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Analysis of Doppler ultrasonography and computer tomography angiography for predicting amputation level and re-amputation rate

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ABSTRACT

OBJECTIVE: Peripheral arterial disease of the lower extremities is one of the most common causes of non-traumatic lower extremity amputation. Computed tomography (CT) angiography and Doppler ultrasonography are mainly used to evaluate distal vascular structures. Our objective was to evaluate the predictive efficacy of Doppler ultrasound and CT angiographic radiographic examinations in determining amputation levels and reamputation rates in patients undergoing lower extremity amputation.

METHODS: Patients with major or minor amputation at various levels due to lower extremity lesions were included in the study. Standard demographic information, clinical accompanying diseases, reamputation datas, Doppler ultrasound, and CT angiography radiological evaluation reports were obtained retrospectively from the hospital system records of the patients.

RESULTS: A total of 166 cases including 119 (71.7%) males and 47 (28.3%) females were included in the study. About 36.7% (n=61) cases had amputation at the level of surgery above the knee, 38.6% (n=64) below the knee and 24.7% (n=41) at the level of foot/finger. In patients who underwent amputation above the knee, occlusion was seen at the level of the iliac artery (88.9%), femoral artery (47.8%), and popliteal artery (37%). The rate of occlusion at the level of the popliteal artery in patients with below-knee amputation (59.3%) was found in patients with foot/finger amputation (51.5%) at the levels arteria dorsalis pedis and posterior tibial artery. According to the level of occlusion at all blood flow levels, it was observed that the rate of reamputation was most common in occlusions at the level of popliteal artery.

CONCLUSION: It was found that radiological data are effective in planning amputation according to blood flow level and does not make any difference per se. It was found that the reamputation rates were related to the determination of the level of blood flow in the primary surgical phase.

Keywords: Amputation; angiography; Doppler ultrasound; limb.

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Peripheral arterial disease of the lower extremities has a spectrum ranging from asymptomatic clinical condition to critical leg ischemia and limb loss. Diabetes and peripheral arterial disease due to ischemia are the most common causes of non-traumatic lower extremity amputations [1, 2]. Peripheral artery disease is observed at a rate of 2–5% in the age group of 50–60 years, while this rate reaches 15% in the population older than 70 years. Moreover, 80–85% of all amputations involve the lower extremities [3–5]. Although drug treatment and interventional radiological methods improve symptoms and disease progression in

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many stages of the disease, this effect is often insufficient in advanced stages of the disease and amputation is inevitable. Patients in this group not only bear the risk of amputation, but also the risk of residual limb complications and reamputation.

Amputation surgery is an important treatment modality to remove necrotic tissue from the body, reduce metabolic burden, and enable the patient for mobilization [6]. The goal of this surgical procedure is to obtain a limb stump that is painless, functional, and as long as possible. At this stage, it is important to determine the most appropriate amputation level. Failure to determine the appropriate primary amputation level is one of the main reasons for reamputation, and reamputation rates of 15–40% have been reported [7, 8]. Computed tomography (CT) angiography and color Doppler ultrasonography (C-DUS) are mainly used to assess distal vascular structures. These methods are used to determine distal flow and for surgical planning in extremities with critical ischemic symptoms.

In this study, we investigated the re-amputation rates and predictive efficiency of C-DUS and CT angiographic radiological examinations in determining the level of amputation in patients undergoing lower limb amputation.

MATERIALS AND METHODS

The study included 166 patients who had undergone major or minor amputation at various levels due to the lower extremity injuries. This study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics committee of Haydarpasa Numune Training and Research Hospital (HNEAH-KAEK 2020/218-2991). Diabetic foot patients presenting to the orthopedic clinic for limb amputation were retrospectively enrolled between 2016 and 2020, after all stages of the amputation and treatment process had been identified. Patients' health status and comorbidity were classified according to the criteria of ASA. The amputation decision for the patients was made considering the following criteria that accompany the committee's evaluation of diabetic foot in diabetic patients and cardiovascular surgery in non-diabetic patients:

- Changes in skin color, malodorous wound, osteomyelitis with skin and soft-tissue necrosis, loss of plantar sensation, septic with exudative prulent discharge and unresponsive wound, 4th and 5th degree wounds.
- Radiographic changes associated with gas and osteomyelitis in soft tissue on radiographic evaluations and the presence of findings supported by the absence of a specific level of total occlusive blood flow on C-DUS and/or CT angiography and the ABI index below 0.5.

