevent edema with a compressive elastic bandage. Elastic bandages have the advantage of being inexpensive but may be associated with serious problems; for example, pressure levels beneath soft dressings can vary substantially (Isherwood et al. 1975) and, if incorrectly applied, it can lead to complications such as pressure sores and persistent edema (Horne and Abramowicz 1982). There are many hypotheses related to the healing process after LLA. Basically, what we know today is that there is a combination of known and unknown factors that lead to edema and that treatment is often based on tradition rather than evidence (Vermeulen et al. 2004).

The effect of compression treatment with an elastic bandage after LLA is not well documented (Smith et al. 2003). It is, however, a widely used method and the knowledge is most likely derived from the results of compression therapy in treatment of leg ulcers (Malanin et al. 1999). The goal of compression treatment is to diminish edema and in doing so shorten the rehabilitation phase and time to prosthetic fitting of the patient. Years of experience have shown that attention to correct wrapping technique is vitally important in preventing complications related to residual-limb pressure damage, overaggressive proximal compression and tissue strangulation (Mooney et al. 1971, Smith et al. 2003).

The manufacturing of a prosthetic socket for permanent use (i.e. definitive prosthesis) has altered substantially over the past decade. The traditional means of manufacturing a laminate or thermoplastic socket has been to mould the socket over a plaster form of the patients stump. Over the past decade CAD-CAM technologies that scan the stump have gradually begun to replace the plaster of Paris method. Use of CAD-CAM allows for a digital model of the stump to be captured and for subsequent rectifications to be made within a software program. A milling machine is then used to produce a positive form of the stump and a plastic or laminate socket is fabricated over this form (Isozaki et al. 2006, McGarry and McHugh 2005). Despite the new possibilities, made available through CAD CAM technology, patients still require more than one visit to their prosthetist before the prosthesis can be used for gait training. Therefore, an alternative system that could give the possibility to a produce prosthetic socket that requires only one visit by the amputee is of interest both in improving rehabilitation and service to the amputees.

Irrespective of what socket system or production methods that are available there is a need to assess the functional outcome of the amputee. For that purpose instruments that are valid, reliable and easily applied in clinical settings are needed. This can be achieved as a first step with the use of patient-based self-administered questionnaires that measure functional mobility. Unfortunately, none of the instruments developed to specifically measure function with prosthesis have been translated to Swedish. For international comparisons to be made, these instruments need to be adapted across cultures (Beaton et al. 2000).

Given that research goals concerning LLA should include (1) more specific incidence reports for identification of the group at risk, (2) a reduction in the number of high level amputations, (3) lowering the risk of additional amputations (i.e. re-

amputation and/or contralateral amputation), (4) more effective postoperative treatment to shorten the length of in-hospital stay and rehabilitation, (5) improving the prosthetic technology for faster delivery of prostheses and (6) instruments that can measure the outcome of rehabilitation with prosthesis. Parts of these topics are addressed in this thesis.

The aim of this thesis was to investigate the age and gender-specific incidence rate of LLA in both diabetic and nondiabetic general population and to study some of the aspects related to the outcome specifically after trans-tibial amputation in this population of patients with PVD.

Definitions and incidence in lower limb amputation

The incidence of amputation is known to vary up to 200 fold between different centres, communities and countries (Global Lower Extremity Amputation Study Group 2000). This is most likely due to the complexity of the issue involved (risk factors, diabetes prevalence, health care system, and lifestyle) as well as differences in population age structure, sources from which cases were identified, level of ascertainment, and the definitions of LLA (Calle-Pascual et al. 2001, Jeffcoate 2005). However, the incidence of amputation is not a definitive marker of the severity of vascular disease affecting the limbs, as the amputation procedure can be performed on one or both sides and more than once on either side, all within wide time intervals and on various levels (toe to hip). A methodological problem in numerous studies related to the epidemiology of LLA lies in the definitions of the numerous procedures that can be performed (van Houtum and Lavery 1997, Jeffcoate 2005). The quoted incidence may for example be overestimated in many studies which refer to all lower limb operations – even though the indications for, and consequences of a toe amputation compared with trans-femoral amputation are fundamentally different and the two do not represent two ends of a common spectrum. Partial foot amputation is undertaken in order to save the limb, whereas amputation through the ankle and higher is undertaken when limb salvage is impossible. The first may permit a patient to stand and to walk unaided, while the second prevents it (Jeffcoate 2005).

Sources of error in reported incidence rates

Because many studies do not make the distinction between the initial amputation and re-amputation or amputation of the contralateral limb but use definitions such as “amputees” (number of amputee in a specific time period), “amputations” (all amputations in a specific time period), or “number of hospitalizations” (number of hospital stays due to amputation during a specific time period), comparison between studies is difficult to perform. The number of ‘amputees’ for example can include patients initially amputated prior to a study period and later become included during the study period due to re-amputation or contralateral amputation. It is therefore necessary to carefully define the additional types of amputation procedures that a patient can potentially undergo.

In comparing the different methods of presenting data related to incidence of amputation, Van Houtum et al. highlighted the importance of considering the study purpose prior to data collection. They suggested that this purpose should be reflected in the category definitions one subsequently adopts (van Houtum and Lavery 1997).

- If one wants to express the actual workload one should use the **incidence of amputations**.
- If financial cost needs to be addressed, the incidence rates with the **number of hospitalizations** in the numerator may be more appropriate because cost is heavily impacted by duration of hospitalizations.
- When human cost is of interest, the **number of amputees** is preferably chosen, because this focuses on the individual suffering associated with amputation (such as in diabetes-related lower limb amputation) (van Houtum and Lavery 1997).

The first amputation of a limb in a person has been defined in numerous ways including; *“Primary amputation*; the first amputation procedure in a sequence until a final outcome (healing or death) (Larsson et al. 1995), *Index amputation* (Dillingham and Pezzin 2008) or *First amputation* (Tentolouris et al. 2004). This definition does not, however, reveal if the procedure is the first amputation in a person or the first amputation of

a particular limb. Throughout this thesis the term "Initial amputation" is used to refer to a person's first amputation procedure. The term can also be used to define an initial amputation performed at a particular level (such as initial trans-tibial amputation). Using this nomenclature, the first amputation on the other leg would be defined as "Contralateral amputation" and as a consequence the person would become a bilateral amputee.

Re-amputation and revision procedures have also been reported with a wide range of definitions. In some studies re-amputation has been defined as all other postamputation surgical procedures without distinguishing between soft tissue revisions, shortening of bone length or re-amputation at a higher level (Stone et al. 2007). Other studies have defined "re-amputation" as amputation performed on an unhealed stump and defined an amputation performed on a healed stump as a "new amputation" (Larsson et al. 1995).

Surgical procedures involving additional amputation (i.e. re-amputation) after the initial or the contralateral amputation need to be presented with levels and time frames. It has been suggested that toe amputations that do not heal and require further surgery to amputate at a higher level need to be distinguished from those which allow a patient to be discharged ambulant and ulcer free (Jeffcoate 2005). The effect of a re-amputation performed after failed healing is entirely different from that of a re-amputation performed after a number of years. Therefore this thesis supports the use of the definition proposed by the ISO working group (TC 168/ WG 1) that re-amputation (including time interval) refers to an amputation from one ISO-defined level (see definition and abbreviations) to another and that surgical procedures performed on the same level should be defined as bone or soft tissue revisions (ISO 2009).

Another issue regarding amputations is that they can be defined and presented separately as major or minor amputations. Many studies define major amputations as those performed through or above the ankle joint (Larsson et al. 1995), whereas others define a major amputation as one performed through or proximal to the tarsometatarsal joint (Global Lower Extremity Amputation Study Group 2000). Given that the dividing line for major and minor amputations is inconsistent in the literature, the ISO has suggested to eliminate the use of the term and to simply use definition specifying the levels of amputation (see Abbreviations and Definitions).

The registration of *"Partial foot amputation"* is often overlooked (Calle-Pascual et al. 2001). As a result, amputations performed at this level are not always included in amputation registers (Larsson et al. 1995). Partial foot amputations that go unregistered are likely to be those performed at the toe or ray level as they are often performed in an emergency room or day clinic and are subsequently not reported into surgical databases (Global Lower Extremity Amputation Study Group 2000). Some studies only report the most proximal amputation level when more than one amputation had been performed on the same patient (Armstrong et al. 1997).

Reported incidence of PVD-related LLA in developed countries (1947–)

When the number of amputations due to PVD began to increase, more efforts were made to separate other causes of amputation such as frostbite, trauma or tumour. The oldest reported incidence rates of amputation due to PVD were presented from Sweden for the period 1947 to 1969. These data indicated an increasing incidence rate of all amputations from 10 to 31 amputations per 100,000 inhabitants/year (Hierton and James 1973). During the same period the percentage of other causes of amputation declined from 40% to 7%. In the period spanning 1984 to 1989, Finland and Australia presented incidence rates of 22 to 33 per 100,000 inhabitants/year (Jones 1990, Laaperi et al. 1993, Pohjolainen and Alaranta 1988). Two Danish studies that were carried out from 1961 to 1971 and from 1971 to 1979 reported the incidence of PVD-related LLA per 100,000 inhabitants/year increasing from 13 (Christensen 1976) to 30 (Mandrup-Poulsen and Jensen 1982). This increasing incidence rate was also observed in Swedish studies spanning1979 to 1986 with incidence rates reported as being 30 to 46 amputations per 100,000 inhabitants/year (Kald et al. 1989, Larsson and Risberg 1988, Liedberg and Persson 1983). Inter-country variation of the incidence rates is large, particularly among countries other than the Scandinavian countries. The GLEA Study Group presented inci-

Table 2. Incidence rates of LLA reported from 10 northern European studies

Authors	Larsson et al. 2008	Trautner et al. 2007	Heikkinen et al. 2007	Eskelinen et al. 2006	Kapelrud 2006	Witso et al. 2001	Krishnan et al. 2008	Morris et al. 1998	Rayman et al. 2004	Current study
Country	Sweden	Germany	Finland	Finland	Norway	Norway	England	Scotland	England	Sweden
Study period	1982–01	1990–05	1990–99	1999–02	1990–99	1994–97	1995–05	1993–94	1999–00	1997–06
Data [a]	P	R	R	R	R	R	P	R	P	P
Population x1000	199–234 [b]	160–162 [b]	440	492–559 [b]	188	143	330–364 [b]	365	338	170
% prevalence of diabetes					3.0	3.3	2.0-3.4 [b]	1.9	2.7	4.4
N	461	692	1034	349		215		221	79	290
Mean age	78	72	68; 75 [c]	72; 76 [d]				71		77; 81 [d]
Levels incl.	TM or higher	All	AD or higher	TT or higher	AD or higher	All	TT or higher	All	All	TT or higher
Numerator	All	Initial	All	Initial	Initial	Initial	Initial	Initial	Initial	Initial
% diabetes related amp.	68	72	39	52	44					46
Incidence rates		[e]	[e]					[e]		[e]
in total population		33; 31 [d]	29	16		34				17
- nondiabetic		18	7.3						9.2	
- diabetic	16; 6.8 [f]		11	5.3		11	7.4; 2.8 [f]		7.1	7.8
in diabetic population		549; 428 [f]			350	440	414; 67 [f]	247	261	179
- men								280		176
- women								188		183
in nondiabetic population		7; 12 [f]			15			20		10
- men								23		24
- women								17		22

Incidence rates are all per 100,000 persons per year
[a] data collection: prospective (P) or retro-prospective (R)
[b] population in the beginning and at the end of the study period
[c] mean age men and women
[d] mean age diabetic and nondiabetic
[e] age-adjusted incidence rate
[f] incidence in the beginning and at the end of the study period

dence rates of all LLA from ten centers around the world for the period 1995 to 1997 (Global Lower Extremity Amputation Study Group 2000). All data were based on the same study protocol and results indicated that the highest reported incidence of LLA was observed in Navajo Indians. This population also recorded the highest prevalence of diabetes which is reflected in an age adjusted incidence rate of 44 per 100,000 inhabitants/year compared with Madrid, Spain that reported the lowest rate of 2.8 per 100,000 inhabitants/year. In another part of Spain during the same period however, a higher rate of 6.3 per 100,000 inhabitants/year in nondiabetic and 136 per 100,000 inhabitants/year in diabetics was reported (Almaraz et al. 2000). Diabetes has been associated with between 25% and 90% of all amputations (Global Lower Extremity Amputation Study Group 2000). This is especially the case among racial and ethnic groups predisposed to diabetes (Ephraim et al. 2003).

Since the beginning of the 90's, several reports from Scandinavia have reported a lowering of the incidence of LLA (Larsson et al. 1995, Wahlberg et al. 1994, Eneroth and Persson 1992). These changes are most likely attributed to improved foot care programs for diabetic patients (Larsson et al. 2008) and an increasing use of angioplasty and vascular reconstruction which in many cases can result in limb salvage rather than amputation (Holstein et al. 2000).

Age and gender-adjusted incidence rate of PVD-related LLA (Table 2)

More recently amputation incidence rates reported in the literature have been modified to fulfil the standards for epidemiologic studies requiring that incidence data be age and gender adjusted. A meta-analysis of previous work has shown that only one-third of incidence studies presented age and gender-specific data. Substantial differences

were noted in incidence rates based on prevalence of diabetes, the age structure of the population (Ephraim et al. 2003), and ethnic differences (Feinglass et al. 2005, Lavery et al. 1999). When considering incidence rates reported during the last decades in a relevant population (northern Europe), the incidence rate of LLA in the total population has been found to vary between 16 and 34 per 100,000 inhabitants, with two studies showing a higher rate of amputation in men compared with women (Heikkinen et al. 2007, Trautner et al. 2007, Eskelinen et al. 2006, Witso and Ronningen 2001) (Table 2). In diabetic persons the amputation rate was found to be between 2.8 and 11 per 100,000 inhabitants (Heikkinen et al. 2007, Krishnan et al. 2008, Larsson et al. 2008, Eskelinen et al. 2006, R ayman et al. 2004, Witso and Ronningen 2001) whereas in nondiabetic persons the variation was wider with amputation rates between 7.3 and 18 per 100,000 inhabitants (Eskelinen et al. 2006, Heikkinen et al. 2007). The prevalence of diabetes varied between 1.9% and 3.4% but only one study used data on the prevalence of diabetes that had been validated for accuracy (Morris et al. 1998). The proportion of amputations due to diabetes varied between 39% and 72% of all amputations. In a diabetic population, the incidence rate of all amputations ranged from 248 to 440 per 100,000 inhabitants (Witso and Ronningen 2001, Morris et al. 1998) and that of amputation through the ankle and higher from 67 to 350 per 100,000 inhabitants (Kapelrud 2006, Krishnan et al. 2008). In a nondiabetic population the variation in the incidence rates was found to be smaller ranging from 12 to 15 per 100,000 inhabitants. Only three of the reports presented age and gender standardized incidence rates (Heikkinen et al. 2007, Trautner et al. 2007, Morris et al. 1998).

Further development in presenting incidence data (person-time and population at risk)

The conventional way to present LLA incidence data is per 10,000 or 100,000 inhabitants per year using the total population as the nominator. A more recent recommendation is to use Person-Time data instead. Person-time should be distinguished from clock time in that it is a summation of time that occurs simultaneously for many people, whereas clock time is not. Person-time represents the observational experience in which disease onset can be observed. When the risk period is of a fixed length (Δt), the total person-time at risk over the period is equal to the average size of the population over the period (N), multiplied by the length of the period (Δt). If we denote the incident number by A, it follows that the person-time rate equals $A/(N \cdot \Delta t)$. It is an important principle that the only events eligible to be counted in the numerator of an incidence rate are those that occur to persons who are contributing time to the denominator of the incidence rate at the time that the disease onset occurs. Likewise, only time contributed by persons eligible to be counted in the numerator if they suffer an event should be counted in the denominator. The time contributed by each person to the denominator is sometimes known as the "time at risk" that is, time at risk of an event occurring. Similarly, the people who contribute time to the denominator of an incidence rate are referred to as the "population at risk". It is typical that the events in the numerator of an incidence rate correspond to the first occurrence of a particular disease, even in those instances in which it is possible for an individual to have more than one occurrence (e.g. amputation). If the amputation procedures that occur after the initial amputation are of interest (re- or contralateral amputation) the "population at risk" can be changes to amputees (e.g. initial unilateral amputees) as these events (risk of becoming an amputee) have already occurred (Rothman and Greenland 1998).

