Surgical wound complications after major lower limb amputations for chronic limb-threatening ischemia

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ABSTRACT

Objective: To investigate rates, risk factors and the impact of surgical wound complications (SWCs) on health care resources after below-knee amputation (BKA) and above-knee amputation (AKA) for chronic limb-threatening ischemia (CLTI).

Methods: This single-center retrospective study included consecutive patients undergoing major amputation for CLTI between 2011 and 2020. The primary end point was SWC, defined as surgical revision, higher amputation, or a non-healing wound at 1 year. Risk factors for SWCs were studied in multivariable analyses and expressed as odds ratios (ORs) with 95% confidence intervals (CIs). Secondary aim was to estimate hospital resources consumed by SWCs.

Results: One hundred twenty patients (27%) with CLTI underwent 132 BKAs and 322 patients (73%) underwent 362 AKAs. One-year mortality was 32% in the BKA group and 52% in the AKA group ($P < .001$). SWC rates were 47% and 11%, respectively ($P < .001$). AKA patients were older, more often female, and memory disorders were more common compared with BKA patients. BKA patients had more often diabetes, chronic kidney disease, and dialysis. None of these factors were associated with SWCs. Nineteen patients (14%) in the BKA group had no continuous arterial line to the amputation level; this factor did not increase the risk of SWC. Nineteen BKA patients (14%) had undergone guillotine ankle amputation before BKA, which was independently protective of SWC (OR, 0.16; 95% CI, 0.04-0.60; $P = .006$). Long-term corticosteroid use increased the risk of SWC after BKA (OR, 2.93; 95% CI, 1.19-7.23; $P = .020$) and AKA (OR, 2.25; 95% CI, 1.07-4.73; $P = .032$). BKA was a major independent risk factor for SWC with more than four times higher risk compared with AKA (OR, 4.13; 95% CI, 2.32-7.35; $P < .001$). BKAs required more hospital resources than AKAs. SWCs more than doubled the median hospital and health care center length of stay and multiplied the mean number of readmissions and outpatient clinic visits.

Conclusions: Nearly one-half of patients with CLTI developed SWC after BKA. Corticosteroid use increases the risk, whereas guillotine amputation was associated with a lower SWC rate after BKA. SWCs increase the need for health care resources significantly. SWCs are difficult to predict and the decision between BKA vs AKA remains a challenge for the vascular surgeon. (J Vasc Surg 2026;83:172-80.)

Keywords: Below-knee amputation; Above-knee amputation; Chronic limb-threatening ischemia; Wound complication; Wound infection; Risk factors

Peripheral artery disease (PAD) affects >200 million people worldwide.[1] Chronic limb-threatening ischemia (CLTI) is the end stage of PAD, and it is associated with the risk of major lower limb amputation.[2] From a vascular surgeon's perspective, amputation may be seen as a failure to salvage the leg. Nevertheless, the decision of when and how to amputate can have a major impact on the patient's quality of life, overall prognosis and the need for health care resources.[3-5] Below-knee amputation (BKA) is preferred because it may allow the patient to ambulate independently with a prosthesis. However, BKA is associated with a higher risk of wound complications that may require additional surgeries, result in higher amputation rates, and prolong the patient's hospitalization.[4,6,7] Above-knee amputation (AKA) wounds, in contrast, heal better but come with a greater risk of the patient being institutionalized owing to loss of ambulation and the ability to live independently.[4,6] The decision between BKA vs AKA in an individual patient is a crucial decision in which the

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surgeon must consider a vast number of contributing factors. There are currently no guidelines to help to choose the optimal level of amputation in a patient with CLTI.

The primary aim of this study was to determine the prevalence of surgical wound complications (SWCs) in patients undergoing BKA or AKA owing to CLTI and assess possible preoperative risk factors for SWCs. A secondary aim was to estimate the need for additional hospital resources caused by SWCs after major lower limb amputation.

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective cohort study
- **Key Findings:** Surgical wound complication occurred in 47% of 132 below-knee amputations and 11% of 362 above-knee amputations. The only major independent risk factor was long-term corticosteroid use; guillotine amputation was protective of wound complications.
- **Take Home Message:** Below-knee amputations in vascular surgical patients are plagued by wound complications, which consume a significant amount of hospital resources.

METHODS

Design and study population. This was a retrospective single-center study. The study was approved by the local institutional review board; the need for patient informed consent was waived. This study adhered to the STROBE guidelines for reporting observational studies. All patients undergoing major amputation (BKA or AKA) in an academic teaching hospital in Eastern Finland between 2011 and 2020 were identified from the electronic medical records according to Nordic Classification of Surgical Procedures (NGQ20 and NFQ20). The decision between AKA and BKA was made based on the patient's overall physical condition, comorbidities, and estimated potential to ambulate with a prosthesis after rehabilitation. There were no specific guidelines on how to assess perfusion of the limb and the potential for BKA wound healing. In essence, decisions were based on the vascular surgeon's assessment and consensus with the patients and their close relatives. The population of the study hospital region is approximately 250,000 inhabitants. Patients who underwent amputation owing to CLTI (*International Classification of Diseases*, 10th edition, code I70.2) during the study period and who had not undergone previous ipsilateral major amputation were included in the study. If the index amputation was bilateral, it was counted as one procedure for further analyses, and the index leg was the one with a possible SWC. The main investigator reviewed the medical records, and a senior consultant in vascular surgery ultimately decided any uncertainties regarding the diagnosis of CLTI.

Data collection and definitions. Patient characteristics such as comorbidities, previous revascularizations, and preoperative ambulation status were collected. Arterial status of the amputated leg was assessed based on digital subtraction angiography or magnetic resonance angiography if done within 12 months before the index amputation. Continuous arterial line to the amputation level was defined as patent iliofemoral, popliteal, and at least one crural artery in BKA patients. Symptomatic cardiac status was defined as myocardial infarction <6 months ago, poorly compensated or symptomatic heart failure, or stable angina pectoris. The Wound, Ischemia and foot Infection classification was used, and a deep ulcer was defined as an ulcer with exposed bone, joint, or tendon, as well as digital or more extensive wound/gangrene in another part of the foot. The definition of severe local infection required >2 cm erythema or cellulitis around the ulcer or an infection involving structures deeper than subcutaneous tissue with or without signs of sepsis or systemic inflammatory response syndrome. The operator experience was defined as consultant (a specialist of vascular or cardiovascular surgery) or trainee.