For amputation, the appropriate level and shape were determined by establishing the absence of necrosis, infection findings, and adequate blood flow. Surgery was planned and performed quickly and electively to reduce pain, relieve the body of the burden of the necrotic portion, and improve function. Patients were then followed up for wound care and, in appropriate patients, for use of prosthesis. Completely healed skin tissue, warming of the wound stump and no signs of infection were accepted as complete healing.

Standard demographic information (age, sex, and side), concomitant clinical conditions (presence of diabetes, renal insufficiency, and the previous ipsilateral lower extremity vascular procedures), elapsed time in patients undergoing reamputation, length of hospital stay, and radiological evaluation reports of C-DUS and CT angiography were retrospectively obtained from hospital records. Surgical reports were evaluated by amputation level, with amputations starting at the ankle counted as major amputations. Patients who underwent a new ipsilateral amputation at any level were defined as having reamputation procedures. Reamputation procedures were considered to be any higher level amputation, including above the knee, below the knee, foot (transmetatarsal, Lisfranc, or Chopart procedures), or Metatarsal Ray. Same-level residual limb revision procedures and amputations for nonvascular reasons (traumatic amputations, malignancies, congenital anom-

Highlight key points

- It was found that 89% of patients who underwent reamputation surgery had a major amputation corresponding to the final amputation level.
- Radiologic evaluations were effective in determining the level of amputation, especially for above-the-knee amputations.
- It was found that there was no difference between C-DUS and CT angiography in determining the level of amputation and also in the rates of reamputation according to the level determined.
- Age (especially in patients aged 5.6 decades) was a negative factor in determining the level of amputation.

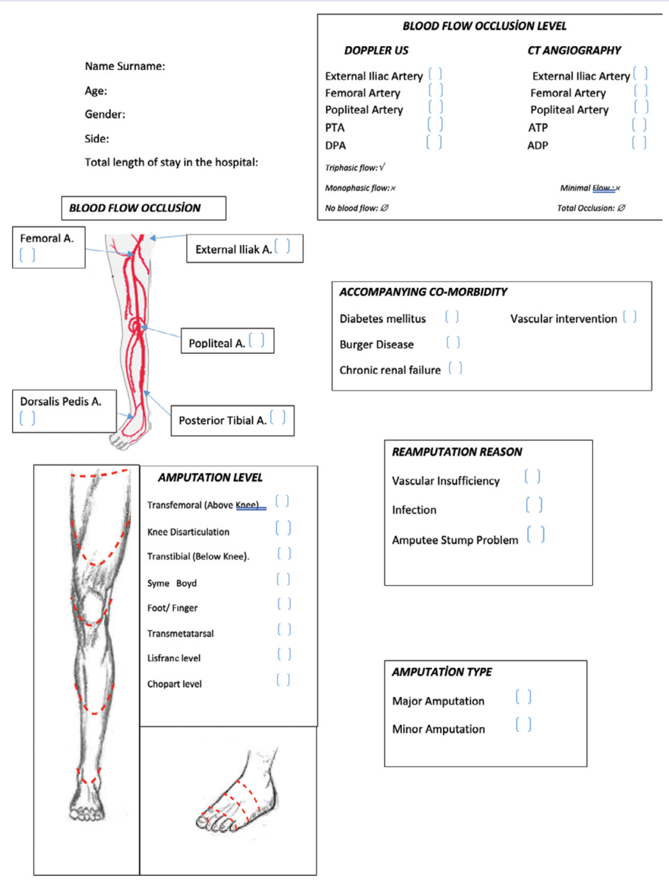

FIGURE 1. Data collection scheme for patients with the lower limb amputation.

alies, and bilateral lower extremity amputations) were excluded from the study. For each patient, the data of the patients were marked on the chart in Figure 1 and the findings were recorded. For each patient, the blood flow and the degree of primary amputation or reamputation were determined. The current value and accompanying differentials such as amputation level, age, and comorbidity in patients who underwent reamputation were compared with those of primary amputees.

Radiological Evaluation

In the study, convex probes of 3.5 Mhz and linear probes of 7.5 Mhz were used for C-DUS (Toshiba Aplio 500). In C-DUS technique, patients were examined in supine position from lower abdominal region to ankle. In C-DUS evaluation, peak systolic velocity (PSH), PSH ratio (PSHO), flow shape, and spectral changes were studied. The PSHO value in each stenotic segment was determined by the ratio of the velocity in the stenotic zone to the velocity of the normal-appearing vessel segment in the prestenotic zone. In the evaluation, a PSHO value ≥2 was assumed to be significant hemodynamic stenosis (>50% stenosis) and 2 was assumed to be no significant hemodynamic stenosis.