Another concern is that the population at risk for LLA secondary to vascular disease is not the total population. The risk groups are the diabetic population and the nondiabetic population at risk of vascular disease (usually older than 45 years). Therefore a modification has been suggested to present the data separately for the diabetic and non-diabetic population at risk of undergoing amputation. The problem in the past has been the prevalence of diabetes in the populations has not been known or the data has been insufficient (Newton et al. 1999). Today more data sources are available that have been validated for accuracy (Berger et al. 1998, Wirehn et al. 2007, Morris et al. 1997).

In Sweden, the number of people aged 65 years and older doubled during the forty-year period of 1950 to 1990 from 721,000 to more than 1.5 mil-

Figure 5. Amputation performed with long posterior flaps, wound shown one week after amputation following removal of the cast.

Figure 6. Amputation performed with sagittal flaps, wound shown one week after amputation following removal of the cast.

lion and it is predicted that, in the next decade, that number will increase by more than 20% and rise to 1.9 million in 2015. Thereafter, the increase will continue further until 2040 when the number of old-age retirees is expected to total 2.4 million (Statistics Sweden 2005). It has been reported that almost one-fifth of people aged 60 to 90 years have some stage of peripheral arterial disease and that the prevalence of severe ischemia, as a measure of critical limb ischemia, is approximately 1% in the general population (Sigvant et al. 2007).

The incidence rate of diabetes-related LLA is dependant both on the prevalence of diabetes and access to medication and preventive care (Larsson et al. 1995, Feinglass et al. 2005).

Accurate estimation of the incidence of PVD-related LLA should be presented separately for the diabetic and nondiabetic populations and calculated based on the at-risk population. **Paper I** reports a population-based study estimating the incidence of initial-, re- and contralateral amputation in the at-risk diabetic and nondiabetic general populations.

Trans-tibial amputation

When the goal of rehabilitation is to regain walking ability, it has been demonstrated that trans-tibial amputations in elderly patients result in a more positive outcome when contrasted to higher level amputations (knee disarticulation or higher) (Nehler et al. 2003). Changes in surgical technique and most likely in revascularization procedures have increased the possibility to preserve the knee joint during amputation surgery. This increases the possibility for more older amputees to become ambulators (Cutson and Bongiorni 1996).

The most common surgical technique for trans-tibial amputation is the long posterior flap or the Burgess technique where myodesis is used (Bowker et al. 1992) (Figure 5). Other common techniques include the sagittal technique (Persson 1974) (Figure 6) and the skew flap technique (Robinson 1991) where myoplasty is typically used. Two studies have shown that healing takes place equally well after a sagittal incision as with a long posterior flap (Falstie-Jensen et al. 1989, Termansen 1977). Still, there is controversy as to which technique yields the best healing potential. It has

been suggested that this is more likely related to the experience of the surgeon and the postoperative treatment than to the type of incision itself (Tisi and Callam 2004).

Several methods have been suggested to determin the exact level at which to perform an amputation in order to achieve an "optimal" stump length. Persson and Liedberg recommend a method of measuring the "proportional" length of the stump instead of using an absolute measure in centimeters (Persson and Liedberg 1983). They suggested that the optimal length of a trans-tibial stump would be 1 to 2 times the breadth of the knee and that a short stump would be less than the knee breadth and long stump twice the knee breadth. In a study of 93 patients the average length of a trans-tibial stump, measured from the distal end of the soft tissues to the medial joint space of the knee, was 16 cm (Persson and Liedberg 1983). A short stump results in a small-moment arm, making knee extension difficult. The disadvantage of a long stump in elderly patients is that poor blood supply in the distal stump could increase the risk for re-amputation.

There are several factors that are believed to have led to an increased ratio of trans-tibial to higher-level amputation in patients with dysvascular or neuropathic lower limbs. These include the use of antibiotics (Sadat et al. 2008), implementation of supplementary nutrition during the acute phase of rehabilitation (Eneroth et al. 1997), and inpatient rehabilitative care (Dillingham and Pezzin 2008). Specific benefits of an amputation performed at the trans-tibial level compared to the trans-femoral level are a lower energy cost of walking (Hagberg et al. 2007) and an improved mechanism for suspension of the prosthesis that facilitates venous return from the stump (Beil et al. 2002).

Postoperative treatment

The aim of stump management following amputation surgery is to allow progressive, uncomplicated wound healing, pain control and shaping of the stump for future prosthetic fitting (Smith et al. 2003). Increased edema in PVD amputees can be caused by a variety of factors that do not relate specifically to the incision itself. These include heart failure, renal diseases, severity of pain, malnutrition and blood glucose levels. The presence of edema in an amputation stump causes an increased pressure in the capillaries which subsequently alter the pressure gradient so that more fluid can enter into the limb tissues. As capillary blood pressure increases when there is arteriolar dilatation or when there is obstruction of the veins, the pressure in the veins distal to the obstruction is simultaneously raised which increases pressure at the venous end of the capillaries. Due to illness, pain and/or medical treatment, many elderly patients may have received limited nutrition during the period before the amputation (Eneroth et al. 1997). This needs to be addressed as soon as possible after the amputation to facilitate strength gain, provide the individual with the best possible opportunity for wound healing and to ensure that they will have the energy required to manage the imminent rehabilitation. When there is an insufficient intake of proteins, deficiency of plasma proteins can occur which increases the likelihood of limb edema (Guyton et al. 2006). The serum/albumin level is also an important indicator in controlling the level of protein in the blood (Stone et al. 2006). When the capillaries become permeable to protein, the protein enters the tissue space resulting in reduction in the osmotic pressure.

The lymphatic system plays an important role in transporting the protein, including albumin, from the tissue spaces when there is a gradual leak of proteins from the capillaries. The lymph also removes surplus tissue fluid. The manner in which an amputation is performed is also a factor that can affect the edema. The more tissue that is involved in the amputation, the more likely it is that edema will appear. This factor needs to be taken into consideration with attention directed toward vascular surgeries that may have taken place prior to the amputation.

Infection is an additional factor that has the potential to affects wound healing. Antibiotic prophylaxis is routinely used in lower limb amputation at most hospitals in the developed world (Sadat et al. 2008). Infection has the potential to affect the capillaries and cause edema around the wound.

Blood glucose level in diabetic patients similarly affects wound healing. Blood glucose should be managed through medication and diet (Eneroth and Persson 1992). Pain relief following amputa-

Figure 7. Circular dressing made from plaster of Paris.

Figure 8. The first step in the application of the ORD.

Figure 9. The air is evacuated from the ORD and rigidity is obtained.

tion is also important in wound healing as pain causes contractions in the capillaries restricting blood flow.

Information related to wound healing and edema management following amputation surgery is largely based upon knowledge and experience from the treatment of varicose ulcers. This literature indicates for instance that painful changing of dressings disturbs or damages ongoing healing and should be avoided. The literature further suggests that dehydration of the wound restrains the healing process and that cell division can only occur in a moist environment (Brunner and Eberlein 2000, Kannon and Garrett 1995).

The use of different types of dressings to restrict postoperative edema (soft, semi-rigid or rigid dressing) after lower limb amputation has been described in more than 400 publications (Nawijn et al. 2005). To date no study has demonstrated soft dressings to be superior than rigid or semi-rigid dressings (Smith et al. 2003). In a review of studies related to postoperative dressings, it was suggested that results were difficult to compare due to differences in parameters that were applied and differences in the populations that received treatment (Smith et al. 2003).

In the 1960's, Weiss in Poland, Berlement in France, and Burgess and Zettl in the United States introduced the technique of rigid dressings using Plaster of Paris with or without a foot attachment (Figure 7).

This technique was applied either directly after surgery or within 7–10 days after surgery and aimed to prevent stump edema. Semi rigid or rigid dressings have been reported to reduce pain and healing time, increase tolerance to weight bearing, and enable early ambulation compared to conventional dressings (Smith et al. 2003). A number of studies have been published on post amputation management and despite the reported advantages of rigid dressings, soft dressings remain the most widely used form of compression therapy (Nawijn et al. 2005). Factors that limit the use of rigid dressings are believed to be related to application difficulties (surgeons may need assistance during application), time (time for application, prolonged anesthesia and cleaning), difficulty in wound inspection (surgeons may prefer to have easy access to the wound especially if complications occur) and an increased risk of pressure ulcers or pressure on the patella (Baumgartner and Botta 1995, Choudhury et al. 2001, Cohen et al. 1974).

To address the limitations associated with rigid dressings, a vacuum-formed removable rigid dressing, the ORD (ÖSSUR Inc. Reykjavik, Iceland)

has been developed for use after trans-tibial amputation. This dressing can be taken off, cleaned, reformed and reapplied with ease and in a very short period of time (Figures 8 and 9).

Paper III compares conventional Plaster of Paris dressings with the new vacuum formed removable rigid dressing in patients who underwent a trans-tibial amputation due to peripheral vascular disease. Primary outcome measures used in this study was the number of days from amputation to prosthetic fitting. The secondary outcome measures were the wound healing rate, functional outcome, the need for socket changes during the first year, and the proportion who had returned to their previous living conditions at 1 year.

The differences between edema control and compression therapy are related to what phase the treatment is in. During the first days after amputation, the goal of rigid dressing is to avoid an increase in edema and the expectation is that the exchange of intra- and extracellular fluid within the capillaries will normalize so that healing can take place. Compression at this stage in PVD patients is associated with higher risk of adversely affecting blood flow, edema and failed healing (Smith et al. 2003).

If a rigid dressing is used postoperatively, compression treatment can be started 5 to 7 days after the initial amputation provided no contraindications such as purulent infection or severe dementia are present. Compression of the veins is a well known treatment of venous ulcers and positive effects have been reported in many studies (Malanin et al. 1999). Compression is also the most effective way to stimulate lymphatic drainage in the residual limb, especially if used in combination with physiotherapy. Traditionally, compression treatment is performed with an elastic bandage (Age Wrapping). The disadvantage of bandages is the frequent need for reapplication. Movement during daily activities quickly loosens the bandages and subsequently compromises the effectiveness of the compression (Lusardi and Owens 2000). If the desired distal-to-proximal pressure gradient is to be achieved, effective application of the elastic bandage requires practice, manual dexterity, and attention to detail (Lusardi and Owens 2000). Ineffectively applied elastic wraps can lead to bulbous, poorly shaped stumps, which are likely to delay prosthetic fitting. Tight circumferential wrapping may significantly compromise blood flow and healing of the incision and may even lead to skin breakdown (Isherwood et al. 1975).

During the 1990's compression therapy using a silicone liner *(*Iceross PostOp, ÖSSUR Inc. Reykjavik, Iceland*)* was promoted as an alternative to traditional methods. The proposed benefit of silicone liners is the provision of similar graded compression irrespective of who applies the treatment.

Paper IV presents the outcome of a study investigating rate of prosthetic fitting, function with a prosthesis and mortality rates in a consecutive population of patients with PVD who underwent an initial unilateral trans-tibial amputation and a new standardized treatment protocol that included a sagittal incision, rigid dressing and compression therapy with a silicone liner.

Rehabilitation

Selected geriatric vascular amputees can be successfully fitted with prostheses and age alone should not determine whether a person is a candidate for prosthetic rehabilitation (Cutson and Bongiorni 1996). It is recommended that goals are set through pre-surgical counseling to facilitate setting of realistic goals (Fletcher et al. 2001).

Receiving inpatient rehabilitation care immediately after the acute care has been associated with reduced mortality, fewer subsequent amputations, greater acquisition of prosthetic devices and greater medical stability compared to sending patients home or to a nursing facility (Dillingham and Pezzin 2008). If the patient's general condition permits, standing training can be commenced as early as the first postoperative day. Previously, the rehabilitation was usually divided into at least two phases regarding prosthetic fitting: 1) healing phase extending from surgery to first fitting of a temporary prosthesis, which usually takes 4 to 8 weeks, and 2) maturation phase, during which a temporary prosthesis or definitive prosthesis is used, which lasts 4 to 6 months. A variety of factors including patient's skills and physical and functional characteristics create the foundation for successful rehabilitation with or without prosthesis.

Although age has been found to be correlated with not wearing prosthesis (Taylor et al. 2005), it has been demonstrated that elderly amputees

remain independent despite infrequent prosthesis use and outdoor ambulation (Nehler et al. 2003).

Trans-tibial prosthesis

A trans-tibial prosthesis has four key components: the socket and its interface, the foot, the pylon that connects these two parts together, and a suspension mechanism. Traditionally, the concept of socket design has been based on the Patellar Tendon Bearing (PTB) socket principle or variations of that concept (mostly related to suspension mechanism) (Lusardi and Nielsen 2000). The PTB socket concept is designed such that the amputee bears their body weight on specific weight tolerant areas of the stump. These are typically limited to the patellar tendon, the proximal medial tibia flare and the popliteal space (Convery and Buis 1998). The form of the stump has usually been captured in Plaster of Paris using a hands-on casting procedure. A positive model of the stump is subsequently rectified by the prosthetist to promote weight bearing in the desired regions and a laminated or thermoplastic socket with a soft custom insert, usually composed of foam material, is manufactured over the positive form. The consistency of the cast rectification procedure has been questioned and differences between prosthetists rectifying the same plaster model have shown high inconsistencies (Convery et al. 2003). The form of the stump model obtained through hand casting needs to be modified to obtain optimal socket shape based on the redistribution of the soft tissue during full load. There is only limited evidence-based research on socket shape and modifications and guidelines used in practice for this method (Convery et al. 2003).

Suspension of the PTB prosthesis is maintained using a sleeve by modifying the proximal walls of the socket to establish purchase of the femoral condyles or by using a circumferential cuff.

Commercially available gel and silicon liners have been available since the mid 1980's and used as an interface between the stump and the hard socket. Most of these liners are worn directly against the skin. Their intended use is to offer protection against friction and/or shear forces and to give a dynamic pressure distribution. The liners are typically applied by rolling them onto the residual limb. All of these liners are airtight so that perspiration cannot escape. Keeping the stump and the liner clean is important to reduce skin problems (Hachisuka et al. 2001). Skin problems can, however, become an issue and can be related to other factors such as the socket design used, the ability of patients to roll on the liner and donn the prosthesis (Baars et al. 2008).

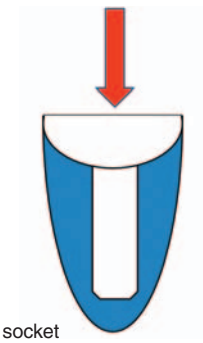

Figure 10. Quasi-hydrostatic socket

For various reasons, a PTB design does not provide an optimum fit when silicone or gel liners are used. In fact, the use of PTB design interfaces can create specific problems when used in conjunction with these liners (Kahle 1999). As a result, a new socket concept was suggested to address the limitations of the PTB socket designs (Kristinsson 1993). This new socket shape was obtained using a pressure casting device and the resulting socket design referred to as a quasi-hydrostatic socket. The theory behind the design was based on Pascal's theory of fluids, which states that any confined custom fluid will react to external forces by evenly distributing the pressure. By adopting this theory it was suggested that the condyles of the tibia and the fibula head contained within the prosthetic socket acted as a "rigid plug" and the distal part of the stump as the "fluid" (Figure 10) (Kristinsson 1993).

The concept of casting a residual limb while under pressure, is a method that was first described in the 1960's (Redhead 1979) and reintroduced after release of a purpose-designed pressure casting chamber (ICECAST Anatomy, ÖSSUR Inc. Reykjavik, Iceland) in the 1990's (Fothergil and Gruben 2007). Shortly after release of the pressure casting device it became possible to produce a carbon fibre socket directly on the patient. This technology (ICEX, ÖSSUR Inc. Reykjavik, Iceland) allows

for direct pressure casting and manufacturing of a prosthetic socket in one session (Johannesson et al. 2004). The promoted benefits of this technique are; elimination of plaster casting and plaster modifications and the fact that the patient is only required to visit the prosthetist once before gait training can be commenced. By using pressure casting, the anatomical shape of the stump is maintained during full weight bearing. Possible pressure points can be adjusted for by adding silicone pads prior to casting. These pads become incorporated within the socket after manufacturing.

