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The wound area as a parameter guiding the timing of abdominal closure in the management of patients undergoing open abdominal procedures

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Abstract. – OBJECTIVE: Surgical site infections (SSI) are incomparably troublesome and complicated, and some of them require an open abdomen (OA) procedure. While deciding the timing of abdominal closure, wound area calculation method and laboratory parameters can be used to guide the timing of abdominal closure after OA procedures.

PATIENTS AND METHODS: The records of the patients who had undergone open abdomen during their treatment course and were followed up with vacuum-assisted closure (VAC) technique between December 2015 and December 2019 were retrospectively analyzed. The laboratory results before the first VAC application and the results after the VAC change were compared to determine a predictive parameter. The ImageJ program was used in five patients to compare the size of the wounds at the time of the decision to close them and before the first VAC application.

RESULTS: 102 patients were analyzed. The ratio of the last wound area to the wound area at the time of the first VAC application in five patients was 0.30, 0.41, 0.34, 0.27, 0.46 (mean: 0.36, standard deviation: 0.078) which were measured and calculated by ImageJ software.

CONCLUSIONS: We think that the concept of wound reduction ratio, which was calculated by a computer program, can be used as a concrete equivalent of the wound closure eligibility criteria decided by clinical experience.

Key Words:
Open abdomen, Vacuum-assisted closure, Wound area, Computer program, ImageJ.

Introduction

The surgical site infection (SSI) rate has declined in the past 30-40 years due to improvements in medical, surgical, and postoperative care conditions, but SSIs are still encountered in practice[1]. Despite developments in sterility, antibiotic therapy, and patient care conditions, SSIs are challenging complications to treat[2].

Although the response to inflammation is systemic, fluid rich in pro-inflammatory mediators that form in the intraperitoneal area may cause inflammation to persist, with progression toward multiorgan failure[3,4]. Various methods have been developed to remove these pro-inflammatory mediators from the environment in patients with open abdomens (OAs)[5]. Regardless of the method used, however, the likelihood that complications (e.g., intraabdominal adhesions, enteroatmospheric fistulas, and fluid-electrolyte imbalance) will develop increases with the length of the follow-up period[6,7]. Thus, the abdomen should be closed as soon as possible in such cases[8].

The literature contains no objective scale for the timing of abdominal closure, which is usually determined based on physicians' clinical experience. Methods based on the wound volume and area have been described[9-11], but they have been used mainly to follow lower-extremity ulcers. No data on the application of such methods to guide the timing of abdominal closure in patients with OAs are available.

This present study aims to identify a wound area calculation method and analyze possible laboratory parameters that can be used to guide the timing of abdominal closure after OA procedures.

Patients and Methods

The Ethics Committee of the Sakarya University School of Medicine approved this study and the data collection (No. 71522473/0.50.01.04/78).

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The records of patients whose management required OA procedures for any reason and who subsequently underwent vacuum-assisted closure (VAC) between December 2015 and December 2019 at the Department of General Surgery, Sakarya University Faculty of Medicine, were retrospectively analyzed. Patients who developed enteroatmospheric fistulas during the clinical follow-up period after VAC or who had significant risk factors known to affect wound healing (i.e., presence of metastatic malignancy, malnutrition, chronic steroid use, uncontrolled diabetes, recent chemotherapy and/or radiotherapy, and chronic diseases with vasculitis affecting the connective tissue) were excluded. Patients with chronic diseases or incomplete records and those who could not be reached for follow-up were also excluded. The Charlson Comorbidity Index (CCI) was used for comparison because the included patients constituted a heterogeneous group in terms of age, primary etiological cause, comorbidities, and surgical history.

A VAC system (ABThera; KCI, San Antonio, TX, USA) was used after the wounds were debrided and washed with the saline solution under operating room conditions. This system employs a 25-mm-thick polyether reticulated polyurethane hydrophobic sponge with 1.24-mm-diameter pores. It applies 500 mmHg negative pressure periodically for 5 minutes at 2-minute intervals. The VAC system was changed every 3 days unless a technical problem was encountered.

The patients' laboratory parameters and neutrophil (neu)/lymphocyte (Lym) ratio were determined before and after VAC application, and during clinical follow-up when necessary. All evaluations were performed using routinely taken blood samples; no additional blood was collected to determine laboratory parameters for this study. Laboratory results obtained before the first VAC application were defined as the baseline values, and those obtained after VAC system changes were defined as the control values.

The same surgical team evaluated all patients' wound sites visually under operating room conditions when the VAC systems were changed, and photographs were taken. Wound closure decisions were made with consideration of the patients' laboratory parameters and clinical conditions after a visual wound evaluation. Wound closures were performed one by one with non-absorbable sutures after the placement of at least one suction drain under each wound's skin flap.