CT angiography of the lower extremities was obtained using a device with 128 detectors CT (GE OPTİMA 660 Medical Systems). Standard images were acquired in 30–40 s from the level of the bifurcation of the common iliac artery to the ankle. The non-ionic contrast agent was 350 mg/100 mL (iohexol) administered at a rate of 4 mL/s. Subsequently, 50 mL of saline was administered as a bolus. An area of interest (ROI) was defined in the abdominal aorta, and imaging was started at a threshold of 180 HU. The structural features of the plaques were classified as non-calcified (50 HU), mixed (60–100 HU), and calcified (>130 HU).

Statistical Analysis

When evaluating the findings obtained in the study, IBM SPSS Statistics 22 for statistical analysis (SPSS IBM, Turkey) programs was used. While evaluating the study data, the suitability of the parameters to the normal distribution was evaluated with the Shapiro–Wilks test. While evaluating the study data, descriptive statistical methods (mean, standard deviation, frequency) as well as the One-way ANOVA test were used for comparing normally distributed parameters between groups in comparison of quantitative data. Kruskal–Wallis test was used for intergroup comparisons of parameters not showing normal distribution, and Dunn's test was used to determine the group that caused the difference. Chi-square test and Fisher Freeman Halton test were used to compare qualitative data. Significance was evaluated at $p<0.05$ level.

RESULTS

A total of 166 cases including 119 (71.7%) males and 47 (28.3%) females were included in the study. The age of the patients ranged from 26 to 98 years, with a mean age of 66.73±13 years. Surgery was performed above the knee in 36.7% (n=61) of cases, below the knee in 38.6% (n=64), and foot/finger amputation in 24.7% (n=41) of cases. Primary amputation was performed in 59% (n=98) of cases and reamputation in 41% (n=68). Of the patients who underwent primary amputation, 69% (n=68) had a major amputation and 31% (n=30) had a minor amputation. According to the final amputation level of the reamputated patients, 89% (n=57) were ma-

Table 1. Distribution of demographic characteristics

Gender	
Male	71.7%; n: 119
Female	28.3%; n: 47
Side	
Right	58.4%; n: 97
Left	41.5%; n: 69
Age group	
0–30 years	1.2%; n: 2
30–40 years	1.2%; n: 2
40–50 years	6%; n: 10
50–60 years	20.5%; n: 34
60–70 years	29.5%; n: 49
70 years and over	41.6%; n: 69

jor amputations and 16% (n=11) were minor amputations. The distribution of cases by age: 1.2% between 0 and 30 years, 1.2% between 30 and 40 years, 6% between 40 and 55 years, 20.5% between 50 and 60 years, 29.5% between 60 and 70 years, and 41.6% over 70 years. The distribution by clinical characteristics is shown in Table 1. According to the results of C-DUS and CT angiography evaluation of the patients, there is no statistically significant difference between the two radiological examination methods in terms of primary or reamputation rates depending on the occlusion level and in determining the final amputation level (p=0.05) (Table 2, 3).

There is a statistically significant difference in blood flow levels in patients amputated above the knee (p=0.001; p=0.05). Occlusion of the iliac artery (88.9%) was significantly higher in amputations above the knee. Occlusions of the femoral artery (47.8%) and popliteal artery (37%) were significantly more frequent (p1: 0.031; p2: 0.018; p3: 0.000; and p: 0.05). The occlusion rate at the level of the popliteral artery (59.3%) was statistically significantly higher than the occlusion rate of the iliac artery (11.1%) and the dorsalis pedis/posterior tibial artery (ADP/PTA) (30.3%) in patients undergoing transtibial amputation (p1: 0.020; p2: 0.047; p 0.05). Occlusion at the level of the ADP/ATP artery was statistically significantly higher in patients undergoing foot/finger amputation compared to the level of the iliac artery (0%), femoral artery (17.4%) and popliteal artery (3.7%) (p1: 0.006; p2: 0.003; p3: 0.000; and p 0.05). The distribution of blood flow values and amputation rates is shown in Table 4.

Table 2. Evaluation of primary amputation and reamputation rates according to occlusion at the Iliacartery, Femoralartery, Poplitealartery, and ADP/ATP level in ColorDoppler US

Doppler US level	Primary amputation		Reamputation	
	n	%	n	%
Iliacartery	0	0	1	100
Femoralartery	8	34.8	15	65.2
Poplitealartery	5	38.5	8	61.5
ADP/ATP	15	57.7	11	42.3
P	0.295		0.295	

Fisher Freeman Halton Test. ADP/ATP: Artery dorsalis pedis/posterior tibial artery; CT: Computer tomography.