The stump loading within ICEX sockets has been shown in a clinical setting to be more equally distributed. However, more pressure is applied distally compared with a PTB socket in which pressure is concentrated proximally (Convery and Buis 1999). Movement of the tibial remnant within quasi-hydrostatic sockets has been shown to be minimized as compared to the PTB design (Narita et al. 1997). This is likely to reduce shear forces within the socket and would reduce energy consumption during ambulation.

Suspension of the ICEX socket differs from the PTB variant. Suspension is obtained in two ways. The first is using a distal suspension through a pin that protrudes straight out from the distal end of the liner and locks into a mechanism inside the socket or lanyard that is screwed to the distal end of the liner and fastened on the outside of the socket. The second way of obtaining suspension is by vacuum, using an airtight sleeve with or without an expulsion valve.

In **Paper IV**, the outcome of initial prosthetic fitting in unilateral trans-tibal amputees using a new socket technology was evaluated over a period of 10 years. The particular outcomes of interest were days to prosthetic fitting and function with a prosthesis.

Outcome assessment

Having had a LLA is a lifelong condition and marks a dramatic change in the life situation of the person involved. Patients with chronic conditions are of special interest when considering health-related quality of life. When the condition as such cannot be cured, the goal of care becomes one of making "the patient's life as comfortable, functional and satisfying as possible" (Sullivan et al. 1999). Historically, the prosthetic community has not been challenged to establish or demonstrate scientific evidence proving the effectiveness of prostheses in improving health outcomes. There is, however, an increasing demand for objectively reporting outcomes of different rehabilitation programs and demonstrating that the care patients receive is facilitating their reintegration into the community (Condie et al. 2007).

Health-related quality of life of lower-limb amputees can be assessed with general (generic) or by disease- or condition-specific measures. Such tools measure the level of performance or perceived performance of a patient at a specific point in time (Gauthier-Gagnon and Grise 2001). Generic tools can be used for comparison of people with different medical conditions while condition-specific tools are designed for specific groups of patients or patients suffering from a specific condition. As a result, the condition-specific tools provide a more detailed perspective of health-related quality of life compared with generic tools (Beaton and Schemitsch 2003).

In a meta-analysis of outcome instruments targeting prosthetic prescription, 340 articles were identified, of which 28 met the inclusion criteria for further analysis (Condie et al. 2007). The instruments identified could be divided into three categories for use in the evaluation of amputees. These were: 'Self-reported', 'Professional reported' or used as a 'Physical performance instruments'. Only one of the professional reported instruments, the SF-36, had been validated for the Swedish population and one physical performance instrument could potentially be used without validation (the Timed "up and go" test) (Schoppen et al. 1999). Both of these instruments are generic and can be used for other conditions. Six measures were recommended for use in routine clinical practice and/or research. One of the 'Self-reported' instruments that measures condition-specific aspects of prosthetic use and has been recommended for routine use and research is the Locomotor Capabilities Index (LCI) (Franchignoni et al. 2004, Gauthier-Gagnon et al. 1998, Streppel et al. 2001). The LCI is a part of The Prosthetic Profile of the Amputee (PPA), which was designed in 1993 by Grisé and Gauthier-Gagnon to evaluate the pros-

thetic use of persons with LLA (Gauthier-Gagnon and Grise 1994). The LCI consists of a 14-item questionnaire. It has also been validated to be used independently as a specific measure of walking ability in lower-limb amputated patients. According to its developers the LCI "computes the global, basic, and advanced locomotor skills of the lower-limb amputee with the prosthesis and assesses level of independence" (Gauthier-Gagnon and Grise 2006). The LCI has demonstrated good validity and reliability in patients with lower limb amputation. It has been translated to several European languages and has been used in international studies (Gauthier-Gagnon and Grise 2006). The LCI has also been demonstrated to work well in daily clinical practice as a means of monitoring patients over longer time periods (Streppel et al. 2001).

When performing cross-cultural adaptation of a questionnaire, questions need to be forward and backward translated, validated and tested for reliability (Beaton et al. 2000b). In **Paper II**, a Swedish version of LCI is evaluated in amputees from 4 rehabilitation units. The decision to use the LCI for cross-cultural adaptation was based on the need of a well evaluated instrument that is easy to use in clinical practice.

Mortality

High mortality rates after LLA due to vascular diseases can be expected considering the high mean age of the patients at the time of amputation. Mortality rates in amputation performed above ankle level for PVD have been reported to be between 61% and 69% within five years (Eneroth 1997). In a US study of 13,000 amputations the 1-year and 5-year survival rates were found to decrease for all levels of amputation when comparing patients amputated during the time periods 1987–1989 and 1995–2000. Data indicated that subjects had a 28% reduced likelihood of dying during the study period. While survival rates were relatively positive at one and five years after amputation, the 30-day mortality rate was found to be unchanged, with significantly worse outcomes for more proximal levels of amputation (Sandnes et al. 2004). In Sweden, the amputee population is 5 to 10 years older at the time of initial amputation (Eneroth and Persson 1992) than those in comparable countries (Heikkinen et al. 2007, Trautner et al. 2001). It is likely that the mortality rates of this amputee population is higher compared with other countries, with a reported 6-month mortality rate of 38% and a 4-year mortality rate of 72% (Eneroth and Persson 1992).

Gender has been suggested as a significant factor influencing the mortality rate of lower limb amputees. In two studies, women were found to have a lower overall median survival rate compared with men (Pohjolainen and Alaranta 1998, Ebskov 1999). In other studies, after appropriate adjustment for age (considering that women undergoing amputation are usually older than men), no significant differences could be found (Heikkinen et al. 2007, Sandnes et al. 2004).

In **Paper I** the mortality rate is analyzed for all PVD amputees in a region of southern Sweden over a ten year period. In **Paper IV** unilateral trans-tibial amputees are specifically targeted.

New standardized surgical and rehabilitation program in trans-tibial amputation

In Hässleholm-Kristianstad, a concept was developed in 1995 to use a standardized surgical technique, a common mean of documenting procedures, a common treatment regime for trans-tibial amputations and early rehabilitation of amputees. A multidisciplinary team approach was used. The team consisted of an orthopedic surgeon, a prosthetist and a physiotherapist as permanent members, with access to other specialties such as a rehabilitation consultant, a nurse and an occupational therapist. All lower limb amputations in the region were performed at one orthopedic department by orthopedic surgeons, and patients considered for amputation secondary to vascular disease were assessed in consultation with vascular surgeons.

The sagittal incision technique described by Persson (Persson 1974, Persson et al. 1981) was used as a standard method for trans-tibial amputation except when previous vascular surgery did not allow that position of the incision. If sagittal incision was not possible, traditional long posterior flaps (Burgess and Marsden 1974) or Brückner amputation techniques were used (Stahel et al. 2006, Schwitalle and Bruckner 1998).

Figure 11. Measurement taken for selection of liner.

Figure 12. The silicone liner turned inside out and alcohol-based lubricant spray is applied.

Figure 13. The liner under the most stretch is aimed to the sagittal flaps and rolled on.

Figure 14. The silicone liner in place.

A circular rigid Plaster of Paris dressing was used as the postoperative standard. During the last year of the study period, ORD® vacuum rigid dressings were used instead. The rigid dressing or ORD® was applied directly after the amputation. After 5–7 days the rigid dressing was removed and if there were no definite contraindications such as severe dementia or purulent infection, compression treatment with a silicone liner was initiated.

A layer of highly absorbing bandage (Aquacel®) was placed over the wound and kept in place with a thin clean film (Opsite®). This was changed at every wound inspection if necessary. No bandage was applied to the flaps so that the silicone liner would make direct contact with the skin. A silicone liner *(*Iceross PostOp®, Össur, Reykjavik, Iceland*)* with a graded pressure distribution (due to the variation of the thickness of the liner) was used as a standard compression method for diminishing edema, shaping the residual limb and of relieving pain. The size of the liner was determined by measuring the circumference 4 cm from the distal end (Figures 11–14).

When the compression therapy was started we followed a standardized procedure of measuring for the right size of the liner and for determining how long it should be used each day. We tried to engage the patients in this procedure at an early stage and in that way to help them deal with their new body image. Silicone liners could be reused after sterilization.

All new patients received in-hospital rehabilitation. Ambulation with an ischial weight-bearing training prosthesis was started when the plaster of Paris dressing was removed, with no load on the residual limb. Patients with higher degree of comorbidity remained as in-patients throughout their rehabilitation while patients with less comorbidity were discharged to a short-stay service home after compression therapy had commenced. These patients received training between 3 and 5 times per week. The rehabilitation setting for these patients in Sweden is mostly provided through so called “Walking Schools”. In Hässleholm-Kristianstad, both in-patients and amputees who had been discharged from rehabilitation were invited to attend weekly training sessions and had access to the multidisciplinary team members for check-ups, adjustments or consulting (Figure 15).

Figure 15. Control of the remaining other leg at the weekly training session.

Figure 16. The carbon fiber applied.

Pressure casting (Figure 13) using the ICE-CAST® in combination with ICEX® was used on all patients for the production of a trans-tibial prosthetic socket. The socket consisted of layers of carbon fiber with a distal aluminum adapter and the carbon is impregnated with polyurethane resin. Additional silicone pads could be used for padding inside the socket for sensitive areas like the tibial crest. The carbon fiber was then immersed in water for 10 seconds and the hardening process started. Within approximately 100 seconds the carbon fiber socket needs to be attached to the distal end of the liner and put in place covering the stump (Figure 16). Thereafter the silicone bladder is rolled-on and inflated. A pressure of 60–80 mmHg was generally used (Figure 17–19). Complete wound healing was not a mandatory for prosthetic fitting.

Figure 17. IceCast Anatomy pressure casting devise applied.

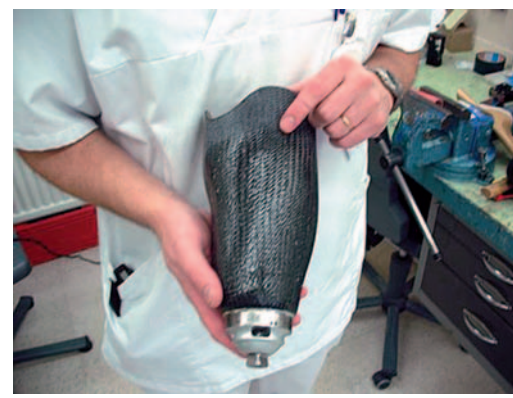

Figure 18. The ICEX socket ready for test.

Figure 19. Amputee, taking the first steps with prosthesis.

Analyses

In **Paper I,** the overall incidence rate of LLA was calculated as the number of persons undergoing initial amputation at or above transmetatarsal level for peripheral vascular disease divided by both the corresponding population at risk (≥ 45 years) and total population per 100,000 person-years. The incidence rate was also calculated separately for diabetic and nondiabetic men and women and across specific age groups. The number of amputations over a 10-year period was assumed to have a Poisson distribution and the number of persons with diabetes to have a binomial distribution (these were assumed to be independent). Parametric bootstrap with 10,000 replications and percentile method was used to estimate 95% confidence intervals (CI) for incidence rate. Incidence rates for contralateral amputations and re-amputations among persons who had undergone an initial unilateral amputation were calculated per 100 amputee-years. In calculating the incidence rates (initial unilateral, contralateral and re-amputation), each patient accounted for no more than one amputation for each incidence rate. The 1-year mortality rates among diabetic and nondiabetic patients were compared using Cox regression analysis adjusting for age and gender. The Kaplan-Meier analysis was used to calculate median time from initial amputation to death.

Interpretation: This measure estimates the expected number of individuals in a population that will become amputees. In addition, the length of time contributed by all persons during the period they were in the population and events was counted. The number of new amputees divided by the person-time is the incidence rate of the population over the study period (Rothman and Greenland 1998). By subdividing into diagnosis, gender and age group, risk groups can by identified more accurately. The 1-year mortality rates among diabetic and non-diabetic patients were compared using Cox regression with adjustment for age and gender. The Kaplan-Meier estimator estimates the survival function from life-time data. It can be used to measure and compare the number of diabetic and nondiabetic amputees living for a certain amount of time after treatment.

In **Paper II** cross-cultural adaption of the Swedish version of the LCI was performed and the Swedish version assessed for validity and reliability.

Validity of an instrument refers to the intended interpretation of the variables which it is intended to measure. For this purpose we used “convergent validity”. Convergent validity is the degree to which an operation is similar to (converges on) other operations that it theoretically should also be similar to. In this case we compared the LCI with the EQ-5 and TUG test and calculated the correlation with the Spearman correlation coefficient (r).

Interpretation: A correlation coefficient of at least 0.7 has been proposed as a standard for correlation in validity studies (Terwee et al. 2007).

Discriminative validity describes the degree to which the operationalisation is not similar to (diverges from) other operationalisations that it theoretically should not be similar to. In this case we compared separately the LCI result between older and younger amputees and by unilateral and bilateral amputees. The hypothesis was that younger and unilateral would have better LCI score than older and bilateral amputees.

Interpretation: For comparison of LCI scores in different age groups (non-parametric) the Kruskal-Wallis test was used. For comparing LCI scores in unilateral and bilateral trans-tibial amputees the Mann-Whitney test was performed. Both tests were 2-sided and a p-value of 0.05 was considered to indicate statistical significance.

In statistics, “reliability” is the consistency of a set of measurements or measuring instrument, often used to describe a test and should be assessed in more than one way.

i) The first aspect of reliability is test-retest reliability (reproducibility) which refers to the stability of the measurements by the same instrument.Test-retest methods require that two assessments with the subjects are administered. The closer the results, the greater the test-retest reliability of the survey instrument.The time

interval between the tests is of particular importance in these analyses. A short time interval may only reflect that the participants remember their previous answers while a longer interval can be influenced by other factors with the potential to affect what is being measured. The intraclass correlation coefficient (ICC), which measure correlation for a set of data when it has multiple groups, can be used for this analysis.

ii) A second aspect of reliability is "internal consistency" which relates to the homogeneity within a multi-item scale and can be assessed with Cronbach's alpha. This calculation is based on one test occasion and therefore not enough to determine if an instrument is reliable.

Interpretation: The ICC can range from 0 (no correlation) to 1 (perfect correlation). For adequate test-retest reliability, ICC values higher than 0.7 are recommended as a minimum standard for reliability (Terwee et al. 2007). A Cronbach's alpha coefficient value between 0.70 and 0.95 has been proposed to indicate good internal consistency (Terwee et al. 2007).

In **Paper III**, the chi-squared test was used to compare groups with regard to gender, smoking status and presence of other medical conditions. The Mann-Whitney test was used to compare patient age. Multiple linear regression analyses were performed to calculate age- and gender-adjusted mean differences and 95% confidence intervals between the groups. As a number of patients did not achieve prosthetic fitting because of death or other reasons, we tested two other models to compare the groups in relation to time to prosthetic fitting: a conventional proportional hazards (Cox) model to include the censored observations and a Fine and Gray proportional hazards model to account also for competing risk (Fine and Gray 1999).

In **Paper IV,** logistic regression was employed for the analysis of associations between baseline factors and 1-year mortality among all patients and between baseline factors and function with prosthesis among patients classified as "walkers" before amputation who survived at least 90 days after amputation. An additional analysis was performed including the occurrence of contralateral amputation between the unilateral trans-tibial amputation and the time of evaluation of walking ability. Kaplan-Meier survival analysis was also applied

Interpretation: In logistic regression a forward stepwise method was used and variables with a p-value of <0.1 were included in the model as possible predictors.

Objectives of the thesis

The objectives of this thesis were to:

1. estimate the overall and age and gender-specific incidence rates of initial amputation, re-amputation and contralateral amputation, performed for peripheral vascular disease, in the at-risk diabetic and nondiabetic general population;

2. investigate the mortality rate after lower limb amputation performed for peripheral vascular disease and after initial trans-tibial amputation;

3. introduce a Swedish version of the Locomotor Capabilities Index and evaluate its reliability and validity in patients who have undergone lower limb amputation;

4. compare a new rigid dressing with conventional Plaster of Paris rigid dressing after trans-tibial amputation with regard to the number of days to prosthetic fitting and function with a prosthesis;

5. evaluate the outcome of a new standardized treatment strategy in trans-tibial amputation in patients with peripheral vascular disease with regard to rate of prosthetic fitting and function with prosthesis and analyze potential baseline predictors of good walking ability with prosthesis.