A flat area of approximately 1 cm at the edge of each wound was identified. Photographs were taken vertically and from a distance of 0.5 m to cover the entire wound. The photographs were transferred to a computer. In five patients whose photograph quality was suitable to be used to calculate wound area, wound areas were calculated using ImageJ software (National Institutes of Health, Bethesda, MD, USA; http://ImageJ. Net/ImageJ) based on the known length of the wound edge portion. These procedures were repeated and recorded separately for each of the five patients before the first VAC application and each VAC change. For patients whose wounds were scheduled to be closed, the change in the wound area (calculated using the shrinkage rate, rather than the net wound area) and the proportion of the area in which granulation tissue had developed were determined by comparing the first and last wound parameters. The granulation tissue area was defined as a red-pink area with bleeding and minimal trauma, but no dead (black/gray/brown) tissue.

Statistical Analysis

Descriptive analyses were performed to provide information on the general characteristics of the study population. Numerical variables are presented as means ± standard deviations or medians (interquartile ranges). Categorical variables are presented as counts and percentages. p values < 0.05 were considered to be significant. Repeated-measures analysis of variance was used to compare hematological parameters between baseline and VAC control periods. All analyses were performed using IBM SPSS Statistics software, version 23.0 (IBM Corp., Armonk, NY, USA).

Results

The records of 117 patients were analyzed. One (0.8%) patient developed vasculitis (Behçet's disease), two (1.5%) patients could not be reached for follow-up, two (1.5%) patients were using chronic steroids, two (1.5%) patients had uncontrolled diabetes, five (3.9%) patients had incomplete records, and three (2.3%) patients developed grade 3-4 enteroatmospheric fistulas (according to the classification of Björck et al[12]; Table I) during the clinical follow-up period and were excluded from the study.

Table I. Björck classification of open abdomen.

Grade	Definition
IA	Clean open abdomen without adherence between the bowel and abdominal wall or fixity (lateralization of the abdominal wall)
IB	Contaminated open abdomen without adherence/fixity
IIA	Clean open abdomen developing adherence/fixity
IIB	Contaminated open abdomen developing adherence/fixity
III	Open abdomen complicated by fistula formation
IV	Frozen open abdomen with adherent/fixed bowel; unable to close surgically; with or without fistula

Fifty-three (52%) of the remaining 102 patients underwent surgery for reasons other than malignancy and 49 (48%) patients underwent surgery for gastrointestinal malignancy. Fifty-eight (56.8%) of the patients were females and 44 (43%) were males; their mean age was 62.86 ± 15.41 years. The mean duration of hospitalization was 22.82 ± 22.27 days among patients with a mean CCI of 4.72 ± 1.77. The patients' demographic characteristics are summarized in Table II.

No significant difference was found between the baseline hemoglobin (Hb) value and any control (VAC change) Hb value in any patient. No significant difference was found between the baseline and any control (VAC change) white blood cell (WBC) counts. No difference was found between the baseline neutrophil (Neu) value and any value of the control. Significant differences between baseline and control lymphocyte (Lym) values were observed for patients who underwent two (1.36 K/μL ± 1.09 *vs.* 2.04 K/μL ± 1.36, $p = 0.025$) and five (1.11 K/μL ± 0.57 *vs.* 1.55 K/μL ± 0.86, $p = 0.026$) VAC changes, but not for those who underwent any other number of VAC changes. The baseline and control Neu/Lym ratios also differed significantly in patients who underwent two (8.28 ± 7.4 *vs.* 4.3 ± 3.44, $p = 0.014$) and five (12.43 ± 14.19 *vs.* 8.25 ± 10.25, $p = 0.022$) VAC changes, but not in other groups.

Table II. General characteristics of the study population.

Patient variables	
Height (cm)	164.63 ± 7.75
Weight (cm)	78.82 ± 13.62
Age (year)	62.86 ± 15.41
Hospitalization duration (day)	22.82 ± 22.27
Charlson comorbidity index	4.72 ± 1.77
Gender	
Female	58 (56.8%)
Male	43 (42.2%)
Type of surgery	
Emergency abdominal surgery not for malignancy (n)	39 (38.6%)
Elective abdominal surgery not for malignancy (n)	14 (13.9%)
Emergency oncological surgery (n)	12 (11.9%)
Elective oncological surgery (n)	36 (35.6%)

Insufficient data were available to detect differences in the C-reactive protein (CRP) and total protein values. No significant difference between the baseline and control albumin (Alb) values was observed in patients who underwent one or two VAC changes. However, these values differed significantly in patients who underwent three (2.83 g/L ± 0.34 *vs.* 3.06 g/L ± 0.41, $p = 0.026$), four (2.54 g/L ± 0.32 *vs.* 2.85 g/L ± 0.33, $p = 0.007$), and five (2.61 g/L ± 0.49 *vs.* 2.79 g/L ± 0.46, $p = 0.012$) VAC changes. No significant difference between the baseline and any control platelet (Plt) count was found in any patient (Table III).