Postoperative SWC was defined as wound dehiscence or deep local infection requiring surgical revision or higher amputation of the index leg within the first year after the index procedure, or as a nonhealing primary amputation wound at the 1-year time point. A superficial wound infection that did not require surgical revision was not considered a SWC. Patients who died within 30 days from the index procedure without an SWC were excluded from the SWC risk factor analysis.

Hospital resource analysis. The length of hospital stay, hospital readmissions, and outpatient clinic visits were registered. If there were readmissions, both the index and readmission hospital days were added to the total amount of hospital days. Since the advent of a common local health care registry in 2014, the length of stay in a primary health care center after the initial hospital stay was registered; this factor was not included in the hospital stay and these data were not available for patients treated between 2011 and 2013. Outpatient clinic visits were recorded until healing of the amputation wound.

Statistical analyses. Nominal data are presented as number (%) and continuous variables as mean $\pm$ standard deviation or medians with interquartile range (IQR). Univariable analyses of risk factors for SWC were performed independently for the BKA group, AKA group, and both groups combined using the Fischer two-sided exact test for nominal variables and Mann-

Whitney *U* test for continuous variables. Variables with a *P* value of ≤.10 were included in multivariable analyses, and logistic regression analyses were performed using binary logistics test to determine independent risk factors of SWC. The results were presented as odd ratios (ORs) with 95% confidence intervals (CIs). *P* values of <.05 were considered statistically significant. IBM SPSS Statistics (IBM Corp.) was used for data processing and statistical analyses.

RESULTS

Study patients. During the 10-year study period, a total of 233 BKA and 765 AKAs were performed in our hospital; 133 BKAs and 372 AKAs were performed in patients with CLTI who met the study inclusion criteria. One BKA and 10 AKAs were bilateral. Altogether, 120 patients (27%) underwent 132 BKAs and 322 patients (73%) underwent 362 AKAs that were included in the study. Eight BKA and 72 AKA patients died without SWCs within 30 days of the index procedure and were excluded from the statistical analyses of SWC risk factors.

Preoperative group differences (BKA vs AKA). Patient comorbidities and medications are presented in Table I. Patients who underwent AKA were older, and the proportion of females and the prevalence of memory disorders were higher compared with those who underwent BKA. In contrast, BKA patients had more often diabetes, chronic kidney disease, and were on dialysis compared with AKA patients. Previous amputations, arterial status, previous revascularizations, and functional status are presented in Table II. Sixty-six (50%) of the BKA patients had undergone previous forefoot amputation and 19 (14%) underwent guillotine ankle amputation before BKA. Most BKA patients (110 [83%]) had undergone previous revascularization, whereas 189 patients (52%) had undergone revascularization before AKA ($P < .001$). A greater proportion of patients in the BKA group had undergone infrapopliteal endovascular

Table I. Preoperative demographics, comorbidities and medications of patients undergoing below-knee amputation (*BKA*) or above-knee amputation (*AKA*)

	BKA (n = 132)	AKA (n = 362)	*P* value
Age, years	71 ± 11	79 ± 9	<.001
Sex, female	38 (29)	185 (51)	<.001
Comorbidities			
Diabetes	94 (71)	186 (51)	<.001
Insulin-dependent diabetes	77 (58)	126 (35)	<.001
Chronic kidney disease, stage 3-5	64 (49)	138 (38)	.039
Dialysis	18 (14)	14 (3.9)	<.001
Hypertension	124 (94)	314 (87)	.025
Hypercholesterolemia	104 (79)	224 (62)	<.001
Coronary artery disease	79 (60)	211 (58)	.836
Cerebrovascular disease	33 (25)	125 (35)	.050
Symptomatic cardiac status	12 (9.1)	44 (12)	.423
Severe lung disease (eg, COPD)	32 (24)	70 (19)	.258
Memory disorder	8 (6.1)	124 (34)	<.001
History of smoking[a]	61 (46)	115 (32)	.078
Current smoker[a]	18 (14)	57 (16)	.203
Medication			
Any anticoagulant or antiplatelet medication	122 (92)	309 (85)	.047
Statin	80 (61)	171 (47)	.006
Corticosteroid use (long term)	40 (30)	81 (22)	.077
Warfarin	44 (33)	135 (37)	.460
DOAC	6 (4.5)	17 (4.7)	1.0
Aspirin	70 (53)	191 (53)	1.0
Clopidogrel	75 (57)	74 (20)	<.001
Other antithrombotic medicine	3 (2.4)	5 (1.4)	.446

COPD, Chronic obstructive pulmonary disease; *DOAC*, direct oral anticoagulant.
Values are mean ± standard deviation or number (%).
[a]Available on 344 patients.

Table II. Previous amputations, arterial status, preoperative functional status and Wound Ischemia and foot Infection classification (*WIfI*) classification of patients undergoing below-knee amputation (*BKA*) or above-knee amputation (*AKA*)

	BKA (n = 132)	AKA (n = 362)	*P* value
Previous amputations			
Previous ipsilateral toe amputation	48 (36)	57 (16)	<.001
Previous ipsilateral TMA	16 (12)	7 (1.9)	<.001
Guillotine ankle amputation	19 (14)	1 (0.3)	<.001
Contralateral BKA or AKA	23 (17)	70 (19)	.697
Arterial status and previous revascularizations of the index leg			
No continuous arterial line to amputation level	19 (14)	-	-
Any revascularization	110 (83)	189 (52)	<.001
Vein bypass	18 (14)	41 (11)	.531
Prosthesis bypass	6 (4.5)	29 (8.0)	.235
Femoral endarterectomy	12 (9.1)	32 (8.8)	1.0
Aortoiliac surgical repair	2 (1.5)	8 (2.2)	1.0
Aortoiliac endovascular repair	8 (6.1)	42 (12)	.091
Femoropopliteal endovascular repair	60 (46)	120 (33)	.015
Infrapopliteal endovascular repair	83 (63)	87 (24)	<.001
Preoperative functional status			
Needs helps in ADL	56 (42)	291 (80)	<.001
Lives in nursing facility/institution	15 (11)	165 (46)	<.001
Nonambulatory	28 (21)	176 (49)	<.001
WIfI classification			
Deep ulcer (W)	124 (94)	296 (82)	<.001
Severe local infection (fI)	64 (49)	151 (42)	.184

ADL, Activities of daily living; *TMA*, transmetatarsal amputation.
Values are number (%).

repair compared with AKA group; 83 patients (63%) vs 87 (14%), respectively ($P < .001$). Nineteen patients (14%) had no continuous arterial line to the amputation level in the BKA group. In the BKA group, 124 patients (94%) had a deep ulcer (W class) compared with 296 (82%) in AKA group ($P < .001$), whereas no group differences were observed in severe local infection (fI class). Before the index BKA, 56 (42%) needed help with activities of daily living, 15 (11%) lived in a nursing facility, and 28 (21%) were nonambulatory; the corresponding numbers were 291 (80%), 165 (46%), and 176 (49%) in patients who underwent AKA ($P < .001$).