Summary of papers with focus on material, method and results

The study population

The study population in **Paper I** included all residents in the Northeastern Skåne health care district undergoing non-traumatic lower limb amputation at transmetatarsal level or higher between the years 1997 and 2006 (Table 3 and Figure 20).

The patients recruited for participation in the study in **Paper II** were mainly from the rehabilitation unit in Hässleholm-Kristianstad Hospitals as well as from three other rehabilitation units in Sweden (Gothenburg, and Stockholm). The inclusion criteria were:

- age 40 years or older
- trans-tibial, knee and trans-femoral amputees
- amputees fitted with prosthesis.

Paper III includes a subcohort of initial trans-tibial amputees from the same study population as in **Paper I**, who were willing to participate in a randomized study. **Paper IV** includes a subcohort comprising all initial trans-tibial amputees from the same population as in **Paper I**.

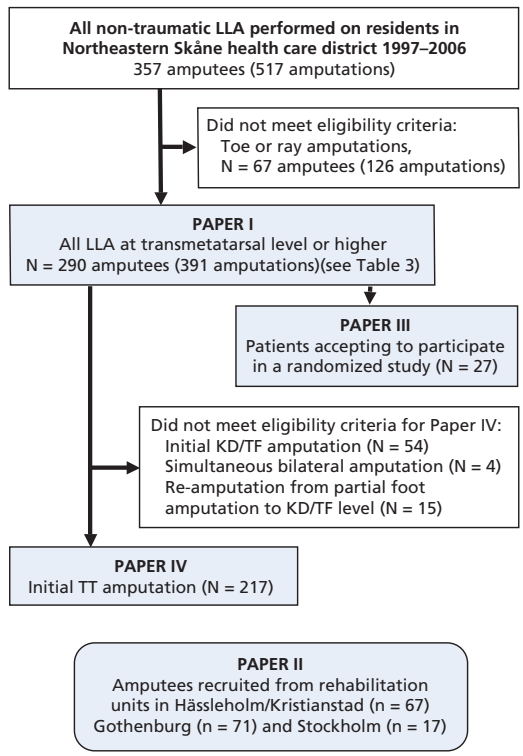

Figure 20. Patients and amputations in the papers.

Table 3. Amputation procedures (initial, contralateral- and re-amputation) and levels

	Amputation level						
	TM	MF [a]	AD	TT	KD	TF	Total
Initial amputation level (IA)	12	7	2	215 [b]	22	32	290
Additional amputations after IA							
IA + contralateral	1	1	1	28		4	35
IA + re-amputation		1		6 [c]	3	28	38
IA + re-amputation + contralateral				4	3	2	9
IA + contralateral + re-amputation				1		4	5
Bone revision [d]				9		5	14
Total	13	9	3	263	28	75	391

[a] including tarsometatarsal joints
[b] 211 included in Paper IV, 4 patients excluded due to simultaneously bilateral amputations
[c] 6 patient included in Paper IV after re-amputation
[d] included in Paper I as re-amputation

Paper I. Incidence of lower-limb amputation in the diabetic and nondiabetic general population: a 10-year population-based cohort study of initial unilateral and contralateral amputations and reamputations

Design: Population-based cohort study.

Participants: During the 10-year study period 133 diabetic patients (53% men) and 157 nondiabetic patients (50% men) who underwent initial lower limp amputation were followed. The mean age of the diabetic patients was 76 (45–95) years and of the nondiabetic patients 81 (59–97) years. The follow-up period was the study period and for patients included during the final year of the study mortality was recorded during 1 year after amputation. In total there were 391 amputations performed.

Methods: The amputations were classified according to the following definitions; an initial unilateral is a person's first LLA at or proximal to transmetatarsal level; a contralateral limb amputation is an amputation at or proximal to transmetatarsal level on the opposite lower limb in a person who had undergone an initial unilateral amputation; a re-amputation is a new amputation at more a proximal level (including procedures in which bone length was shortened within the same level) in a person who had undergone an initial unilateral or a contralateral limb amputation. Patients were considered diabetic if they had a diagnosis of diabetes treated with oral hypoglycemic agents or insulin at the time of amputation. All postoperative care and new surgical procedures were performed at the study region's hospital. The overall and sex and age-specific incidence rates for initial amputation were calculated for diabetic and nondiabetic persons. Because only one diabetic person and no nondiabetic person below 45 years of age underwent amputation at transmetatarsal or higher level during the study period, the diabetic and nondiabetic populations at risk were considered to comprise all persons aged 45 years or older. All patients were residing in the region during the study period.

Results: The overall incidence of initial amputation in the diabetic population was 195 (95% CI 163–231) per 100,000 person-years. In the nondiabetic population it was 23 (95% CI 19–26) per 100,000 person-years. Among diabetic persons of both sexes the incidence increased gradually with age, with similar incidence rates between 45 to 85 years, after which the incidence was threefold higher in men compared with women (and five times higher when comparing with total population of men). Among nondiabetic persons the incidence was low up to 75 years but increased sharply thereafter and for the age group 85+ the incidence was 15-fold higher in men and 12-fold higher for women compared with the total population respectively. Among diabetic amputees the incidence of re-amputation was 19 (95% CI 12–28) per 100 amputee-years and among nondiabetic amputees it was 14 (95% CI 9–22). The most frequent re-amputation level among diabetic persons was trans-tibial and among nondiabetic persons was trans-femoral. Among initial trans-tibial amputees, re-amputation was performed on 7 (7%) of the diabetic and 16 (15%) of the nondiabetic persons. The incidence of contralateral amputation among diabetic amputees was 17 (95% CI 10–25) per 100 amputee-years and among nondiabetic amputees 13 (95% CI 8–20). The most frequent contralateral amputation level among the diabetic and nondiabetic persons was trans-tibial. Thirteen diabetic persons (10%) and 10 nondiabetic persons (6%) became bilateral trans-tibial amputees. The time from initial amputation to re-amputation showed no statistically significant differences between sexes in both groups whereas the time to contralateral amputation was shorter in the nondiabetic group and with tendency of being shorter for men in both groups. The median survival time for the diabetic persons was 440 (95% CI 303–577) days and for the nondiabetic persons was 563 (95% CI 368–758) days. Of the 133 diabetic and 157 nondiabetic persons who had undergone amputation during the study period, 60 (45%) and 78 (50%), respectively, died during the first year after initial amputation. When adjusted for age and sex the 1-year mortality did not differ significantly between the 2 groups.

Paper II. The Locomotor Capabilities Index: validity and reliability of the Swedish version in adults with lower limb amputation

Design: Cross-cultural validation study

Participants: 155 amputees attending after-rehabilitation training from 4 centers participated. 11 were excluded because of incomplete data. Data from the remaining 144 amputees were used for the analyses. The amputees included 89 men with mean age of 73 (44–91) years, and 55 women with mean age of 75 (40–93) years. The amputation was a trans-tibial amputation (TTA) in 110, knee disarticulation (KD) in 5 and trans-femoral amputation (TFA) in 13 patients. 16 patients were bilateral amputees. The data were collected from September 2003 through December 2007.

Methods: Evaluation of validity included examination of the completeness of item responses, the distribution of the scores, and the extent of ceiling and floor effects among all 144 participants. Construct validity of the LCI was assessed by testing a number of predefined hypotheses regarding its relationship with other measures of function and health (convergent validity) and its ability to discriminate among groups expected to differ in locomotor capabilities (discriminative validity). Convergent validity was determined by comparing the LCI results with the TUG test in a subgroup of 40 TTA patients (15 women), mean age 74 (41–89) years. A subgroup of 20 amputees (10 women), mean age 76 (41–91) years, participated in testing the relationship between the LCI and the EQ-5D health utility and quality of life measure and a test-retest examination of the LCI. Discriminative validity of the LCI was assessed by analyzing its ability to discriminate among 123 amputees (50 women) in different age groups and amputation levels. Evaluation of internal consistency reliability was done using the LCI responses for all 144 amputees.

Results: Basic item 1 ”rising from a chair” and item 2 “walk indoors” had the highest mean scores (2.9 and 2.7 respectively) and the worst scores were registered for advanced items 5 and 6 “getting up and down a stair without a handrail”, both scoring a mean of 1.2. Of all participants, 1 amputee (0.7%) had a worst possible score (floor effect) and 12 had scores below 8. 43 amputees had scores of 40 or higher and 33 (23%) had a maximum possible score (ceiling effect). The mean total score was 28.5 (SD 12.5, median 33) and the mean basic score was 17.2 (SD 5.5, median 21) and the mean advanced score was 11.3 (SD 7.8, median 12). High scores were more common among men than women. The mean LCI score for amputees in younger age groups was significantly better than that for amputees in older age groups. The mean LCI score for unilateral amputees was 30.5 (SD 11.4) and for bilateral amputees was 12.9 (SD 12.8) ($p < 0.001$). In the subgroup that performed the TUG test, the mean LCI was 29.6 (range 2–42) and the mean TUG result was 34.2 (range 9–92) seconds. The correlation between the LCI and the TUG was strong ($r = -0.75$, 95% CI −0.89 to −0.56, $p < 0.001$). The mean EQ-5D index was 0.63 (SD 0.3). The correlation between the LCI and EQ-5D index was strong ($r = 0.84$, 95% CI 0.58–0.95, $p < 0.001$). Internal consistency was high, with Cronbach’s alpha for the total LCI 0.95 (95% CI 0.94–0.96), for basic activities 0.93 (95% CI 0.91–0.95), and for advanced activities 0.94 (95% CI 0.92–0.95). The item-total correlations ranged from 0.42 (basic item 1) to 0.85 (advanced item 3). In test-retest reliability, the ICC values for the total LCI and for the basic and advanced subscales were high (0.88, 0.92, and 0.91, respectively) and all the 95% confidence intervals were above 0.70.

Paper III. Comparison of vacuum-formed removable rigid dressing with conventional rigid dressing after trans-tibial amputation: similar outcome in a randomized controlled trial involving 27 patients

Design: Randomized controlled trial

Participants: 27 patients fulfilled the eligibility criteria and accepted to participate in the study. 3 patients died after surgery and one patient developed a 45-degree contracture in the knee which precluded prosthetic fitting. The remaining 23 patients were randomized in to two groups; 13 patients (9 men) mean age 76 (45–91) years, to the ORD (O) group and 10 patients (5 men), mean age 76 (43–89) years, to the CRD (C) group. Age, sex,

proportion with diabetes and smoking status were similar in the two groups. 12 patients were diagnosed with diabetes at the time of amputation. No patient had undergone lower level amputation prior to the present amputation.

Methods: The patients were randomly assigned, using sealed envelopes opened at surgery, to one of the two groups and vacuum-formed removable rigid dressing (ORD) or conventional plaster of Paris rigid dressing (CRD) was subsequently applied. A sagittal incision was used in all patients except one in whom a transverse incision was used because of previous vascular surgery. A residual length of approximately 1½ times the width of the knee, considered optimal for prosthetic fitting was achieved in all except 3 patients (ORD group) of whom 2 had a shorter and one a longer residual limb length. Good blood circulation at the incision level was observed in all patients at the time of surgery and all wounds were closed with primary suture. No drain was applied. The sutures were removed 3 weeks after surgery. The patients in both groups received identical postoperative treatment (including oral or intravenous supplementary nutrition), wound care management, compression treatment with silicone liner, training and prosthetic technique. Both dressings were worn full time including at night and during physiotherapy sessions if applicable. The physiotherapist at the rehabilitation center and the prosthetist were blinded as to whether the patients were participants in the study and to the type of dressing they had received. All prostheses were made by the same prosthetist and, to avoid delay in the rehabilitation process, the prostheses were delivered on the same day the decision regarding prosthetic fitting was made. Three months after the amputation, a follow-up evaluation was performed according to a standardized protocol and functional outcome was measured using the Locomotor Capabilities Index (LCI) and the Timed "Up and Go" (TUG) test. The primary outcome measure was the number of days from amputation to prosthetic fitting. The secondary outcome measures were the wound healing rate, functional outcome as measured with the LCI and TUG test at 3 months, need for socket changes during the first year, and the rate of returning to previous dwelling at 1 year.

Results: When patients received the first definitive prosthesis, wound status was complete closure in 6 of 13 patients in the O group and in 4 of 10 patients in the C group ($p = 0.6$). The shape of the residual limb was described as cylindrical in 11 patients and bulbous in 2 patients in the O group and cylindrical in 9 patients and conical in 1 patient in the C group. 1 patient in each group had an adherent scar at the time of prosthetic fitting.

The mean time from amputation to prosthetic fitting was 37 (26–54) days in the O group and 34 (21–47) days in the C group with no significant differences between the groups (sex and age adjusted $p = 0.4$ for Cox regression model and $p = 0.4$ for Fine and Gray model). No statistically significant differences in the results of the functional tests were found between the two groups at the 3-month follow-up evaluation. A wide range of LCI and TUG values were observed in both groups. No socket change was needed during the first year in 4 patients in the O group and 2 patients in the C group. Among the patients who had socket change, mean time to socket change was 185 (95–269) days in the O group and 206 (95–267) days in the C group ($p = 0.9$). At 1 year, all patients had returned to their previous dwelling except 2 patients (C group) who had moved from their own home to a community service home.

Paper IV. Outcomes of a standardized surgical and rehabilitation program in trans-tibial amputation for peripheral vascular disease: a 10-year prospective cohort study

Design: Population-based cohort study.

Participants: 217 consecutive patients (111 (51%) diabetic and 106 (49%) nondiabetic) who underwent initial unilateral trans-tibial amputation because of PVD at a single orthopedic department. Of these 217 amputations, 6 were re-amputations after transmetatarsal or midfoot amputation. During the study period 4 other patients who had undergone trans-tibial amputation and simultaneous contralateral amputation at transmetatarsal level or higher were not included.

Methods: All patients went through the same standard management strategy consisting of a

sagittal incision, rigid dressing, compression with silicone liner and direct manufacturing prosthetic socket system. At discharge from in-hospital rehabilitation and 1 year after surgery all patients were examined by an orthopedic surgeon, physical therapist and a prosthetist. Prosthetic functional status was recorded and classified as good or poor. Functioning was defined as good if the patient wore the prosthesis daily and was able to walk alone or with assistance outdoors or alone indoors. Functioning was defined as poor if the patient did not wear the prosthesis daily and was unable to walk indoors without assistance or used a wheelchair most or all the time or did not receive a prosthesis. Mortality was recorded prospectively and for the patients included during the final year of the study mortality was recorded up to 1 year after amputation. The outcome measures were the rate of prosthetic fitting, walking ability with a prosthesis and mortality. The baseline factors analyzed as potential predictors of function with prosthesis were diagnosis, age, gender, type of residence before amputation, side of amputation, surgery on the amputated limb during the preceding year and surgery in the contralateral limb during the preceding year.

Result: After initial unilateral amputation the 3-month mortality rate was 24% (53 patients) and the 1-year mortality rate was 40% (86 patients). Of the 119 patients who received trans-tibial prosthesis 20 (17%) and of the 98 patients who did not receive prosthesis or were re-amputated 66 (67%) died within the first year. The 1-year mortality was similar among diabetic and nondiabetic patients when adjusting for age and gender. Living in a service home prior to the amputation was significantly associated with higher 3-month mortality.

The overall median survival time was 587 days. Patients with good walking ability before amputation who received prosthesis had longer survival than patients not selected for prosthetic fitting. Median survival time for the 102 patients with poor walking ability prior to the amputation or with good walking ability prior to the amputation but did not receive trans-tibial prosthesis was 108 days. The median survival time for the 115 patients who had good walking ability before amputation and were fitted with prosthesis was almost 12-fold longer (1248 days).

Prosthetic fitting was achieved in 119 patients for an overall prosthetic fitting rate of 55%. Of the prosthetic recipients, 62 (52%) were men with mean age of 75 (SD 10) years and 57 (48%) were women with mean age of 78 (SD 9) years. Of the diabetic patients 62 (56%) and of the non-diabetic patients 57 (54%) received prosthesis. The median time from amputation to prosthetic fitting was 41 (range 12–147) days, with no differences between diabetic (40 days, range 13–147) and non-diabetic patients (42 days, range 12–131). Of the patients who received prostheses 115 (97%) had been classified as “walkers” prior to the amputation and 4 (3%) as “non-walkers”. The prosthetic fitting rate in patients classified as “walkers” was 69% at 3 months (109 of 157) and 66% at 1 year (95 of 143). Among the 126 patients classified as “walkers” and who survived at least 90 days after amputation, prosthetic fitting was achieved in 109 patients (86%) (in 5 after re-amputation). Five of 27 patients who died within 90 days had been provided with prostheses.