Table 3. Evaluation of primary amputation and reamputation rates according to occlusion at the iliac artery, femoral artery, popliteal artery, and ADP/ATP level in CT angiography

CT angiography level	Primary amputation		Reamputation	
	n	%	n	%
Iliac artery	5	45.5	6	54.5
Femoral artery	21	58.3	15	41.7
Popliteal artery	7	38.9	11	61.1
ADP/ATP	7	63.6	4	36.4
P	0.458		0.458	

Chi-square test. ADP/ATP: Artery dorsalis pedis/posterior tibial artery; CT: Computer tomography.

There is no statistically significant association between concomitant diseases (DM, Burger, Renal Failure) and the number of surgeries in patients who underwent reamputation (p=0.05) (Table 5).

It was found that the number of hospital days was statistically significantly lower in patients with 2 or fewer operations than in patients with 3 or more operations (p1: 0.004; p2: 0.000; p 0.05). When the number of surgeries increased to 3 or more, it was found that there was no statistical difference between the number of surgeries and the length of hospital stay (p=0.05). When the association between level of surgery and length of hospital stay was evaluated, it was found that the length of stay of patients who had above knee surgery was statistically significantly higher than those who had foot/finger level amputation (p: 0.003; p 0.05) (Table 6).

TABLE 4. Evaluation of blood flow and amputation rates and levels according to findings

Blood flow level	Reamputation		Above-knee amputation		Below knee amputation		Foot/finger amputation	
	n	%	n	%	n	%	n	%
Iliacartery	4	44.4	8	88.9	1	11.1	0	0
Femoralartery	24	52.2	22	47.8	16	34.8	8	17.4
Popliteal artery	15	55.6	10	37	16	59.3	1	3.7
ADP/ATP	14	42.4	6	18.2	10	30.3	17	51.5
P	[1]0.753		[2]0.001*		[2]0.029*		[2]0.000*	

ADP/ATP: Artery dorsalis pedis/posterior tibial artery; 1: Fisher freeman halton test; 2: Chi-square Test; *: P<0.05.

TABLE 5. Demographic and co-morbidity distribution of patients with two or more reamputations

Number of operations group	n	Age	Days of hospitalization		DM		Burger		CRF	
		Mean±SD	Mean±SD	Median	n	%	n	%	n	%
Number of operations 2	51	66±12.4	11.69±6.12	11	41	80.4	29	56.9	8	15.7
Number of operations 3	12	61.58±14.88	20.5±13.69	15	11	91.7	4	33.3	2	16.7
Number of operations 4	3	57.67±8.5	36.67±11.55	30	3	100	1	33.3	1	33.3
Number of operations 5	2	58±4.24	35±0	35	2	100	0	0	0	0
P		[1]0.256	[2]0.000*		[3]0.613		[3]0.153		[3]1.000	

SD: Standard deviation; DM: Diabetis mellitus; CRF: Cronic renal failure; 1: One-way ANOVA test; 2: Kruskal–Wallis Test; 3: Fisher Freeman Halton Test; *: P<0.05.

TABLE 6. Evaluation of the number of operations and days of hospitalization according to the operation level

Amputation level	Number of operations			Days of hospitalization		
	Min–Max	Mean±SD	Median	Min–Max	Mean±SD	Median
Above knee	1–4	1.66±0.68	2	2–50	10.26±8.38	8
Below knee	1–5	1.5±0.8	1	2–35	7.86±6.41	5
Foot/finger	1–5	1.49±0.98	1	2–58	9.2±11.83	4
P		0.045*			0.009*	

SD: Standard deviation; Min: Minimum; Max: Maximum; Kruskal Wallis Test; *: P<0.05.

DISCUSSION

Amputation surgery is 75% more common in men, and 80–85% of these amputations involve the lower extremities. The most common cause of non-traumatic lower extremity amputations is diabetes and peripheral arterial disease due to ischemia [9–11]. Peripheral vascular disease occurs due to many pathologies affecting the vascular structure, such as diabetes, atherosclerosis, Reynaud's disease, and thromboangitis obliterans (Burger's)

[12–14]. In our study, it was found that the percentage of male patients was higher. It was found that there were similar concomitant diseases (diabetes mellitus [DM], chronic renal failure [CRF], Burger) and concomitant comorbidity had no particular impact in re-amputation surgeries compared to primary amputation surgeries. Fard et al. [15] found that severe vascular disease could be an indicator of mortality, especially in patients who had transfemoral amputation or major lower extremity amputation, and also DM, past revascularization and previous minor or major LLA did not affect mortality rates. In our study, it was found that primary or reamputation cases who underwent major amputation had signs of vascular disease. It was found that 89% of patients who underwent reamputation surgery had major amputation according to the final amputation grade. It was found that the most common concomitant diseases in reamputation cases were DM, Burger and CRF.