One-year outcomes after index amputation. Eleven patients (8.3%) who underwent BKA and 78 patients (22%) who underwent AKA died within 30 days ($P < .001$). Forty-two patients (32%) who underwent BKA and 189 patients (52%) who underwent AKA died within 1 year of the index procedure ($P < .001$). There were significantly more SWCs within the BKA compared with the AKA group; 62 SWCs (47%) were recorded within 1 year in the BKA group compared with 41 (11%) in the AKA group ($P < .001$). During the 1-year follow-up, 40 (30%) patients underwent higher AKA after the index BKA. Surgical wound revisions were required in 29 patients (22%) in the BKA group and 40 (11%) in the AKA group ($P = .003$). Twenty-three of 62 patients (37%) with SWC after BKA died within 1 year, whereas 19 of 70 patients (27%) without SWC after BKA died within 1 year ($P = .26$). Twenty-one of 41 patients (51%) with SWC after AKA died within 1 year, whereas 168 of 321 patients (52%) without SWC after AKA died within 1 year ($P = 1.0$).

Risk factors for SWC after BKA. Univariable analyses of risk factors showed that, for example, the absence of continuous arterial line to amputation level, diabetes or chronic kidney disease were not associated with SWCs after BKA (Supplementary Table I, online only). Multivariable analyses showed that guillotine amputation at ankle level prior to the BKA (OR, 0.16; 95% CI, 0.04-0.60; $P = .006$) and aspirin use (OR, 0.45; 95% CI, 0.21-0.99; $P = .046$) were protective of SWCs, whereas long-term corticosteroid use (OR, 2.93; 95% CI, 1.19-7.23; $P = .020$) and symptomatic heart disease (OR, 6.04; 95% CI, 6.19-30.72; $P = .030$) were independent risk factors for SWC after BKA (Table III).

Risk factors for SWC after AKA. Univariable analyses showed that comorbidities such as diabetes or chronic

Table III. Multivariable analysis of risk factor for surgical wound complications (SWCs) in patients undergoing below-knee amputation (BKA) (n = 124)

Variable	OR	95% CI	*P* value
Symptomatic cardiac status	6.04	6.19-30.72	.030
Corticosteroid use (long term)	2.93	1.19-7.23	.020
Warfarin	1.74	0.72-4.24	.222
ASA	0.45	0.21-0.99	.046
Guillotine ankle amputation	0.16	0.04-0.60	.006
Severe local infection (WIfI)	0.70	0.32-1.54	.373

ASA, Aspirin; *CI*, confidence interval; *OR*, odds ratio; *WIfI*, Wound, Ischemia, and foot Infection.
Patients who died within 30 days from index procedure without SWCs were excluded.

kidney diseases, even dialysis, were not associated with SWCs after AKA (Supplementary Table II, online only). In multivariable analyses, long-term corticosteroid use (OR, 2.25; 95% CI, 1.07-4.73; $P = .032$) and previous femoropopliteal endovascular repair (OR, 2.41; 95% CI, 1.21-4.78; $P = .012$) were associated with SWCs, and controversially, deep ulcer in the wound classification appeared as protective of SWCs with borderline statistical significance (OR, 0.45; 95% CI, 0.20-1.00; $P = .046$) (Table IV).

Risk factors for SWC after any major lower limb amputation. All preoperative factors were analyzed as potential risk factors for SWC after AKA or BKA (Supplementary Table III, online only). In multivariable analysis, BKA was a major independent risk factor for SWCs with more than a four times higher risk compared with AKA (OR, 4.13; 95% CI, 2.32-7.35; $P < .001$). In addition, long-term corticosteroid use (OR, 1.87; 95% CI, 1.01-3.47; $P = .047$) was also an independent risk factor for SWC after major lower limb amputation (Table V). During the first one-half of the study period (2011-2015), 64 of 278 patients (23%) had SWC compared with 39 of 177 patients (18%) during the second one-half (2016-2020; $P = .183$). Approximately one-half of BKAs and AKAs were performed by consultant vascular or cardiovascular surgeons and one-half by trainees. Operator experience and the length of the operation did not associate with SWCs.

The need for health care resources after major lower limb amputation. The analyzed health care resources are presented in Table VI. The median hospital stay was 8 days (IQR, 5-14 days) after BKA and 3 days (IQR, 3-6 days) after AKA ($P < .001$). BKA patients required significantly more hospital resources than AKA, apart from health care center resources. SWCs more than doubled the median hospital and health care center stays. SWCs multiplied the mean number of readmissions and outpatient clinic visits per patient. When comparing BKA with SWC and AKA with SWC, there were significantly more wound revisions and more outpatient clinic visits within the AKA group, but no other differences. In patients undergoing BKA without SWC compared with AKA without SWC, there were more hospital days and outpatient clinic visits within the BKA group (Supplementary Table IV, online only). When comparing BKA with SWC and BKA without SWC, SWC patients consumed more health care resources all measures except outpatient clinic visits in the BKA group (Supplementary Table V, online only).

DISCUSSION

This study showed that one-half of patients undergoing BKA for CLTI had wound healing problems and one-third required higher amputation within a year. Patients with CLTI undergoing BKA had a four times higher risk of SWC than those undergoing AKA. In the previous

Table IV. Multivariable analysis of risk factor for surgical wound complications (SWCs) in patients undergoing above-knee amputation (*AKA*) (n = 290)

Variable	OR	95% CI	*P* value
Corticosteroid use (long term)	2.25	1.07-4.73	.032
Hypercholesterolemia	1.49	0.64-3.47	.361
Previous contralateral BKA or AKA	1.88	0.86-4.08	.111
Any revascularization	1.38	0.45-4.26	.579
Femoral endarterectomy	2.17	0.80-5.85	.126
Femoropopliteal endovascular repair	2.41	1.21-4.78	.012
Infrapopliteal endovascular repair	1.63	0.72-3.65	.239
Deep ulcer (WIfI)	0.45	0.2-1.0	.046

BKA, Below-knee amputation; *CI*, confidence interval; *OR*, odds ratio; *WIfI*, Wound, Ischemia, and foot Infection.
Patients who died within 30 days from index procedure without SWCs were excluded.