Evaluation at discharge was performed in general two week after limb fitting (median 97 days, range 55–172). Of the 115 patients, defined as “walkers” before the amputation and fitted with prosthesis 4 patients (3%) died before evaluation could be performed, (7 did not need any aid, 21 used cane, crutches or walking frame, 73 used walking frame with wheels, and 10 were confined to wheelchair and used the prosthesis for short transfers (between wheelchair and bed) or for cosmetic purpose). Of the 49 patients classified as “walkers” before amputation but who could not receive prosthesis 41 (84%) died during the first year. Of the diabetic patients, 38 (61%) obtained good function with prosthesis and 24 (39%) had poor function with prosthesis during the first year compared with 38 (67%) and 19 (33%) respectively of the nondiabetic patients.

Function with prosthesis at 1 year after amputation was similar to that at discharge. Among all amputees classified as “walkers” before amputation patients living in service home before amputation were significantly more likely to obtain poor function. Among those subsequently fitted with prosthesis no baseline factors were found to be significant predictors of function with prosthesis.

The re-amputation rate during the first year was 8.3% (18 patients). The mean time from the initial trans-tibial amputation to re-amputation was 27 days (range 10–65). Of the 18 re-amputated patients 11 had been "walkers" and 7 had been "non-walkers" before the trans-tibial amputation, of whom 3 and 2 respectively were subsequently fitted with trans-femoral prosthesis. The contralateral amputation rate during the first year was 5.5% (12 patients). The mean time interval from initial trans-tibial amputation to contralateral amputation was 180 days (range 25–331).

Of the 12 contra-laterally amputated patients 11 had been "walkers" before the initial trans-tibial amputation and 6 of them were subsequently fitted with bilateral prostheses (5 bilateral trans-tibial prostheses and 1 trans-tibial and trans-femoral).

General discussion

Incidence and mortality

Since the 1950s several studies have reported the incidence rate of LLA (Ephraim et al. 2003). Methodological issues particularly in relation to the specific definitions used to register procedures limit the ability to make comparisons and draw general conclusions from these studies (Jeffcoate 2005, van Houtum and Lavery 1997). Age-adjusted incidence rates of LLA related to vascular disease calculated separately with regard to gender and diagnosis using the diabetic and nondiabetic population at risk as the numerator have been presented only in few studies previously. The present study (**Paper I**) is the first population-based study in which the incidence rate of initial amputation is presented for both the diabetic and nondiabetic populations at risk (≥45 years). In addition, the study is based on a well-defined population, with all amputations performed at one orthopedic department and all data validated for accuracy (including the estimation of the prevalence of diabetes). For incidence rates of re-amputation and contralateral amputation, the population of amputees was used as the nominator. An important finding is that the incidence in the nondiabetic population was found to be more than twice as a high when using the risk population (nondiabetic patients ≥45 years) compared with total population. When using the risk population in diabetic persons (diabetic persons ≥45 years) the difference in incidence rates was smaller.

One limitation of the present study might be that toe and ray amputations were not included, thus underestimating the incidence rates. However, given that reporting of partial foot procedures is poor, inclusion would have resulted in inaccurate statistics (Calle-Pascual et al. 2001, Global Lower Extremity Amputation Study Group 2000). Another aspect is that toe amputations have much lesser impact on the residual function of the patients compared with higher-level amputations (Jeffcoate 2005). Amputations, distal to the transmetatarsal joints, account for between 26% and 44% of all LLA in previously published work (Larsson et al. 2008, Morris et al. 1998, Trautner et al. 2007).

Another aspect regarding the total incidence rate for LLA is that differences in the prevalence of diabetes can substantially affect the incidence rate (Global Lower Extremity Amputation Study Group 2000). Incidence rates for LLA observed in the present thesis indicated that the incidence is low. These findings are in contrast to rates reported in a study from Scotland in which the prevalence of diabetes was estimated to be 1.9% and all amputations (N = 221) were included (toe and partial toe amputation accounted for 42% of all amputations). This is to be compared with our study in which the prevalence of diabetes was 4.4% and toe amputations were excluded. Differences in the two studies may be attributed to the fact that in the Scottish study the total incidence rate was higher in the diabetic population (247 compared with 179 per 100,000 person-years in our study) and in the nondiabetic population (20 compared with 10 per 100,000 person-years in our study) (Morris et al. 1997).

Similar to many other studies, the incidence of LLA in our study increased with age. In the diabetic population the incidence rates in the youngest and oldest age groups were 75 and 329 per 100,000 person-years in women and 73 and 929 per 100,000 person-years in men. In the nondiabetic population the corresponding incidence rates were 7 and 123 per 100,000 person-years in women, 12 and 154 per 100,000 in men (Table 2).

The re-amputation rate in our study (20% including both legs) was found to be comparable with a Danish study (Ebskov and Josephsen 1980) from the 1970's including 2029 amputations and with a 16.5% re-amputation rate (after initial amputation) within three months. The risk of contralateral amputation within four years reported in that study was 44.3%. This rate is in contrast to that shown in our study in which the risk of contralateral amputations was approximately 15% during the study period of 10 years. Some of these differences can be attributed to the decision inclusion of the fact-

that all amputation levels were inculded in the Danish study.

The incidence rates found in the present study are higher than those presented in a Finnish study of 646 amputations performed during 1984–1985 that included the same levels of amputation as in our study. In the Finnish study, the contralateral amputation rate was reported to be 4.2% during the 2-year study period. These differences can partly be explained by the lower rate of initial trans-tibial amputation in the Finnish study (36%) compared with ours (74%) (Pohjolainen and Alaranta 1988). Another study reported a trans-tibial rate of 81% and re-amputation rate of 14% in a population in which the mean age was 8 years lower than that in the present study (McCollum et al. 1988).

The 1-year mortality rates in our study (45% in the diabetic and 50% in nondiabetic patients) were higher than those reported in a Scottish study 33% and 27% respectively) (Schofield et al. 2006). This was also reflected in the mean time to death 17.9 months for the diabetic and 19.8 months for the nondiabetic patients in our study compared with 27.2 months and 46.7 months, respectively in the Scottish study. These differences can be explained by the inclusion of all amputations, lower mean age (almost 10 years) and the lower prevalence of diabetes in the Scottish study.

Outcome assessment

One of the objectives of this thesis was to validate a practical clinical instrument for measuring the functional outcome in amputees fitted with prostheses. Such a tool would facilitate international comparisons. Out of several possible instruments we decided to perform a cross-cultural adaptation of the LCI which has been demonstrated to be useful both in daily clinical practice, and in research and can be easily administrated (self- administrated, face-to-face, or telephone interview) (Condie et al. 2007, Gauthier-Gagnon and Grise 2001). At the time of performing the cross-cultural adaptation and assessment of reliability and validity for the LCI (**Paper II**) no other specific instrument that measured the functional outcome prosthesis-fitted amputees was available in a Swedish version.

The Swedish version of the LCI demonstrated good reliability and validity in adult amputees but the high ceiling effect may imply that it would be most useful in assessing amputees with low or moderate functional abilities. The high ceiling effect has been noted previously and changes have been suggested to extend the scale from 4 to 5-levels to adjust for this (Franchignoni et al. 2004). Information regarding these changes was not available during our study set-up and the main part of our data had been collected at the time the changes were suggested.

Postoperative treatment after trans-tibial amputation

The use of rigid dressings after trans-tibial amputation appears to be mainly recommended by orthopedic surgeons (Dillingham and Pezzin 2008, Pinzur et al. 2007, Smith et al. 2003). It is suggested that this approach is most useful in a clinical setting where a multidisciplinary team approach is used (Nicholas and DeMuth, Jr. 1976). Studies on the use of rigid dressings are still a matter of controversy (Geertzen and Emmelot 2004, Emmelot and Geertzen 2006, Pinzur et al. 2007). Research findings have been difficult to compare (Smith et al. 2003) and/or the quality of studies has been found to be insufficient to allow conclusions to be drawn (Nawijn et al. 2005, Smith et al. 2003). Five studies, comparing a thigh-level rigid dressing with a soft dressing, (**Paper III**) recommend or prefer the use of rigid dressing as conclusion of the study outcome (Baker et al. 1977, Barber et al. 1983, Mooney et al. 1971, Nicholas and DeMuth, Jr. 1976, van Velzen et al. 2005). Two of these studies found the main advantage compared with soft dressing to be the shortening of time to prosthetic fitting (Baker et al. 1977, van Velzen et al. 2005). Application difficulties and cost have been the main arguments why rigid dressings have not been commonly accepted. In addition, their use requires more time at surgery and the availability of a skilled surgical or prosthetic team (Smith et al. 2003) as there is a risk of excessive pressure on the patella or the distal tibia if incorrectly applied (Baumgartner and Botta 1995). The benefit of the new vacuum formable dressing tested in

our study is simplicity of application and ease of wound inspection. The dressing alone, however, is not the only parameter for successful early prosthetic fitting. Optimization of the surgical method used, well-performed compression therapy and early rehabilitation with and without prosthesis are likely to be equally important.

In a randomized study of patients undergoing amputation due to arterial disease, a comparison was made between the uses of silicone liners and elastic compression bandages (28 patients in both groups) in the treatment of open wounds after LLA (Vigier et al. 1999). The outcome showed a significantly shorter mean time to healing and shorter length of hospital stay in the silicone group.

During the 10-year study period, all patients who underwent trans-tibial amputation received the same standardized treatment, including a sagittal incision (in 90% of all cases (Johannesson et al. 2004)) and rigid dressing, both performed and applied by the orthopedic surgeon performing the amputation, with compression therapy using silicone liner administrated by a physiotherapist. Prior to the study period we used two years to refine this standard procedure. There have been indications that this method works equally well in England and Japan with a similar approach having been presented in two previous descriptive studies (Earle 2007, Kimura et al. 2007).

Prosthetic fitting after trans-tibial amputation

In **Paper IV**, we address outcomes in elderly new amputees after receiving a standardized treatment protocol including ICEX prosthetic socket technology. Of particular interest in this population were the rate of prosthetic fitting and function with a prosthesis. Outcomes demonstrated a high rate of prosthetic fitting with a short delivery time (median time of 41 days after the amputation). Two-thirds of the patients obtained good function with their prosthesis. Additionally, we found that the functional outcome at discharge was maintained at the 1-year evaluation. This could be related to the additional services that are offered to all amputees in our district even after discharge, with access to the multidisciplinary team once a week and training. Most of these amputees made use of this opportunity, which we felt gave them confidence in functioning with a progressive vascular disease. This could be the explanation of the low re- and contralateral amputation rates in this elderly population of amputees.

Table 4. Days (mean) from amputation to casting and/or prosthetic fitting in different studies of trans-tibial (TT) amputees

Author	Levels included [a]	Days to casting	Days to prosthetic fitting
Fletcher et al., 2002	All		116
Pohjolainen et al., 1990	All		111
Laaperi et al., 1993	All		97
Hughes et al., 1998	TT		46 [b]
Wong and Edelstein, 2000	TT		34 [b]
Woodburn et al., 2004	TT	36 [b]	
Deutsch et al., 2005	TT	20 [b]	23 [b]

[a] All = TT and higher levels
[b] After introduction of the rigid dressing

Outcomes of prosthetic fitting in patients with PVD is highly related to the proportion of trans-tibial amputations to higher level amputations (Campbell et al. 1994). The fact is that elderly patients who have lost their anatomical knee joint are infrequently provided with prostheses (Fletcher et al. 2001) and if provided with one are only likely to achieve low functional mobility (Davies and Datta 2003).

As can be seen in Table 4, the number of days from amputation to prosthetic fitting, including all levels, varies in studies from 46 to 116 days (Pohjolainen et al. 1990, Fletcher et al. 2002, Hughes et al. 1998, Johannesson et al. 2004, Laaperi et al. 1993).

These results from Table 4 can be questioned in at least two ways. Firstly, are the differences in time to prosthetic fitting due to the introduction of a new dressing or can they be attributed to better communication within the professions involved? Communication between professions has been highlighted as a necessary element when conducting multidimensional studies (Deutsch et al. 2005). Secondly, are the outcome parameters of days to casting and days to fitting appropriate for assessing outcomes? Using time to casting as an outcome does not benefit the rehabilitation of an amputee, whereas time to prosthetic fitting indicates when

the amputee can start to use the prosthesis in rehabilitation.

Outcomes are however strongly related to the healing rate (Aulivola et al. 2004) and likewise the healing rate is correlated with the rate of prosthetic fitting (Fletcher et al. 2001), function with prosthesis, quality of life (the patients' expectancy (Asano et al. 2008)) and cost (Eneroth et al. 1996). The dilemma is that the definition of wound healing differs between studies and no consensus is yet to be reached (Smith et al. 2003).

Some authors recommend that the outcome of healing after LLA should be defined as intact skin for at least 6 months (Larsson et al. 2008). If the outcome is measured after 6 months with the above mentioned definition, rate of prosthetic fitting and function with prosthesis, it would provide much more relevant information than time to prosthetic fitting. This approach was used in **Papers III and IV**.

The prosthetic technology (ICEX) used in our treatment program is relatively new. The direct benefits, observed when testing this direct manufacturing technique, encouraged us to take it on as our standard practice and in doing so completely changed our approach toward making prosthetic sockets.

The outcome of using the ICEX socket system has been addressed in two randomized studies carried out on experienced amputees, who previously used a PTB system. In the first study, the additional cost of providing the new socket system and gait performance was analysed. According to the authors, routine provision of ICEX to unselected trans-tibial amputees was not recommended (Datta et al. 2004). In the second study, the material cost was found to be higher in the ICEX group, whereas the manufacturing time in the same group was lower (Selles et al. 2005). The authors suggested that it is not justifiable to change the socket system from PTB to TSB in experienced trans-tibial amputees. It is possible that the finding of no change in walking performance in the aforementioned studies could have been due to the fact that tissue loading and the redistribution of the pressure within the two socket systems is markedly different. In a PTB system, the soft tissue is adapted to accept load primarily on proximal structures whereas in the TSB socket the soft tissue is stabilized within the liner in a downward direction and pressure is concentrated on more distal structures. When switching from a PTB to a TSB socket it is subsequently likely that amputees would require a period of accommodation before any improvement can be verified (English et al. 1995). Since the conclusion of this study the ICEX system has been further developed. The new system, termed the Modular socket®, operates under the same basic principles of direct manufacture under pressure. However, the previously used resin carbon has now been replaced with glass fiber and rather than having the material pre-impregnated with resin, lamination is achieved by injecting the resin into material. This new system Modular socket® has now replaced the ICEX system. We have now used it for two years and it is our experience that the new socket has additional features; the socket is airtight, more durable, lighter and stronger. It is also our belief that the direct manufacturing process gives better service to our patients as the socket replacement needed due to volume changes (Figure 21) can be done within two hours.

Figure 21. Ten years between the amputations showing reduction of the soft tissue over longer period.

Prosthetic fitting has in the past not been recommended to be performed before the wound is fully healed. However, successful case-reports have indicated that this is possible in cases were higher level amputation and/or risk for contralateral amputation would be the option (Brunelli et al. 2008, Johannesson, 2008). The low rate of re-amputation presented in our study can be related to the early prosthetic fitting, were amputees with delayed wound healing have also been provided

Figure 22. Trans-tibal amputation in an 82 year old patient amputated in 2003, were the wound opened up after the removal of the sutures. Picture taken the day before the patients was fitted with prosthesis

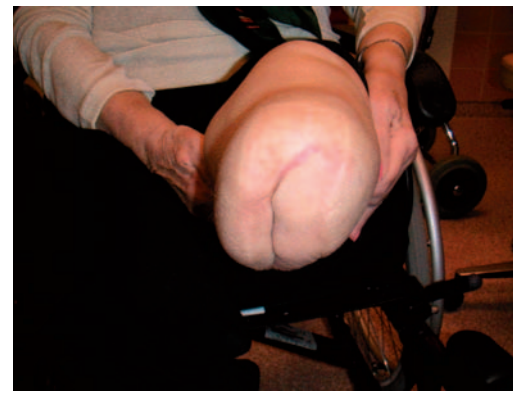

Figure 23. Picture taken 3-months later. The patient had a wound on the opposite heel that healed when she was able to enhance the circulation by walking. The patient did not require any further amputation and was still alive 5 years later.

with prosthesis (Figure 22) and mobilized with successful outcome (Figure 23).