In assessing the relationship between age and amputation rates, it was found that primary amputation rates were higher in patients over 70 years of age than in reamputation patients. However, reamputation rates did not show parallelism with the increase in age. On the contrary, it was found that reamputation rates and the number of reamputations were higher at a lower age. It was found that age (especially in patients with age of 5.6 decades) was a negative factor in determining the level of amputation (expectation, inability to accept amputation, treatment effort, etc.), and this affected the reamputation rates.

The main finding of the study was that radiographic evaluations were effective in determining the level of amputation, especially for amputations above the knee. Occlusion at the level of the iliac artery resulted in 88.9% of amputation above the knee, and this rate was higher than that of occlusion at the level of the femoral artery (47.8%). In addition, the rate of reamputation was found to be lower for occlusions at the level of the iliac artery than for occlusions at the level of the femoral artery. When comparisons were made by level of occlusion, it was found that the rate of reamputation occurred primarily in occlusions at the level of the popliteal artery. It was observed that occlusions at the level of the popliteal fossa ended in amputation below the knee (59.3%), while the rate of amputations above the knee was close to this value (37%). It was found that obstruction of the arterial groups ADP and PTA resulted in minor amputations to a significant extent (51.5%). It was found that obstruction above ADP and PTA did not lead to minor amputations.

The results of C-DUS and CT angiography were evaluated separately, and it was found that there was no difference between the two methods in determining the level of amputation, nor was there a difference in reamputation rates depending on the level determined. Martinelli et al. [16] compared CT angiography and C-DUS for distal flow assessment in patients with critical lower extremity ischemia and found that RDUSG assessments performed by well-trained operators could be an alternative to CT angiography. In addition, it was noted that in cases where adequate distal flow cannot be determined and the decision to use a surgical approach is inadequate, a complete review can be performed with the imaging modality of CT angiography. In studies comparing C-DUS and CT angiography in lower extremity ischemia, CT angiography was found to provide anatomic assessment because it allowed for a three-dimensional examination [17, 18]. However, it has been noted that CT angiography cannot fully reflect the hemodynamic data of the peripheral arterial lesion, as only the luminal filling is visualized, and that it has technical limitations in some lesions, especially in severe proximal stenoses, such as not being able to detect the presence of small peripheral stenoses [19–21]. The limitations of the C-DUS method are the inability to assess all arterial structures (deep-seated arterial structures in obese patients) and the need for a very careful and long-term examination to detect the presence of complete occlusion and severe stenosis. In this method, the patient's factors (obesity, widespread edema, presence of flatulence, open wounds, and the surgical area) lead to some further limitations [22–24]. In our study, when Doppler USG and CT angiography of the arterial system were evaluated, no difference was found between the two methods in the group of patients with end-stage necrosis and planned amputation.

For concomitant diseases, the presence of common concomitant diseases such as DM, CRF and ischemic peripheral vascular disease was investigated, whereas the presence of concomitant diseases such as smoking, hypertension, dyslipidemia and obesity, which may affect amputation and the course of treatment, was not investigated. With a higher number of patients, the concomitant disease profile can be more comprehensively assessed. In addition, further analysis of amputation/reamputation surgery could be explored by adding analysis values for patient cost and mortality and comparing them with radiological examination results. In the study, minor amputation surgeries were performed by considering only one of the ADP and PTA occlusions that was completely occluded. ADP and PTA arterial occlusions could be evaluated separately by considering which anatomical region of the foot (finger, Chopart, Lisfrank, transmetatarsal) was amputated. In addition, knee disarticulations, Syme and Boyd amputations are not commonly performed in our hospital. The inclusion of this group of patients will make the study even more valuable.

Although no treatment suggestions could be made due to the observational nature of this study, it was concluded that reamputation rates should be considered when determining the level of patients eligible for amputation surgery. In evaluating the amputation results, it was found that radiological data were effective in planning the level of amputation according to the level of blood flow and that these methods did not make a difference on their own. In addition, it was found that reamputation rates were related to blood flow during the primary surgical phase and that concomitant diseases did not affect the process, and that patient age had an effect on the number and rates of reamputations in amputation surgery.

Ethics Committee Approval: The Haydarpasa Numune Training and Research Hospital Clinical Research Ethics Committee granted approval for this study (date: 09.11.2020, number: HNEAH-KAEK 2020/218-2991).

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Authorship Contributions: Concept – LA; Design – LA, BK; Supervision – LA, BK; Materials – LA; Data collection and/or processing – BK; Analysis and/or interpretation – LA; Literature review – LA; Writing – LA, BK; Critical review – BK.

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