Table V. Multivariable analysis of risk factor for surgical wound complications (SWCs) in patients undergoing a major lower limb amputation (below-knee amputation [*BKA*] or above-knee amputation [AKA], n = 414)

Variable	OR	95% CI	*P* value
BKA	4.13	2.32-7.35	<.001
Age	1.01	0.98-1.04	.406
Hypercholesterolemia	1.13	0.45-2.81	.801
Memory disorder	0.68	0.26-1.82	.447
Current smoking	0.67	0.31-1.44	.305
Statin	1.58	0.88-2.86	.128
Corticosteroid use (long term)	1.87	1.01-3.47	.047
Clopidogrel	0.88	0.45-1.72	.708
Any previous ipsilateral amputation	0.66	0.35-1.30	.239
Any previous revascularization	2.02	0.99-4.12	.054
Previous ipsilateral infrapopliteal endovascular revascularization	1.14	0.55-2.37	.728
Needs help in ADL	0.96	0.49-1.87	.893
Living in nursing facility/institution	1.06	0.45-2.53	.893

ADL, Activities of daily living; *CI*, confidence interval; *OR*, odds ratio.
Patients who died within 30 days from index procedure without SWCs were excluded.

literature, wound complication rates after BKA vary from 8.0% to 35.8%,[4,8-15] and the rates of reamputation to the above-knee level varied from 3.2% to 19.0%.[8,14,16] AKA amputation wounds are known to have lower wound complication rates compared with BKA, ranging from 7.0% to 16.5%.[8,10-12] The SWC rates in the present study were in line with the previous literature in AKA patients (in this study, the SWC rate being 11%). However, complication rates were higher than previously reported in BKA patients. Some of the differences between this study and previous studies may be attributed to the definition of SWC. In this study, SWC was defined as the need for surgical revision, a higher reamputation, or a nonhealing wound at 1 year. For example, in studies by Curran et al[10] and Hasanadka et al,[11] a wound complication was defined as any 30-day surgical site infection (including superficial infection) or dehiscentia. Another factor that may associate with a higher incidence of wound complications is that the patients of this study had high burden of atherosclerotic disease and associated comorbidities. Coronary artery disease and its risk factors, such as high blood pressure and high cholesterol levels, are much more common in Eastern Finland compared with the western side of the country.[17]

Predicting SWCs in patients undergoing major amputation for CLTI proved difficult. A common belief among vascular surgeons is that a patent profound artery is a prerequisite for BKA wound healing, whereas others

Table VI. The need for hospital resources in patients undergoing major lower limb amputation stratified by below-knee amputation (*BKA*) vs above-knee amputation (*AKA*) and with or without surgical wound complication (*SWC*)

	BKA (n = 132)	AKA (n = 362)	*P* value	No SWC (n = 391)	SWC (n = 103)	*P* value
Hospital days	8 (5-14)	3 (3-6)	<.001	4 (3-6)	11 (7-17)	<.001
Health care center days[a]	32 (14-75)	21 (12-71)	.069	21 (5-51)	45 (14-99)	.042
Hospital readmissions	0.6 ± 0.9	0.2 ± 0.6	<.001	0.1 ± 0.4	1.3 ± 0.9	<.001
Outpatient clinic visits	1.3 ± 3.5	0.3 ± 1.2	<.001	0.4 ± 1.9	1.4 ± 2.7	<.001
Surgical revisions	0.4 ± 0.9	0.2 ± 0.7	.002	0.0 ± 0.0	1.2 ± 1.2	<.001
At least 1 hospital readmission	60 (46)	60 (17)	<.001	28 (9.0)	88 (85)	<.001
At least 1 outpatient clinic visit	40 (30)	45 (12)	<.001	38 (12)	42 (41)	<.001
At least 1 surgical revision	29 (22)	40 (11)	.003	0 (0)	69 (67)	<.001
Hospital readmissions, total	85	86		38	133	
Outpatient clinic visits, total	165	112		135	142	
Surgical revisions, total	51	64		0	120	

Values are median (interquartile range), mean ± standard deviation or number (%).
[a]Data available in 91 BKA and 244 AKA patients.

teach that a continuous arterial line to the amputation level is required. No such association was found in this study. The European Society for Vascular Surgery guidelines for the treatment of CLTI state that there are no methods to predict adequate preoperative tissue perfusion, even though there have been many promising methods, such as measuring of transcutaneous oxygen pressure.[2] Selçuk et al[18] saw in their retrospective single-center study of 253 CLTI patients undergoing major amputations that an occluded popliteal artery was associated with higher revision rates after BKA, but no other level of occlusion was significant for healing of BKA or AKA. Alfawaz et al[19] conducted a single-center retrospective study of 135 patients and showed that higher tibial baseline vessel run off (defined as numbers from zero to three according to how many tibial vessels are open in angiography) was associated with higher healing rates, fewer complications, and shorter time to healing. Also, in Aimanan et al's[20] retrospective single-center study of 90 CLTI patients, an occluded iliac artery did not have effect on AKA wound healing, if the deep femoral artery was fully patent.

Diabetes, chronic kidney disease, and especially end-stage kidney disease requiring dialysis are commonly believed to increase the risk of SWCs. However, this was not the case in the present study. Previous literature presents controversial evidence regarding the association of these diseases with SWCs in amputation wounds. O'Brien et al[12] saw that end-stage renal disease is an independent risk factor for 30-day SWCs on the healing of 8878 transmetatarsal, BKA, and AKA wounds (OR, 1.39; 95% CI, 1.19-1.63) within the National Surgical Quality Improvement Program registry, which consisted of 66.3% CLTI patients. Diabetes, instead, was not associated with SWCs.[12] Cheun et al[21] saw in their single-center retrospective study consisting of 116 patients having diabetes mellitus and PAD that patients with end-stage renal disease had significantly more 30-day stump complications than patients without. On the contrary, Wukich et al[12] saw in their single-center retrospective study of 102 diabetes mellitus patients (50% having PAD) that hemodialysis or peritoneal dialysis was not associated with healing of BKA wounds. End-stage renal disease, diabetes, or insulin use were not associated with need of revision amputations in the study by Selçuk et al.[18] In a retrospective single-center study by Lee et al[22] of 181 patients having either diabetes alone (32.6%), diabetes and chronic kidney disease (6.6%), diabetes and PAD (47%), and all the above (13.8%), there was no statistically significant difference in wound healing problems between the groups. We found no studies suggesting that diabetes is associated with SWCs in amputation wound healing of CLTI patients.