The median cost of providing prostheses to elderly dysvascular patients has been calculated for 71 patients in Sweden and estimated to be 4359 USD per patient (2008 prices) during an 8-year period including maintenance. The mean cost of hospital stay and surgery in the same part of Sweden was found to be 74 203 USD (2008 prices) (Eneroth et al. 1996). The cost of the prosthesis corresponded to 6% of the total cost of hospitalization and surgery (Hermodsson and Persson 1998).

Conclusions

- In the general population aged 45 years or older, the incidence of vascular lower limb amputation at or proximal to the transmetatarsal level is 8 times higher in diabetic persons than in nondiabetic persons. One in four amputees may require a contralateral amputation and/or re-amputation. Almost half of these patients died during the first year after initial amputation. When adjusted for age and gender no difference was found between diabetic and nondiabetic patients.

- The Swedish version of the Locomotor Capabilities Index (LCI) demonstrated good reliability and validity in adult amputees but the high ceiling effect may imply that it would be most useful in assessing amputees with low or moderate functional abilities.

- The use of a vacuum-formed removable rigid dressing compared with conventional plaster of Paris rigid dressing after trans-tibial amputation showed that the two dressings appear to yield similar results regarding time to prosthetic fitting. No statistically significant differences regarding wound healing, functional outcome after 3 months, rate of socket changes during the first year or return to previous dwelling at 1 year were observed. An easily applicable and removable vacuum-formed rigid dressing can be favorably used as an alternative to conventional cast rigid dressing after trans-tibial amputation.

- Evaluation of a new surgical and rehabilitation strategy in initial unilateral trans-tibial amputation in patients with PVD demonstrated that more than half of all amputees can be fitted with a prosthesis after a median time of six weeks. Almost two-thirds of these patients can obtain good function 3 months after amputation. Among amputees who could walk before the amputation and were fitted with prosthesis no basline factors were found to be significantly associated with good function with prosthesis. The fitted patients can expect a median survival of approximately 3.5 years.

Future perspectives

Although lower limb amputations in patients with vascular disease are highly immobilizing, many of these patients can be rehabilitated to reach satisfactory levels of mobility with the use of prostheses and to continue to live independently. This group of patients is however highly affected by comorbidities such as heart failure and pulmonary disease making prediction of functional outcomes complicated. Studies of high quality and those that are randomized are few. This is also a costly group and the intervention taking place prior to the amputation, the amputation itself, and the outcome have not been addressed adequately, with regards to quality of life in these patients. Further studies are required to analyze this pathway not only regarding function and mobility but also in relation to quality of life and health economy which is a rising issue. Despite these needs, lack of financial resources either within traditional government funding or with the support of the industry restricts further possibilities for studies especially within the area of prosthetic fitting and functional outcomes.

Prostheses have been provided by different craftsmen for hundreds of years, though the profession has only been university educated since the beginning of the 1980's. More recently, practitioners in Sweden have been required to become certificated by the government to practice. Evaluation of the work provided by a prosthetist has seldom been questioned in the past. Today the costs have become an issue because of more sophisticated technology and products available and more evidence is required to demonstrate the cost-effectiveness of products and/or treatments. A first step that is needed is to provide clinicians with general tools or instruments that can be used in the daily clinical practice to collect data for non-randomized cohort studies. This is because randomized studies are often difficult to perform, especially in elderly dysvascular patients.

A future step in analyzing limb amputations is the work initiated by the Swedish section of the International Society of Prosthetics and Orthotics in building a database where lower limb amputation data can be stored by hospitals that are willing to participate. The database will not only record the level of amputation but also various other data including co-morbidity, days in-hospital, days to prosthetic fitting, the rate of prosthetic fitting, details of technique and outcome using validated instruments. This opportunity can lead to best practice benchmarking and gives a huge research possibility in a similar way to the Swedish Hip Arthroplasty Register (Karrholm et al. 2009). A similar database has been established in Scotland since 2002 and presents a national survey report for the period 2002–2006 including data from 690 amputees. The report, presented in May 2008, revealed substantial differences between hospitals in selection of amputation level and rate of prosthetic fitting.

Summary

The current prevalence of persons amputated at transmetatarsal level or higher in Sweden can be estimated to be between 5000 and 5500 persons (approx. 0.06 % of the population). The majority of these are patients with vascular disease (≈ 80%). In Sweden between 1000 and 1100 new amputees can be expected every year. Less than 5% of all amputations will be related to causes other than vascular disease.

Lower limb amputation (LLA) in patients with vascular disease may not only be a highly disabling surgical procedure but also costly in hospital management. The incidence differs between countries due to age structure of the population, prevalence of vascular disease and the prevalence of diabetes. In **Paper I** we prospectively evaluated LLA performed at transmetatarsal level or higher during 10 years. The overall incidence of initial unilateral amputation in the diabetic population was eight times higher compared with that in the nondiabetic population (195 vs. 23 per 100,000 person-years). The incidence of contralateral amputation among diabetic amputees was 17 and among the nondiabetic amputees 13 per 100 amputee-years. The most frequent contralateral amputation level among the diabetic and nondiabetic patients was trans-tibial. The incidence of re-amputation among the diabetic amputees was 19 and among the nondiabetic amputees 14 per 100 amputee-years. The most frequent re-amputation level among diabetic patients was trans-tibial and among nondiabetic patients was trans-femoral.

The 1-year mortality rate, adjusted for age and gender, did not differ significantly between the two groups.

In **Paper II** we introduce a Swedish version of the Locomotor Capabilities Index (LCI) outcome instrument and evaluate its reliability and validity. Following the process of translation and cultural adaptation, the Swedish version of the LCI was found to be reliable and valid instrument that can provide a standardized measure of amputee-centered outcomes. The high ceiling effect of the LCI may imply that it would be most useful in assessing amputees with low to moderate function abilities.

In **Paper III** we tested two different dressings after trans-tibial amputation, the conventional rigid dressing of plaster of Paris and a new vacuum-formed removable rigid dressing. The primary outcome measure was time to prosthetic fitting while the secondary outcomes included function with the prosthesis 3 months after amputation measured with the LCI and the Timed "Up and Go" (TUG) test. Twenty-seven consecutive patients were included and prosthetic fitting was achieved in 23 patients (mean age 76 years). The same postoperative treatment and rehabilitation was applied in both groups. To minimize the possible influence of using different types of prostheses in measuring functional outcome ICEX prosthetic sockets were used in all patients. The new vacuum-formed removable rigid dressing appear to yield similar results regarding wound healing, time to prosthetic fitting and function, rate of socket changes during the first year or return to previous dwelling when compared with conventional plaster of Paris rigid dressing.

In **Paper IV** we prospectively evaluated the outcome of a standardized surgical and rehabilitation program in trans-tibial amputation in a large consecutive and population-based series of 219 patients. We analyzed the outcome regarding rate of prosthetic fitting, walking ability and mortality. A circular, plaster of Paris rigid dressing was applied by the surgeon in the operating room. This rigid dressing was removed after 5 to 7 days and compression treatment with a silicone liner was started. Ambulation with an ischial weight bearing training prosthesis was started when the plaster of Paris dressing was removed, with no load on the residual limb. A prosthetic socket that is cast and made directly on the residual limb using pressure casting technique, resulting in a definitive socket was used. Functioning was defined as good if the patient wore the prosthesis daily and was able to walk alone or with assistance outdoors or alone indoors. Functioning was defined as poor

if the patient did not wear the prosthesis daily and was unable to walk indoors without assistance or used a wheelchair most or all the time or did not receive prosthesis. All prostheses were produced and delivered on the same visit to the prosthetic workshop. More than half of all amputees could be fitted with a prosthesis after a median time of six weeks and almost two-thirds of these have good function 3 months after amputation and the functional status remained unchanged at 1 year. Of the patients who could walk with or without an aid prior to the amputation and who survived at least 90 days after amputation, more than 80% could be provided with a prosthesis with 68% achieving good function. These patients can expect a median survival of approximately 3.5 years.

Summary in Swedish – Sammanfattning på svenska

Antalet personer som är amputerade ovanför tålederna i Sverige kan uppskattas till mellan 5000 och 5500. (ca 0.06 % av befolkningen). Största delen av dessa är amputerade pg.a. av kärlsjukdom (≈ 80 %). Antalet årligen nytillkomna benamputerade i Sverige kan uppskattas till mellan 1000–1100 och mindre än 5 % av dessa fall är relaterade till andra orsaker, t.ex. trauma eller cancer.

Benamputationer utförda på kärlsjuka patienter är inte enbart kritiska ur mobilitetssynpunkt utan är också slutskedet på ett sjukdomsförlopp ofta relaterat till smärta, depression och ångest för patienten och en hög kostnad för samhället. Benamputationers orsak och antal skiljer sig mellan och inom länder p.g.a. åldersfördelning, antal individer som lider av kärlsjukdom och hur stor andel av dess som är diabetiker. Under 10 års tid registrerades alla de patienter bosatta i Nordöstra Skånes sjukvårdsdistrikt som amputerades ovanför tålederna p.g.a. kärlsjukdom. I **delarbete I** sammanställs resultaten för beräkning av incidens och dödlighet hos de 290 patienter som genomgick amputation. Patienterna följdes under 1 till 11 år. Ålder, kön, diagnos samt sida och nivå för amputationen registrerades och definierades som initial amputation (d.v.s. första amputationen), kontralateral amputation (d.v.s. första amputation på andra benet) och som re-amputation (d.v.s. ny amputation om den förra inte läkte eller p.g.a. ytterligare försämrad blodcirkulation). Årlig incidens av kärlsjukdomsrelaterade amputationer uppskattades för diabetiker och icke-diabetiker för populationen äldre än 45 år. Under perioden genomgick 133 diabetiker (53 % män) och 157 icke-diabetiker (50 % män) sin första amputation.

Den generella incidensen av initial amputation hos diabetiker var åtta gånger högre än hos icke-diabetiker, 195 jämfört med 23 per 100,000 personer/år. Den vanligaste nivån var underbensnivån (transtibial) som utgjorde 75 % av alla initiala amputationer. Incidensen av amputationer på andra benet hos amputerade diabetiker var 17 per 100 amputerade/år jämfört med 13 hos icke-diabetiker. Den vanligaste amputationsnivån på det andra benet hos både diabetiker och icke-diabetiker var också transtibial. Incidensen av re-amputationer hos amputerade diabetiker var 19 per 100 amputerade/år jämfört med 14 hos icke-diabetiker. Den vanligaste re-amputationsnivån hos diabetiker var underbensnivå till skillnad från lårbensnivå hos icke-diabetiker. Ettårsdödlighet visade ingen skillnad mellan diabetiker och icke-diabetiker när man justerat för ålder och könsskillnader.

I **delarbete II** presenterar vi den svenska versionen av funktionsmätinstrumentet Locomotor Capabilities Index (LCI) som är ett frågeformulär. LCI utvärderades för reliabilitet (reproducerbarhet) och validitet. Den svenska versionen av LCI som översatts och kulturellt anpassats visades vara reliabel och valid, framför allt hos äldre amputerade med låg eller medelhög aktivitetsnivå. Därmed skulle LCI kunna fungera som det första utvärderingsinstrument (frågeformulär) för benamputerade i Sverige som också kan användas vid internationella jämförelser.

I **delarbete III** jämförs två olika förband som används direkt efter underbensamputation. Det traditionella cirkulära gipsförbandet (CRD) och ett nytt vakuumformat förband (ORD®) som lätt kan justeras och om nödvändigt tvättas och återplaceras. Utfallsvariabler som analyserades var andel läkta sår, tid till protesförsörjning, funktion med protes (där två mätinstrument, ett subjektivt (LCI) och ett objektivt (Timed ”Up and Go”), användes), antal hylsbyten under första året samt möjlighet att återgå till sitt tidigare boende. Totalt inkluderades 27 patienter, varav alla var amputerade p.g.a. kärlsjukdom och accepterade att delta i studien. Protesförsörjning lyckades i 23 fall (14 män, medelålder 76 år (43–91)). Samma efterbehandling och rehabilitering användes i båda grupperna. För att minska påverkan av proteshylsformen vid funktionstest användes ICEX-hylsteknik på alla amputerade. Det nya förbandet (ORD) verkar ge samma resultat gällande sårläkning, tid till protesförsörjning, antal hylsbyten första året och möjlighet att återgå till sitt tidigare boende jämfört med det traditionella förbandet (CRD).

I **delarbete IV** undersöktes utfallet av en ny behandlingsstrategi vid underbensamputation på 219 patienter. Vid denna behandling användes som standard sagitellt snitt och stelt förband i 5–7 dagar. Detta efterföljdes av kompressionsbehandling med silikonhylsa. Träning med tuberstödjande protes användes under rehabiliteringsfasen så snart gipset tagits bort, men utan att lägga belastning på underbenet. Ny teknik vid hylstillverkning, ICEX, som bygger på att tillverka och leverera en träningsfärdig protes vid ett och samma besök, användes. Gångförmågan före insjuknandet bedömdes. Vid utskrivning från rehabilitering bedömdes gångförmågan med protes. Gångfunktionen bedömdes som god om den amputerade kunde använda protesen dagligen och gå utan stöd inomhus eller med stöd utomhus. Gångfunktionen bedömdes som dålig om den amputerade inte använde protesen dagligen, inte kunde gå utan stöd inomhus eller använde rullstol större delen av tiden. I denna grupp ingick också de patienter som inte fick protes.

Alla proteserna gick att tillverka och leverera vid första besöket. Mer än hälften (55 %) av alla underbensamputerade fick protes, i genomsnitt 41 dagar efter amputationen. Närmare två tredjedelar uppnådde god funktion med protes vid utskrivning från rehabilitering. Av de patienter som bedömdes ha god gångförmåga före amputationen och som överlevde mer än 90 dagar efter amputationen fick 80 % protes och 68 % uppfyllde kriterierna för god funktion med protes. Dessa patienters överlevnadstid var i genomsnitt tre och ett halvt år.

Acknowledgments

Many people deserve thanks for their involvement in this project. In particular:

All patients: for your participation in the studies – for undergoing the tests and answering all the questions.

All **professionals** at the "Walking Schools" in Hässleholm and Kristianstad: It has been a privilege to be a part of your team in initiating, implementing and developing services for these patients.

Isam Atroshi, my supervisor, **Nerrolyn Ramstrand** and **Henrik Lauge-Pedersen** my co-advisers. It has been a privilege to work with you all. With your different personalities and specialities you have been a perfect team. **Isam**, for sharing his great knowledge in the field of research and for always making the complicated simple. **Nerrolyn**, for your enthusiasm and the insight in to prosthetics research. **Henrik**, for being there when I needed help. I thank you all, expecially for your efficency!

Gert-Uno Larsson, Brita Larsson (and family), my co-authors. Without your friendship, support and guidance, and of course the English and Swedish corrections I would never have reached this far.

Hilmar B. Janusson and **Guđjon Kárason**, for your enthusiastic and visionary personality. Without your support this work would never have been initiated or finished.

Anders Wallin and **Bo Lindberg** for your frendship and support throughout the years.

My Colleagues at **Ortopedteknik AB** for helping me out, one way or the other.

Peder Vibe, Helen Brown, Eyđor Bender, Catarina Mård Löwenadler, Gunnar Helgesson, Finn and Lisa Gramnäs, Johan Snyder, Alfonso Diaz, Kerstin Hagberg, Magnus Lilja, Yvonne and **Fredrik Meyer** for your friendship and support throughout the years.

Ferdinad Róbert Eríksson for bringing me into the field of O&P.

Ulf Strömberg, Philippe Wagner and **Aleksandra Turkiewicz** my statistical advisers.

Kaj Knutson for the layout.

Friends and family, for your support. Most of all my wife **Gitte**, and children **André, Elin, Frida** and **Julia**, who may have suffered from neglect throughout these years. You are what really matters!

In Memoriam: My former supervisor **Tommy Öberg** for leading me in to the field of research.

The project was supported by research grant from Össur hf (Reykjavik, Iceland), Ortopedteknik AB, Hässleholm Hospital Research and Developing unit (FoU), Stiftelsen för bistånd åt rörelsehindrade i Skåne, Region Skåne and the Faculty of Medicine, Lund University.