Long-term use of corticosteroid medication was determined as an independent risk factor for SWCs in all analyses. Corticosteroids affect each stage of wound healing, for example, by reducing cytokine reactions and affecting function of collagen.[23] Belmont et al[13] saw in their study of BKA patients from National Surgical Quality Improvement Program registry (in total 2911 patients), which consisted of 69.8% PAD patients, that the risk of major complications within 30 days from index procedure (of which two most common were return to operating room and wound infection) was higher with patients using steroids. Symptomatic cardiac disease was an independent predictor of SWCs after BKA but not after AKA. In the literature, this phenomenon is new within BKA amputation wounds. It can be speculated whether the reason is decreased perfusion to a more distal amputation wound or the fragile condition of these patients. Andersen et al[24] found in a retrospective Vascular Quality Initiative amputation registry of 3855 PAD patients facing BKA that a higher frailty score, which included congestive heart failure (12.5% of patients), was associated with more overall complications compared with nonfrail patients. Frailty and sarcopenia should be investigated further, preferably in a prospective setting, to determine whether these factors will predict amputation wound healing in vascular surgery patients.

Guillotine ankle amputation has been used varyingly for control of infection before second, definitive BKA. In this study, even to our surprise, guillotine amputation was independently associated with a >80% lower risk of SWC after BKA. Over decades, guillotine amputation has been associated with fewer wound complications, especially in patients having wet gangrene, but also in diabetic patients regardless of the Wound, Ischemia and foot Infection classification.[10,21,25] One benefit of the guillotine amputation is that the infection control amputation can be done by a resident during on-call hours, and the second stage BKA can be done later during the daytime by an experienced surgeon.

BKA consumed significantly more health care resources by almost all measures compared with AKA owing to the higher rate of SWCs. Based on the subgroup analysis of health care resources, BKA patients with SWC had fewer outpatient clinic visits and revisions compared with AKA patients with SWC. This was likely because BKA patient with SWC will require a higher amputation, whereas wound problems in AKA patients are treated for as long as needed. Our data support findings from previous studies indicating that primary amputation is the most expensive treatment of CLTI[26,27] owing to the long hospital stay. Barshes et al[27] reported that an amputation required more resources than treatment of a chronic wound. However, if BKA is successful and the patient can successfully ambulate with a prosthesis, it may allow the patient to live at home independently, and therefore, reduce the health care resources needed compared with the patient being

institutionalized. Health care center refers to a bed ward where patients receive immediate rehabilitation and wound care after hospital care. From health care center, patients are discharged to home or, if that is not feasible, to a long-term care institution such as a nursing home. For this study, only health care center days were assessed; long-term data were not available. Because the treatment of atherosclerosis and CLTI requires a lot of health care resources and is often quite burdensome for the patient, special attention should be paid to choosing the optimal amputation level in patients for whom amputation remains the only treatment option.

The strength of this study lies in the use of data from a well-defined population in Eastern Finland over a 10-year period, with information available for most patients who underwent amputation at our hospital. Our study region represents a White population with a high burden of atherosclerosis and cardiovascular risk factors. However, the results of this study should be generalizable to other populations with similar demographics. The study results are only generalizable to CLTI patients and not other causes of amputation. This study has several limitations. It is a retrospective study based on patient records, and, particularly, the absence of health care center data before 2014 limits the information available from the early years. Another limitation of the health care resource analysis is that we were unable to access data on increased institutionalization or the number of outpatient clinic visits to health care centers after major amputation. As a result, the estimated health care burden may be underestimated.

CONCLUSIONS

BKA was associated with high risk of SWCs in nearly one-half of patients with CLTI. AKA was associated with greater 1-year mortality rates, and patients with BKA consumed more health care resources driven by the higher rate of SWCs. BKA was identified as an independent risk factor for SWCs with a four times greater risk compared with AKA. An ankle-level guillotine amputation preceding BKA was associated with a lower risk of SWC, whereas symptomatic heart disease and long-term use of corticosteroids were independent risk factors for SWC after BKA. The presence of a patent arterial line or end-stage renal disease was not associated with SWC rates. Choosing the optimal amputation level in patients with CLTI remains a challenge for vascular surgeons, and guidelines are needed for consistent decision making. Short-term recovery, wound healing, and health care resources are important, but future studies should assess long-term outcomes such as functional recovery, independent living, and quality of life after major amputation.

AUTHOR CONTRIBUTIONS

Conception and design: MV, MK, HN, JH, JK, JMK
Analysis and interpretation: MV, JMK
Data collection: MV, EB
Writing the article: MV, JMK
Critical revision of the article: MV, EB, MK, HN, JH, JK, JMK
Final approval of the article: MV, EB, MK, HN, JH, JK, JMK
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DISCLOSURES

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Supplementary Table I (online only). Univariable analysis of preoperative risk factors for surgical wound complication (*SWC*) in patients undergoing below-knee amputation (*BKA*)[a]