Appendix

Swedish version of LCI

LOCOMOTOR CAPABILITIES INDEX
Funktionsindex för benamputerade

Namn .....
Personnummer .....
Amputationsnivå .....
Datum .....

Även om Du inte använder Din protes just nu, hur uppfattar Du Din förmåga att utföra följande aktiviteter med protesen på?
(Personlig intervju)

Skala:

0 = nej	1 = ja, med hjälp av annan person	2 = ja, med tillsyn	3 = ja, självständigt

Ringa in en siffra för varje påstående.

GRUNDLÄGGANDE AKTIVITETER	**SKALA**			
1. Resa Dig från en stol	0	1	2	3
2. Gå inomhus	0	1	2	3
3. Gå utomhus på jämn mark	0	1	2	3
4. Gå uppför en trappa med hjälp av ledstång	0	1	2	3
5. Gå nerför en trappa med hjälp av ledstång	0	1	2	3
6. Kliva uppför en trottoarkant	0	1	2	3
7. Kliva nerför en trottarkant	0	1	2	3
Poängsumma	**/21**			
KRÄVANDE AKTIVITETER				
1. Plocka upp ett föremål från golvet (när Du står med Din protes på)	0	1	2	3
2. Resa Dig upp från golvet (t ex om Du fallit)	0	1	2	3
3. Gå utomhus på ojämn mark (t ex gräs, grus eller i sluttning)	0	1	2	3
4. Gå utomhus i dåligt väder (t ex snö, regn eller halka)	0	1	2	3
5. Gå uppför några trappsteg utan hjälp av ledstång	0	1	2	3
6. Gå nerför några trappsteg utan hjälp av ledstång	0	1	2	3
7. Gå och samtidigt bära ett föremål	0	1	2	3
Poängsumma	**/21**			
Total poängsumma	**/42**			

© Gautire-Gagnon & Grisé, 1993

References

Almaraz M C, Soriguer F, Zamorano D, Ruiz de A S, Gonzalez E, Esteva I, Garcia J, Lopez M J. [Incidence of amputation of the lower extremities in the population with diabetes mellitus in Malaga (1996-1997)]. Aten Primaria 2000; 26(10): 677-680.

Armstrong D G, Lavery L A, Harkless L B, van Houtum W H. Amputation and reamputation of the diabetic foot. J Am Podiatr Med Assoc 1997; 87(6): 255-259.

Asano M, Rushton P, Miller W C, Deathe B A. Predictors of quality of life among individuals who have a lower limb amputation. Prosthet Orthot Int 2008; 32(2): 231-243.

Aulivola B, Hile C N, Hamdan A D, Sheahan M G, Veraldi J R, Skillman J J, Campbell D R, Scovell S D, LoGerfo F W, Pomposelli F B, Jr. Major lower extremity amputation: outcome of a modern series. Arch Surg 2004; 139(4): 395-399.

Baars E C, Dijkstra P U, Geertzen J H. Skin problems of the stump and hand function in lower limb amputees: A historic cohort study. Prosthet Orthot Int 2008; 32(2): 179-185.

Baker W H, Barnes R W, Shurr D G. The healing of below-knee amputations: a comparison of soft and plaster dressing. Am J Surg 1977; 133(6): 716-718.

Barber G G, McPhail N V, Scobie T K, Brennan M C, Ellis C C. A prospective study of lower limb amputations. Can J Surg 1983; 26(4): 339-341.

Baumgartner R, Botta P. Amputation und Prothesenversorgung der unteren extremität: indikationsstellung, operative technik, nachbehandlung, prothesenversorgung, gangschulung, rehabilitation. Stuttgart: Ferdinand Enke; 1995.

Beaton D E, Bombardier C, Guillemin F, Ferraz M B. Guidelines for the process of cross-cultural adaptation of self-report measures. Spine 2000; 25(24): 3186-3191.

Beaton D E, Schemitsch E. Measures of health-related quality of life and physical function. Clin Orthop Relat Res 2003; (413): 90-105.

Beil T L, Street G M, Covey S J. Interface pressures during ambulation using suction and vacuum-assisted prosthetic sockets. J Rehabil Res Dev 2002; 39(6): 693-700.

Berger B, Stenstrom G, Chang Y F, Sundkvist G. The prevalence of diabetes in a Swedish population of 280,411 inhabitants. A report from the Skaraborg Diabetes Registry. Diabetes Care 1998; 21(4): 546-548.

Bowker J H, Michael J W, American Academy of Orthopaedic Surgeons. Atlas of limb prosthetics: surgical, prosthetic, and rehabilitation principles. Mosby Year Book, St. Louis 1992.

Brunelli S, Averna T, Porcacchia P, Traballesi M. Vacuum assisted socket system in below-knee amputees: clinical reports. 2008. Leipzig, Germany, ORTHOPÄDIE+REHA-TECHNIK.

Brunner U, Eberlein T. Experiences with hydrofibres in the moist treatment of chronic wounds, in particular of diabetic foot. Vasa 2000; 29(4): 253-257.

Burgess E M, Marsden F W. Major lower extremity amputations following arterial reconstruction. Arch Surg 1974; 108(5): 655-660.

Calle-Pascual A L, Garcia-Torre N, Moraga I, Diaz J A, Duran A, Monux G, Serrano F J, Martin-Alvarez P J, Charro A, Maranes J P. Epidemiology of nontraumatic lower-extremity amputation in area 7, Madrid, between 1989 and 1999: a population-based study. Diabetes Care 2001; 24(9): 1686-1689.

Campbell W B, St Johnston J A, Kernick V F, Rutter E A. Lower limb amputation: striking the balance. Ann R Coll Surg Engl 1994; 76(3): 205-209.

CDC. Diabetes: Disabling Disease to Double by 2050. Centers for Disease Control and Prevention; 2008. Available from: http://www.cdc.gov/diabetes/statistics/prev/national/figpersons.htm

Choudhury S R, Reiber G E, Pecoraro J A, Czerniecki J M, Smith D G, Sangeorzan B J. Postoperative management of transtibial amputations in VA hospitals. J Rehabil Res Dev 2001; 38(3): 293-298.

Christensen S. Lower extremity amputations in the county of Aalborg 1961-1971. Population study and follow-up. Acta Orthop Scand 1976; 47(3): 329-334.

Cohen S I, Goldman L D, Salzman E W, Glotzer D J. The deleterious effect of immediate postoperative prothesis in below-knee amputation for ischemic disease. Surgery 1974; 76(6): 992-1001.

Condie E, Scott H, Treweek S. Lower Limb Prosthetic Outcome Measures: A Review of the Literature 1995 to 2005. J Prosthet Orthot 18[1S], 13-45. 2007.

Convery P, Buis A W. Conventional patellar-tendon-bearing (PTB) socket/stump interface dynamic pressure distributions recorded during the prosthetic stance phase of gait of a trans-tibial amputee. Prosthet Orthot Int 1998; 22(3): 193-198.

Convery P, Buis A W. Socket/stump interface dynamic pressure distributions recorded during the prosthetic stance phase of gait of a trans-tibial amputee wearing a hydrocast socket. Prosthet Orthot Int 1999; 23(2): 107-112.

Convery P, Buis A W, Wilkie R, Sockalingam S, Blair A, McHugh B. Measurement of the consistency of patellar-tendon-bearing cast rectification. Prosthet Orthot Int 2003; 27(3): 207-213.

Cowie C C, Rust K F, Byrd-Holt D D, Eberhardt M S, Flegal K M, Engelgau M M, Saydah S H, Williams D E, Geiss L S, Gregg E W. Prevalence of diabetes and impaired fasting glucose in adults in the U.S. population: National Health And Nutrition Examination Survey 1999-2002. Diabetes Care 2006; 29(6): 1263-1268.

Cutson T M, Bongiorni D R. Rehabilitation of the older lower limb amputee: a brief review. J Am Geriatr Soc 1996; 44(11): 1388-1393.

Datta D, Harris I, Heller B, Howitt J, Martin R. Gait, cost and time implications for changing from PTB to ICEX sockets. Prosthet Orthot Int 2004; 28(2): 115-120.

Davies B, Datta D. Mobility outcome following unilateral lower limb amputation. Prosthet Orthot Int 2003; 27(3): 186-190.

Deutsch A, English R D, Vermeer T C, Murray P S, Condous M. Removable rigid dressings versus soft dressings: a randomized, controlled study with dysvascular, trans-tibial amputees. Prosthet Orthot Int 2005; 29(2): 193-200.

Dillingham T R, Pezzin L E. Rehabilitation setting and associated mortality and medical stability among persons with amputations. Arch Phys Med Rehabil 2008; 89(6): 1038-1045.

Dormandy J, Belcher G, Broos P, Eikelboom B, Laszlo G, Konrad P, Moggi L, Mueller U. Prospective study of 713 below-knee amputations for ischaemia and the effect of a prostacyclin analogue on healing. Hawaii Study Group. Br J Surg 1994; 81(1): 33-37.

Earle J. Experiences in using Post-Op Silicone liners with Transtibial Amputees. World Congress of the International Society for Prosthetics and Orthotics. Post-operative care in lower limb amputees, 423. 2007.

Ebskov B. Relative mortality and long term survival for the non-diabetic lower limb amputee with vascular insufficiency. Prosthet Orthot Int 1999; 23(3): 209-216.

Ebskov B, Josephsen P. Incidence of reamputation and death after gangrene of the lower extremity. Prosthet Orthot Int 1980; 4(2): 77-80.

Eliasson M, Bostrom G. Chapter 5.2: major public health problems - diabetes. Scand J Public Health Suppl 2006; 67: 59-68.

Emmelot C H, Geertzen J H. Letter to the editor. Prosthet Orthot Int 2006; 30(1): 102-103.

Eneroth M. Amputation for vascular disease: Prognostic factors for healing, long term outcome and costs [dissertation]. Lund University, Department of Orthopedics, Lund Univeristy Hospital, Sweden; 1997.

Eneroth M, Apelqvist J, Larsson J, Persson B M. Improved wound healing in transtibial amputees receiving supplementary nutrition. Int Orthop 1997; 21(2): 104-108.

Eneroth M, Apelqvist J, Troeng T, Persson B M. Operations, total hospital stay and costs of critical leg ischemia. A population-based longitudinal outcome study of 321 patients. Acta Orthop Scand 1996; 67(5): 459-465.

Eneroth M, Persson B M. Amputation for occlusive arterial disease. A prospective multicentre study of 177 amputees. Int Orthop 1992; 16(4): 383-387.

English R D, Hubbard W A, McElroy G K. Establishment of consistent gait after fitting of new components. J Rehabil Res Dev 1995; 32(1): 32-35.

Ephraim P L, Dillingham T R, Sector M, Pezzin L E, MacKenzie E J. Epidemiology of limb loss and congenital limb deficiency: a review of the literature. Arch Phys Med Rehabil 2003; 84(5): 747-761.

Eskelinen E, Eskelinen A, Alback A, Lepantalo M. Major amputation incidence decreases both in non-diabetic and in diabetic patients in Helsinki. Scand J Surg 2006; 95(3): 185-189.

Falstie-Jensen N, Christensen K S, Brochner-Mortensen J. Long posterior flap versus equal sagittal flaps in below-knee amputation for ischaemia. J Bone Joint Surg Br 1989; 71(1): 102-104.

Feinglass J, Rucker-Whitaker C, Lindquist L, McCarthy W J, Pearce W H. Racial differences in primary and repeat lower extremity amputation: results from a multihospital study. J Vasc Surg 2005; 41(5): 823-829.

Fine J P, Gray R J. A proportional hazards model for the subdistribution of a competing risk. J Am Stat Assoc 1999; 94: 496-509.

Fletcher D D, Andrews K L, Butters M A, Jacobsen S J, Rowland C M, Hallett J W, Jr. Rehabilitation of the geriatric vascular amputee patient: a population-based study. Arch Phys Med Rehabil 2001; 82(6): 776-779.

Fletcher D D, Andrews K L, Hallett J W, Jr., Butters M A, Rowland C M, Jacobsen S J. Trends in rehabilitation after amputation for geriatric patients with vascular disease: implications for future health resource allocation. Arch Phys Med Rehabil 2002; 83(10): 1389-1393.

Fothergil I, Gruben K. Transtibial Pressure Casting With ICECAST® Anatomy. Journal of Proceedings 2007. http://www.oandp.org/publications/jop/2007/2007-42.asp

Franchignoni F, Orlandini D, Ferriero G, Moscato T A. Reliability, validity, and responsiveness of the locomotor capabilities index in adults with lower-limb amputation undergoing prosthetic training. Arch Phys Med Rehabil 2004; 85(5): 743-748.

Gauthier-Gagnon C, Grise M C. Prosthetic profile of the amputee questionnaire: validity and reliability. Arch Phys Med Rehabil 1994; 75(12): 1309-1314.

Gauthier-Gagnon C, Grise MC. Tools for outcome measurments in lower limb amputee rehabilitation. 10th World Congress of the International Society for Prosthetic and Ortothics. Glasgow, Scotland, Institute de Readaption de Montreal, Quebec, Canada; 2001.

Gauthier-Gagnon C, Grise M C. Tools to measure outcome of people with lower limb amputation; Update on the PPA and LCI. J Prosthet Orthot 2006; 18(1S): 61-69.

Gauthier-Gagnon C, Grise M C, Lepage Y. The Locomotor Capabilities Index: content validity. J Rehabil Outcomes Measurement 1998;(2): 20-46.

Geertzen J H, Emmelot K. Letter to the editor. Prosthet Orthot Int 2004; 28: 192.

Global Lower Extremity Amputation Study Group. Epidemiology of lower extremity amputation in centres in Europe, North America and East Asia. The Global Lower Extremity Amputation Study Group. Br J Surg 2000; 87(3): 328-337.

Guyton A C, Hall J E, Montani J P. The Body Fluid Compartments: Extracellular and Intracellular Fluids; Interstitial Fluid and Edema. In: Medical Physiology. (Eds. Guyton AC, Hall JE). Jackson, Mississippi, Elsevier and Saunders; 2006; 11: p. 291-306.

Hachisuka K, Nakamura T, Ohmine S, Shitama H, Shinkoda K. Hygiene problems of residual limb and silicone liners in transtibial amputees wearing the total surface bearing socket. Arch Phys Med Rehabil 2001; 82(9): 1286-1290.

Hagberg K, Haggstrom E, Branemark R. Physiological cost index (PCI) and walking performance in individuals with transfemoral prostheses compared to healthy controls. Disabil Rehabil 2007; 29(8): 643-649.

Harrison B J, Silman A J, Hider S L, Herrick A L. Cigarette smoking as a significant risk factor for digital vascular disease in patients with systemic sclerosis. Arthritis Rheum 2002; 46(12): 3312-3316.

Heikkinen M, Saarinen J, Suominen V P, Virkkunen J, Salenius J. Lower limb amputations: differences between the genders and long-term survival. Prosthet Orthot Int 2007; 31(3): 277-286.

Hermodsson Y, Persson B M. Cost of prostheses in patients with unilateral transtibial amputation for vascular disease. A population-based follow-up during 8 years of 112 patients. Acta Orthop Scand 1998; 69(6): 603-607.

Hierton T, James U. Lower extremity amputation in Uppsala county 1947-1969. Incidence and prosthetic rehabilitation. Acta Orthop Scand 1973; 44(4): 573-582.

Holstein P, Ellitsgaard N, Olsen B B, Ellitsgaard V. Decreasing incidence of major amputations in people with diabetes. Diabetologia 2000; 43(7): 844-847.

Horne G, Abramowicz J. The management of healing problems in the dysvascular amputee. Prosthet Orthot Int 1982; 6(1): 38-40.

Hughes S, Ni S, Wilson S. Use of removable rigid dressing for transtibial amputees rehabilitation: A Greenwich Hospital experience. Aust J Physiother 1998; 44(2): 135-137.

Isherwood P A, Robertson J C, Rossi A. Pressure measurements beneath below-knee amputation stump bandages: elastic bandaging, the Puddifoot dressing and a pneumatic bandaging technique compared. Br J Surg 1975; 62(12): 982-986.