Dichotomous test variables		SWC rate in patients with test variable	SWC rate in patients without test variable	
Continuous test variables	All BKAs (n = 124)	Test value in patients with SWC (n = 62)	Test value in patients without SWC (n = 62)	*P* value
Sex, female	37 (30)	21 (57)	41 (47)	.433
Age, years	71 ± 11	72 ± 11	70 ± 12	.151
Comorbidities				
Diabetes	88 (71)	43 (49)	19 (53)	.843
Insulin-dependent diabetes	72 (58)	32 (44)	30 (58)	.203
Chronic kidney disease, stage 3-5	58 (47)	26 (45)	36 (55)	.368
Dialysis	16 (13)	5 (31)	57 (53)	.179
Hypertension	116 (94)	58 (50)	4 (50)	1.000
Hypercholesterolemia	97 (78)	48 (50)	14 (52)	1.000
Coronary artery disease	73 (59)	37 (51)	25 (49)	1.000
Cerebrovascular disease	31 (25)	18 (58)	44 (47)	.407
Symptomatic cardiac status	11 (8.9)	9 (82)	53 (27)	.054
Severe lung disease (eg COPD)	29 (23)	18 (62)	44 (46)	.203
Memory disorder	6 (4.8)	3 (50)	59 (50)	1.000
History of smoking[b]	56 (45)	23 (41)	21 (53)	.303
Current smoker[b]	18 (15)	5 (28)	39 (50)	.117
Medications				
Statin	75 (61)	40 (53)	22 (45)	.463
Corticosteroid use (long term)	36 (29)	23 (64)	39 (44)	.074
Warfarin	38 (31)	24 (63)	38 (44)	.079
DOAC	6 (4.8)	2 (33)	60 (51)	.680
Aspirin	67 (54)	28 (42)	34 (60)	.071
Clopidogrel	73 (59)	36 (49)	26 (51)	1.000
Other antithrombotic medicine	3 (2.4)	0 (0.0)	62 (51)	.244
Any anticoagulant or antiplatelet medication	115 (93)	57 (50)	5 (56)	1.000
Previous amputations				
Guillotine ankle amputation	19 (15)	4 (21)	58 (55)	.011
Previous ipsilateral toe amputation	45 (36)	23 (51)	39 (49)	1.000
Previous ipsilateral TMA	15 (12)	6 (40)	56 (51)	.583
Contralateral BKA or AKA	21 (17)	8 (38)	54 (52)	.338
Arterial status and previous revascularization				
No continuous arterial line to amputation level[c]	18 (15)	7 (39)	49 (52)	.441
No continuous line to inguinal level[c]	1 (0.8)	0 (0.0)	56 (51)	1.000
No continuous line to popliteal level[c]	15 (12)	6 (40)	50 (52)	.580
Any revascularization	103 (83)	52 (51)	10 (48)	1.000
Vein bypass	17 (14)	8 (47)	54 (51)	1.000
Prosthesis bypass	6 (4.8)	4 (67)	58 (49)	.680
Femoral endarterectomy	12 (9.7)	5 (42)	57 (51)	.763
Aortoiliac surgical repair	2 (1.6)	1 (50)	61 (50)	1.000
Aortoiliac endovascular repair	8 (6.5)	6 (75)	56 (48)	.273
Femoropopliteal endovascular repair	56 (45)	23 (41)	39 (57)	.104
Infrapopliteal endovascular repair	78 (63)	42 (54)	20 (44)	.353

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Supplementary Table I (online only). Continued.

Dichotomous test variables		SWC rate in patients with test variable	SWC rate in patients without test variable	
Continuous test variables	**All BKAs (n = 124)**	**Test value in patients with SWC (n = 62)**	**Test value in patients without SWC (n = 62)**	***P* value**
Preoperative functional status				
Needs helps in ADL	51 (41)	29 (57)	33 (45)	.273
Lives in nursing facility/institution	14 (11)	8 (57)	54 (49)	.778
Nonambulatory	28 (23)	14 (50)	48 (50)	1.000
Laboratory values				
Creatinine	94 (38-89)	87 (62-127)	99 (75-162)	.119
GFR	64 ± 37	67 ± 35	60 ± 38	.173
LDL[d]	2.2 ± 0.9	2.3 ± 0.7	2.2 ± 1.1	.341
CRP[e]	95 ± 87	75 ± 66	114 ± 101	.083
Leukocytes	11.5 ± 5.4	11.1 ± 3.9	12.0 ± 6.6	.715
Severity of wound and foot infection (WIfI)				
Deep ulcer (W)	116 (94)	57 (49)	5 (63)	.717
Severe local infection (fI)	59 (48)	25 (42)	37 (57)	.150
Operation-dependent factors[f]				
Operation time, minutes	73 ± 35	68 ± 29	78 ± 41	.319
Trainee as main operator	54 (48)	29 (59)	29 (46)	.117

ADL, Activities of daily living; *BKA*, below-knee amputation; *COPD*, chronic obstructive pulmonary disease; *CRP*, C-reactive protein; *DOAC*, direct oral anticoagulant; *GFR*, glomerular filtration rate; *LDL*, low-density lipoprotein cholesterol; *SWC*, surgical wound complication; *TMA*, transmetatarsal amputation; *WIfI*, Wound, Ischemia, and foot Infection.
Values are number (%), mean ± standard deviation, or median (interquartile range).
[a]Eight patients who deceased within 30 days from index procedure without SWCs were excluded.
[b]Available for 96 patients.
[c]Available for 112 patients; in 10 patients with only selective angiography available, the patent aortoiliac line was defined as palpable femoral pulse.
[d]Available for 89 patients.
[e]Available for 123 patients.
[f]Available for 112 patients.

Supplementary Table II (online only). Univariable analysis of preoperative risk factors for surgical wound complications (*SWCs*) in patients undergoing above-knee amputation (*AKA*)[a]