ISO. ISO: International Standards for Business, Government and Society, TC 168; 2009. Available from: http://www.iso.org/iso/standards_development/technical_committees/list_of_iso_technical_committees/iso_technical_committee.htm?commid=53630

Isozaki K, Hosoda M, Masuda T, Morita S. CAD/CAM evaluation of the fit of trans-tibial sockets for trans-tibial amputation stumps. J Med Dent Sci 2006; 53(1): 51-56.

Jeffcoate W J. The incidence of amputation in diabetes. Acta Chir Belg 2005; 105(2): 140-144.

Johannesson A, Larsson G U, Oberg T. From major amputation to prosthetic outcome: a prospective study of 190 patients in a defined population. Prosthet Orthot Int 2004; 28(1): 9-21.

Johannesson A. Bilateral transtibial amputation and delayed wound healing in patient with peripheral vascular disease: walking with prosthesis or re-amputation? 2008. American Academy of Orthotists and Prosthetist

Jones L E. Lower limb amputation in three Australian states. Int Disabil Stud 1990; 12(1): 37-40.

Kahle J T. Conventional and Hydrostatic Transtibial Interface Comparison. J Prosthet Orthot 1999; 11(4): 85-91.

Kald A, Carlsson R, Nilsson E. Major amputation in a defined population: incidence, mortality and results of treatment. Br J Surg 1989; 76(3): 308-310.

Kannon G A, Garrett A B. Moist wound healing with occlusive dressings. A clinical review. Dermatol Surg 1995; 21(7): 583-590.

Kapelrud H. [Lower-limb amputations and diabetes]. Tidsskr Nor Laegeforen 2006; 126(17): 2261-2263.

Karrholm J, Garellick G, Herberts P. The Swedish National Hip Arthroplasty Register; 2009. Available from: http://www.jru.orthop.gu.se/

Kimura H, Nakanishi T, Nagatomi A, Ochi M. A new rehabilitation method for a transtibial amputation due to ischemic lower limb disease. 12th World Congress of the International Society for Prosthetics and Orthotics; 2007. p. 232.

Kirkup J. Introduction and Sources and Natural Causes of Dismemberment. In: A history of limb amputation. Springer; 2007. p. 12.

Kostuik J P, Gillespie R. Amputation Surgery and Rehabilitation. Churchill Livingstone; 1981.

Krishnan S, Nash F, Baker N, Fowler D, Rayman G. Reduction in diabetic amputations over 11 years in a defined U.K. population: benefits of multidisciplinary team work and continuous prospective audit. Diabetes Care 2008; 31(1): 99-101.

Kristinsson O. The ICEROSS concept: a discussion of a philosophy. Prosthet Orthot Int 1993; 17(1): 49-55.

Laaperi T, Pohjolainen T, Alaranta H, Karkkainen M. Lower-limb amputations. Ann Chir Gynaecol 1993; 82(3): 183-187.

Larsson J, Apelqvist J, Agardh C D, Stenstrom A. Decreasing incidence of major amputation in diabetic patients: a consequence of a multidisciplinary foot care team approach? Diabet Med 1995; 12(9): 770-776.

Larsson J, Eneroth M, Apelqvist J, Stenstrom A. Sustained reduction in major amputations in diabetic patients: 628 amputations in 461 patients in a defined population over a 20-year period. Acta Orthop 2008; 79(5): 665-673.

Larsson P A, Risberg B. Amputations due to lower-limb ischemia. Analysis of a 3-year series. Acta Chir Scand 1988; 154(4): 267-270.

Lavery L A, van Houtum W H, Ashry H R, Armstrong D G, Pugh J A. Diabetes-related lower-extremity amputations disproportionately affect Blacks and Mexican Americans. South Med J 1999; 92(6): 593-599.

Liedberg E, Persson B M. Increased incidence of lower limb amputation for arterial occlusive disease. Acta Orthop Scand 1983; 54(2): 230-234.

Lusardi M M, Nielsen C C. Transtibial Prosthesis. In: Orthotics and Prosthetic in Rehabilitation. Butterworth-Heinemann, Woburn, 2000; 1: 438-439.

Lusardi M M, Owens L L F. Postoperative and Preoperative Care. In: Orthotics and Prosthetics in Rehabilitation. (Eds. Lusardi M M, Nilsen C C). Woburn, Butterworth-Heinemann; 2000. p. 402-405.

Lyot C. Traite de Chirugie. Bailliére, Paris 1896.

Malanin K, Kolari P J, Havu V K. The role of low resistance blood flow pathways in the pathogenesis and healing of venous leg ulcers. Acta Derm Venereol 1999; 79(2): 156-160.

Mandrup-Poulsen T, Jensen J S. Incidence of major amputations following gangrene of the lower limb. Prosthet Orthot Int 1982; 6(1): 35-37.

McCollum P T, Spence V A, Walker W F. Amputation for peripheral vascular disease: the case for level selection. Br J Surg 1988; 75(12): 1193-1195.

McGarry T, McHugh B. Evaluation of a contemporary CAD/CAM system. Prosthet Orthot Int 2005; 29(3): 221-229.

Mooney V, Harvey J P, Jr., McBride E, Snelson R. Comparison of postoperative stump management: plaster vs. soft dressings. J Bone Joint Surg Am 1971; 53(2): 241-249.

Morris A D, Boyle D I, MacAlpine R, Emslie-Smith A, Jung R T, Newton R W, MacDonald T M. The diabetes audit and research in Tayside Scotland (DARTS) study: electronic record linkage to create a diabetes register. DARTS/MEMO Collaboration. BMJ 1997; 315(7107): 524-528.

Morris A D, McAlpine R, Steinke D, Boyle D I, Ebrahim A R, Vasudev N, Stewart C P, Jung R T, Leese G P, MacDonald T M, Newton R W. Diabetes and lower-limb amputations in the community. A retrospective cohort study. DARTS/MEMO Collaboration. Diabetes Audit and Research in Tayside Scotland/Medicines Monitoring Unit. Diabetes Care 1998; 21(5): 738-743.

Narita H, Yokogushi K, Shii S, Kakizawa M, Nosaka T. Suspension effect and dynamic evaluation of the total surface bearing (TSB) trans-tibial prosthesis: a comparison with the patellar tendon bearing (PTB) trans-tibial prosthesis. Prosthet Orthot Int 1997; 21(3): 175-178.

National Center for Chronic Disease Prevention and Health Promotion Division of Diabetes Translation. Number of Persons with Diagnosed Diabetes, United States, 1980-2005. Centers for Disease Control and Prevention [serial online] 2008. Available from: http://www.cdc.gov/diabetes/statistics/prev/national/figpersons.htm.

Nawijn S E, van der Linde H, Emmelot C H, Hofstad C J. Stump management after trans-tibial amputation: a systematic review. Prosthet Orthot Int 2005; 29(1): 13-26.

Nehler M R, Coll J R, Hiatt W R, Regensteiner J G, Schnickel G T, Klenke W A, Strecker P K, Anderson M W, Jones D N, Whitehill T A, Moskowitz S, Krupski W C. Functional outcome in a contemporary series of major lower extremity amputations. J Vasc Surg 2003; 38(1): 7-14.

Newton K M, Wagner E H, Ramsey S D, McCulloch D, Evans R, Sandhu N, Davis C. The use of automated data to identify complications and comorbidities of diabetes: a validation study. J Clin Epidemiol 1999; 52(3): 199-207.

Nicholas G G, DeMuth W E, Jr. Evaluation of use of the rigid dressing in amputation of the lower extremity. Surg Gynecol Obstet 1976; 143(3): 398-400.

Persson B. Lower limb amputation. Part 1: Amputation methods--a 10 year literature review. Prosthet Orthot Int 2001; 25(1): 7-13.

Persson B M. Sagittal incision for below-knee amputation in ischaemic gangrene. J Bone Joint Surg Br 1974; 56(1): 110-114.

Persson B M, Bereiter H, Liedberg E. Lower leg amputation with sagittal section in vascular diseases--a study of 692 patients. Beitr Orthop Traumatol 1981; 28(12): 656-663.

Persson B M, Liedberg E. A clinical standard of stump measurement and classification in lower limb amputees. Prosthet Orthot Int 1983; 7(1): 17-24.

Pinzur M S, Gottschalk F A, Pinto M A, Smith D G. Controversies in lower-extremity amputation. J Bone Joint Surg Am 2007; 89(5): 1118-1127.

Pohjolainen T, Alaranta H. Lower limb amputations in southern Finland 1984-1985. Prosthet Orthot Int 1988; 12(1): 9-18.

Pohjolainen T, Alaranta H. Ten-year survival of Finnish lower limb amputees. Prosthet Orthot Int 1998; 22(1): 10-16.

Pohjolainen T, Alaranta H, Karkkainen M. Prosthetic use and functional and social outcome following major lower limb amputation. Prosthet Orthot Int 1990; 14(2): 75-79.

Rayman G, Krishnan S T, Baker N R, Wareham A M, Rayman A. Are we underestimating diabetes-related lower-extremity amputation rates? Results and benefits of the first prospective study. Diabetes Care 2004; 27(8): 1892-1896.

Redhead R G. Total surface bearing self suspending above-knee sockets. Prosthet Orthot Int 1979; 3(3): 126-136.

Robinson K P. Skew-flap below-knee amputation. Ann R Coll Surg Engl 1991; 73(3): 155-157.

Rothman K J, Greenland S. Measures of Disease Frequency. In: Modern Epidemiology. Second Ed. (Eds. Rothman KJ, Greenland S). Philadelphia, Lippincott Williams and Williams; 1998. p. 30-32.

Sadat U, Chaudhuri A, Hayes P D, Gaunt M E, Boyle J R, Varty K. Five day antibiotic prophylaxis for major lower limb amputation reduces wound infection rates and the length of in-hospital stay. Eur J Vasc Endovasc Surg 2008; 35(1): 75-78.

Sandnes D K, Sobel M, Flum D R. Survival after lower-extremity amputation. J Am Coll Surg 2004; 199(3): 394-402.

Schofield C J, Libby G, Brennan G M, MacAlpine R R, Morris A D, Leese G P. Mortality and hospitalization in patients after amputation: a comparison between patients with and without diabetes. Diabetes Care 2006; 29(10): 2252-2256.

Schoppen T, Boonstra A, Groothoff J W, de Vries J, Goeken L N, Eisma W H. The Timed ”up and go” test: reliability and validity in persons with unilateral lower limb amputation. Arch Phys Med Rehabil 1999; 80(7): 825-828.

Schwitalle M, Bruckner L. [Longitudinal study of vascular patients with standardized Bruckner distal limb amputation]. Zentralbl Chir 1998; 123(3): 235-238.

Selles R W, Janssens P J, Jongenengel C D, Bussmann J B. A randomized controlled trial comparing functional outcome and cost efficiency of a total surface-bearing socket versus a conventional patellar tendon-bearing socket in transtibial amputees. Arch Phys Med Rehabil 2005; 86(1): 154-161.

Sigvant B, Wiberg-Hedman K, Bergqvist D, Rolandsson O, Andersson B, Persson E, Wahlberg E. A population-based study of peripheral arterial disease prevalence with special focus on critical limb ischemia and sex differences. J Vasc Surg 2007; 45(6): 1185-1191.

Smith D G, McFarland L V, Sangeorzan B J, Reiber G E, Czerniecki J M. Postoperative dressing and management strategies for transtibial amputations: a critical review. J Rehabil Res Dev 2003; 40(3): 213-224.

Snyder R J. Controversies regarding vascular disease in the patient with diabetes: a review of the literature. Ostomy Wound Manage 2007; 53(11): 40-48.

Stahel P F, Oberholzer A, Morgan S J, Heyde C E. Concepts of transtibial amputation: Burgess technique versus modified Bruckner procedure. ANZ J Surg 2006; 76(10): 942-946.

Statistics Sweden. From population increase to decrease. World population development 1950 to 2050. 2005.

Stewart C P. The influence of smoking on the level of lower limb amputation. Prosthet Orthot Int 1987; 11(3): 113-116.

Stone P A, Flaherty S K, AbuRahma A F, Hass S M, Jackson J M, Hayes J D, Hofeldt M J, Hager C S, Elmore M S. Factors affecting perioperative mortality and wound-related complications following major lower extremity amputations. Ann Vasc Surg 2006; 20(2): 209-216.

Stone P A, Flaherty S K, Hayes J D, AbuRahma A F. Lower extremity amputation: a contemporary series. W V Med J 2007; 103(5): 14-18.

Streppel K R, de V J, van Harten W H. Functional status and prosthesis use in amputees, measured with the Prosthetic Profile of the Amputee (PPA) and the short version of the Sickness Impact Profile (SIP68). Int J Rehabil Res 2001; 24(3): 251-256.

Sullivan M, Karlsson J, Taft C. How to assess quality of life in medicine: rationale and methods. Progress in obesity research, 8th International Congress on Obesity. John Libbey & Company Ltd; 1999.

Taylor S M, Kalbaugh C A, Blackhurst D W, Hamontree S E, Cull D L, Messich H S, Robertson R T, Langan E M, III, York J W, Carsten C G, III, Snyder B A, Jackson M R, Youkey J R. Preoperative clinical factors predict postoperative functional outcomes after major lower limb amputation: an analysis of 553 consecutive patients. J Vasc Surg 2005; 42(2): 227-235.

Tentolouris N, Al-Sabbagh S, Walker M G, Boulton A J, Jude E B. Mortality in diabetic and nondiabetic patients after amputations performed from 1990 to 1995: a 5-year follow-up study. Diabetes Care 2004; 27(7): 1598-1604.

Termansen N B. Below-knee amputation for ischaemic gangrene. Prospective, randomized comparison of a transverse and a sagittal operative technique. Acta Orthop Scand 1977; 48(3): 311-316.

Terwee C B, Bot S D, de Boer M R, van der Windt D A, Knol D L, Dekker J, Bouter L M, de Vet H C. Quality criteria were proposed for measurement properties of health status questionnaires. J Clin Epidemiol 2007; 60(1): 34-42.

Tisi P V, Callam M J. Type of incision for below knee amputation. Cochrane Database Syst Rev 2004; (1): CD003749.

Trautner C, Haastert B, Mauckner P, Gatcke L M, Giani G. Reduced incidence of lower-limb amputations in the diabetic population of a German city, 1990-2005: results of the Leverkusen Amputation Reduction Study (LARS). Diabetes Care 2007; 30(10): 2633-2637.

Trautner C, Haastert B, Spraul M, Giani G, Berger M. Unchanged incidence of lower-limb amputations in a German City, 1990-1998. Diabetes Care 2001; 24(5): 855-859.

Treves F. Influence of constitutinal conditions upon injuries. In: A System of Surgery. (Ed. Treves F). London, Cassell; 1895. p. 269.

van Houtum W H, Lavery L A. Methodological issues affect variability in reported incidence of lower extremity amputations due to diabetes. Diabetes Res Clin Pract 1997; 38(3): 177-183.

van Velzen A D, Nederhand M J, Emmelot C H, Ijzerman M J. Early treatment of trans-tibial amputees: retrospective analysis of early fitting and elastic bandaging. Prosthet Orthot Int 2005; 29(1): 3-12.

Vermeulen H, Ubbink D, Goossens A, de V R, Legemate D. Dressings and topical agents for surgical wounds healing by secondary intention. Cochrane Database Syst Rev 2004; (2): CD003554.

Vigier S, Casillas J M, Dulieu V, Rouhier-Marcer I, D'Athis P, Didier J P. Healing of open stump wounds after vascular below-knee amputation: plaster cast socket with silicone sleeve versus elastic compression. Arch Phys Med Rehabil 1999; 80(10): 1327-1330.

Wahlberg E, Lepner U, Olofsson P. Limb loss in association with vascular surgery--a five-year series of major lower-limb amputation. Eur J Surg 1994; 160(10): 561-567.

Wirehn A B, Karlsson H M, Carstensen J M. Estimating disease prevalence using a population-based administrative healthcare database. Scand J Public Health 2007; 35(4): 424-431.

Witso E, Ronningen H. Lower limb amputations: registration of all lower limb amputations performed at the University Hospital of Trondheim, Norway, 1994-1997. Prosthet Orthot Int 2001; 25(3): 181-185.

Ziegler-Graham K, MacKenzie E J, Ephraim P L, Travison T G, Brookmeyer R. Estimating the prevalence of limb loss in the United States: 2005 to 2050. Arch Phys Med Rehabil 2008; 89(3): 422-429.