Dichotomous test variables		SWC rate in patients with test variable	SWC rate in patients without test variable	
Continuous test variables	All AKAs (n = 290)	Test value in patients with SWC (n = 41)	Test value in patients without SWC (n = 249)	*P* value
Sex, female	142 (49)	23 (16)	18 (12)	.400
Age, years	79 ± 10	79 ± 8	79 ± 10	.959
Comorbidities				
Diabetes	146 (50)	18 (12)	23 (16)	.403
Insulin-dependent diabetes	98 (34)	12 (12)	29 (15)	.595
Chronic kidney disease, stage 3-5	104 (36)	13 (13)	28 (15)	.602
Dialysis	10 (3.4)	0 (0.0)	41 (15)	.367
Hypertension	249 (86)	37 (15)	4 (9.8)	.475
Hypercholesterolemia	187 (65)	32 (17)	9 (8.7)	.054
Coronary artery disease	167 (58)	25 (15)	16 (13)	.734
Cerebrovascular disease	102 (35)	17 (17)	24 (13)	.381
Symptomatic cardiac status	33 (11)	3 (9.1)	38 (15)	.594
Severe lung disease (eg, COPD)	55 (19)	8 (15)	33 (14)	1.000
Memory disorder	98 (34)	10 (10)	31 (16)	.213
History of smoking[b]	96 (33)	11 (12)	19 (18)	.234
Current smoker[b]	51 (18)	6 (12)	24 (16)	.506
Medications				
Any anticoagulant or antiplatelet medication	249 (86)	37 (15)	5 (9.8)	.475
Statin	142 (49)	24 (17)	17 (12)	.238
Corticosteroid use (long term)	64 (22)	14 (22)	27 (12)	.065
Warfarin	108 (37)	16 (15)	25 (14)	.862
DOAC	15 (5.2)	3 (20)	38 (14)	.453
Aspirin	158 (55)	23 (15)	18 (14)	.867
Clopidogrel	55 (19)	10 (18)	31 (13)	.389
Other antithrombotic medicine	3 (1.0)	0 (0.0)	41 (14)	1.000
Previous amputations				
Previous ipsilateral toe amputation	51 (18)	7 (14)	34 (14)	1.000
Previous ipsilateral TMA	4 (1.4)	0 (0.0)	41 (14)	1.000
Contralateral BKA or AKA	60 (21)	13 (22)	28 (12)	.094
Arterial status and previous revascularizations				
Any revascularization	153 (53)	30 (20)	11 (8.0)	.006
Vein bypass	39 (13)	5 (13)	36 (14)	1.000
Prosthesis bypass	25 (8.6)	6 (24)	35 (13)	.140
Femoral endarterectomy	25 (8.6)	7 (28)	34 (13)	.064
Aortoiliac surgical repair	7 (2.4)	2 (29)	39 (14)	.259
Aortoiliac endovascular repair	31 (11)	2 (6.5)	39 (15)	.277
Femoropopliteal endovascular repair	98 (34)	22 (22)	19 (9.9)	.007
Infrapopliteal endovascular repair	73 (25)	17 (23)	24 (11)	.018
Preoperative functional status				
Needs helps in ADL	228 (79)	28 (12)	13 (21)	.099
Lives in nursing facility/institution	123 (42)	16 (13)	25 (15)	.734
Nonambulatory	141 (49)	21 (15)	20 (13)	.739

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Supplementary Table II (online only). Continued.

Dichotomous test variables		SWC rate in patients with test variable	SWC rate in patients without test variable	
Continuous test variables	All AKAs (n = 290)	Test value in patients with SWC (n = 41)	Test value in patients without SWC (n = 249)	*P* value
Laboratory values				
Creatinine	80 (58-107)	80 (55-89)	81 (58-109)	.319
GFR	69 ± 28	73 ± 22	69 ± 28	.449
LDL[c]	2.0 ± 0.9	2.0 ± 1.1	2.0 ± 0.8	.740
CRP[d]	89 ± 87	97 ± 69	88 ± 89	.136
Leukocytes[e]	11.6 ± 4.4	11.5 ± 3.8	11.6 ± 4.4	.946
WIfI classification				
Deep ulcer (W)	241 (83)	29 (12)	12 (25)	.040
Severe local infection (fI)	122 (42)	14 (12)	27 (16)	.308
Operation-dependent factors[f]				
Operation time, minutes	61 ± 27	62 ± 28	61 ± 27	.924
Trainee as main operator	141 (53)	18 (13)	19 (15)	.598

ADL, Activities of daily living; *BKA,* below-knee amputation; *COPD,* chronic obstructive pulmonary disease; *CRP,* C-reactive protein; *DOAC,* direct oral anticoagulant; *GFR,* glomerular filtration rate; *LDL,* low-density lipoprotein cholesterol; *TMA,* transmetatarsal amputation; *WIfI,* Wound, Ischemia, and foot Infection.
Values are number (%), mean ± standard deviation, or median (interquartile range).
[a]Seventy-two patients who died within 30 days from index procedure without SWCs were excluded.
[b]Available for 200 patients.
[c]Available for 135 patients.
[d]Available for 271 patients.
[e]Available for 289 patients.
[f]Available for 266 patients.

Supplementary Table III (online only). Univariable analysis of risk factors for surgical wound complications (*SWCs*) after major lower limb amputation (above-knee amputation [*AKA*] or below-knee amputation [*BKA*])[a]

Dichotomous test variables		SWC rate in patients with test variable	SWC rate in patients without test variable	
Continuous test variables	All BKAs and AKAs (n = 414)	Test value in patients with SWC (n = 103)	Test value in patients without SWC (n = 311)	*P* value
BKA	124 (30)	62 (50)	41 (14)	<.001
Sex, female	179 (43)	44 (25)	59 (25)	1.000
Age, years	76 ± 11	75 ± 10	77 ± 11	.048
Comorbidities				
Diabetes	234 (57)	61 (26)	42 (23)	.567
Insulin-dependent diabetes	170 (41)	44 (26)	59 (24)	.729
Chronic kidney disease, stage 3-5	162 (39)	39 (24)	64 (25)	.816
Dialysis	26 (6.3)	5 (19)	98 (25)	.641
Hypertension	365 (88)	95 (26)	8 (16)	.161
Hypercholesterolemia	284 (69)	80 (28)	23 (18)	.027
Coronary artery disease	240 (58)	62 (26)	41 (24)	.646
Cerebrovascular disease	133 (32)	35 (26)	68 (24)	.715
Symptomatic cardiac status	44 (11)	12 (27)	91 (25)	.713
Severe lung disease (eg, COPD)	84 (20)	26 (31)	77 (23)	.159
Memory disorder	104 (25)	13 (13)	90 (29)	<.001
History of smoking[b]	152 (37)	34 (22)	40 (28)	.287
Current smoker[b]	69 (17)	11 (16)	63 (28)	.056
Medications				
Any anticoagulant or antiplatelet medication	364 (88)	94 (26)	9 (18)	.295
Statin	217 (52)	64 (30)	39 (20)	.023
Corticosteroid use (long term)	100 (24)	37 (37)	66 (27)	.002
Warfarin	146 (35)	40 (27)	63 (24)	.406
DOAC	21 (5.1)	5 (24)	98 (25)	1.000
Aspirin	225 (54)	51 (23)	52 (28)	.304
Clopidogrel	128 (31)	46 (36)	57 (20)	<.001
Other antithrombotic medicine	6 (1.4)	0 (0.0)	103 (25)	.344
Previous amputations				
Previous ipsilateral toe amputation	96 (23)	30 (31)	73 (23)	.107
Previous ipsilateral TMA	19 (4.6)	6 (32)	97 (25)	.586
Contralateral BKA or AKA	84 (20)	21 (26)	82 (25)	.886
Arterial status and previous revascularizations				
Any revascularization	256 (62)	82 (32)	21 (13)	<.001
Vein bypass	56 (14)	13 (23)	90 (25)	.868
Prosthesis bypass	31 (7.5)	10 (32)	93 (24)	.387
Femoral endarterectomy	37 (8.9)	12 (32)	91 (24)	.318
Aortoiliac surgical repair	9 (2.2)	3 (33)	100 (25)	.696
Aortoiliac endovascular repair	39 (9.4)	8 (21)	95 (25)	.566
Femoropopliteal endovascular repair	154 (37)	45 (29)	58 (22)	.127
Infrapopliteal endovascular repair	151 (37)	59 (39)	44 (17)	<.001

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Supplementary Table III (online only). Continued.

Dichotomous test variables		SWC rate in patients with test variable	SWC rate in patients without test variable	
Continuous test variables	**All BKAs and AKAs (n = 414)**	**Test value in patients with SWC (n = 103)**	**Test value in patients without SWC (n = 311)**	***P* value**
Preoperative functional status				
Needs helps in ADL	279 (67)	57 (20)	46 (34)	.004
Lives in nursing facility/ institution	137 (33)	24 (18)	79 (29)	.016
Nonambulatory	169 (41)	35 (21)	68 (28)	.107
Laboratory values				
Creatinine	83 (45-90)	80 (50-91)	83 (43-90)	.812
GFR	68 ± 31	70 ± 31	67 ± 31	.461
LDL[c]	2.1 ± 0.9	2.2 ± 0.9	2.0 ± 0.9	.184
CRP[d]	91 ± 87	83 ± 67	93 ± 92	.928
Leukocytes[e]	11.6 ± 4.7	11.2 ± 3.8	11.7 ± 4.9	.935
WIfI classification				
Deep ulcer (W)	357 (86)	86 (24)	17 (30)	.409
Severe local infection (fI)	181 (44)	39 (22)	64 (28)	.171
Operation-dependent factors[f]				
Operation time, minutes	65 ± 30	66 ± 28	64 ± 31	.535
Trainee as main operator	190 (50)	47 (25)	48 (26)	.906

ADL, Activities of daily living; *BKA*, below-knee amputation; *COPD*, chronic obstructive pulmonary disease; *CRP*, C-reactive protein; *DOAC*, direct oral anticoagulant; *GFR*, glomerular filtration rate; *LDL*, low-density lipoprotein cholesterol; *TMA*, transmetatarsal amputation; *WIfI*, Wound, Ischemia, and foot Infection.
Values are number (%), mean ± standard deviation, or median (interquartile range).
[a]Eigth BKA and 72 AKA patients who deceased within 30 days from index procedure without SWC were excluded.
[b]Available for 296 patients.
[c]Available for 224 patients.
[d]Available for 394 patients.
[e]Available for 413 patients.
[f]Available for 378 patients.

Supplementary Table IV (online only). The need for hospital resources in patients undergoing major lower limb amputation stratified by below-knee amputation (*BKA*) with surgical wound complication (*SWC*) vs above-knee amputation (*AKA*) with SWC and BKA without SWC vs AKA without SWC

	BKA with SWC (n = 62)	AKA with SWC (n = 41)	*P* value	BKA without SWC (n = 62)	AKA without SWC (n = 249)	*P* value
Hospital days	12 (7-18)	11 (7-15)	.248	6 (4-9)	3 (3-5)	<.001
Health care center days[a]	42 (14-89)	64 (14-114)	.702	29 (11-47)	33 (12-64)	.477
Hospital readmissions	0.9 ± 0.4	1.5 ± 1.1	.161	0.2 ± 0.7	0.1 ± 0.3	.782
Outpatient clinic visits	1.1 ± 2.6	1.8 ± 2.8	.016	1.5 ± 4.4	0.1 ± 0.7	<.001
Surgical revisions	0.8 ± 1.1	1.7 ± 1.2	<.001	-	-	-
At least 1 hospital readmission	53 (86)	35 (85)	1.0	6 (9.7)	22 (8.4)	.806
At least 1 outpatient clinic visit	19 (31)	23 (56)	.009	19 (31)	19 (7.6)	<.001
At least 1 surgical revision	29 (47)	40 (98)	<.001	-	-	-
Hospital readmissions, total	73	60		8	23	
Outpatient clinic visits, total	69	73		94	36	
Surgical revisions, total	51	69		-	-	

Patients who died within 30 days from index procedure without SWCs were excluded from SWC analyses.
[a]Data available in 91 BKA and 244 AKA patients.

Supplementary Table V (online only). The need for hospital resources in patients undergoing major lower limb amputation stratified by below-knee amputation (*BKA*) with surgical wound complication (*SWC*) vs above-knee amputation (*AKA*) without SWC and AKA with SWC vs AKA without SWC

	BKA with SWC (n = 62)	BKA without SWC (n = 62)	*P* value	AKA with SWC (n = 41)	AKA without SWC (n = 249)	*P* value
Hospital days	12 (7-18)	6 (4-9)	<.001	11 (7-15)	3 (3-5)	<.001
Health care center days[a]	42 (14-89)	29 (11-47)	.027	64 (14-114)	33 (12-64)	.006
Hospital readmissions	0.9 ± 0.4	0.2 ± 0.7	<.001	1.5 ± 1.1	0.1 ± 0.3	<.001
Outpatient clinic visits	1.1 ± 2.6	1.5 ± 4.4	.913	1.8 ± 2.8	0.1 ± 0.7	<.001
Surgical revisions	0.8 ± 1.1	-	-	1.7 ± 1.2	-	-
At least 1 hospital readmission	53 (86)	6 (9.7)	<.001	35 (85)	22 (8.4)	<.001
At least 1 outpatient clinic visit	19 (31)	19 (31)	1.0	23 (56)	19 (7.6)	<.001
At least 1 surgical revision	29 (47)	-	-	40 (98)	-	-
Hospital readmissions, total	73	8		60	23	
Outpatient clinic visits, total	69	94		73	36	
Surgical revisions, total	51	-	-	69	-	-

Patients who died within 30 days from index procedure without SWCs were excluded from SWC analyses.
[a]Data available in 91 BKA and 244 AKA patients.