The ratios of the last wound area to the wound area at the time of initial VAC application in the five patients whose clinical conditions were evaluated and in whom VAC application was terminated, and whose wounds were subsequently closed, were 0.30, 0.41, 0.34, 0.27, and 0.46 (mean, 0.36; standard deviation, 0.078), respectively (Figures 1-3; Table IV).

Discussion

The fascia ideally should be closed during the early period (the first 5-8 days) after OA procedures are performed for various reasons. When the OA period is prolonged, the inflammatory process becomes chronic and the incidence of complications, such as enteroatmospheric fistula, increases[13]. Thus, various temporary abdominal closure methods have been developed for situations in which the fascia cannot be closed during the early period, and different closure

Table III. Follow-up changes of hematological parameters according to number of VAC changes.

		Number of VAC changes				
		1	2	3	4	5
Albumin (g/L)	n	11	13	16	10	27
	Baseline	3.2 ± 0.42	2.6 ± 0.54	2.83 ± 0.34	2.54 ± 0.32	2.61 ± 0.49
	3. day	3 ± 0.49	2.78 ± 0.34	2.84 ± 0.36	2.81 ± 0.2	2.72 ± 0.44
	6. day		2.79 ± 0.54	2.98 ± 0.34	2.78 ± 0.31	2.72 ± 0.35
	9. day			3.06 ± 0.41	2.88 ± 0.27	2.72 ± 0.32
	12. day				2.85 ± 0.33	2.88 ± 0.41
	15. day					2.79 ± 0.46
	p	0.71	0.317	0.026	0.007	0.012
	adj-*p**	0.484	0.656	0.675	0.645	0.023
C-reactive protein (mg/L)	n	3	3	6	1	4
	Baseline	23 ± 19.67	24.71 ± 19.72	61.97 ± 40.63	124	209.75 ± 152.68
	3. day	18.11 ± 20.99	8.32 ± 4.84	34.85 ± 15.5	87.4	89.7 ± 8.37
	6. day		4.78 ± 1.84	24.64 ± 23.42	23.8	93.1 ± 26.2
	9. day			30.78 ± 29.04	20.3	88.5 ± 33.47
	12. day				9.97	52.43 ± 24.3
	15. day					39.75 ± 33.03
	p					
	adj-*p**					
Hemoglobin (g/dL)	n	13	21	20	16	30
	Baseline	11 ± 2.09	10.54 ± 1.61	10.52 ± 1.19	9.74 ± 1.36	9.83 ± 1.66
	3. day	10.75 ± 1.3	10.64 ± 1.17	10.53 ± 1.34	10.14 ± 0.88	10.12 ± 1.17
	6. day		10.32 ± 1.35	10.43 ± 1.21	10.59 ± 1.92	10.38 ± 1.14
	9. day			10.58 ± 1.36	9.96 ± 1.02	10.02 ± 1.06
	12. day				10.26 ± 1.04	9.99 ± 1.15
	15. day				10.02 ± 1.01	
	p	0.549	0.308	0.842	0.604	0.103
	adj-*p**	0.077	0.723	0.402	0.172	0.787
Lymphocyte (K/µL)	n	13	21	19	16	30
	Baseline	1.96 ± 0.85	1.36 ± 1.09	1.43 ± 0.65	1.12 ± 0.83	1.11 ± 0.57
	3. day	2.12 ± 1.03	1.63 ± 1.14	1.61 ± 0.73	1.82 ± 1.48	1.36 ± 0.67
	6. day		2.04 ± 1.36	1.74 ± 0.89	1.55 ± 1.11	1.89 ± 1.64
	9. day			1.85 ± 0.93	1.53 ± 0.92	1.61 ± 0.83
	12. day				1.55 ± 0.98	1.66 ± 0.87
	15. day					1.55 ± 0.86
	p	0.233	0.025	0.239	0.196	0.026
	adj-*p**	0.388	0.21	0.47	0.134	0.389
MPV (fl)	n	13	19	20	14	28
	Baseline	7.25 ± 0.79	8.33 ± 1.48	8.07 ± 0.86	8.81 ± 1.44	8.49 ± 1.92
	3. day	7.57 ± 1.33	8.23 ± 1.2	7.99 ± 1.07	8.09 ± 1.33	8.01 ± 1.8
	6. day		8.08 ± 1.44	7.9 ± 1.17	7.92 ± 1.22	8.27 ± 2.67
	9. day			7.94 ± 1.19	8.1 ± 1.55	7.96 ± 1.67
	12. day				8.23 ± 1.78	7.93 ± 2
	15. day					8.11 ± 2.23
	p	0.263	0.768	0.824	0.091	0.132
	adj-*p**	0.144	0.954	0.91	0.979	0.769
Neutrophil (K/µL)	n	13	21	20	16	30
	Baseline	7.08 ± 5.1	6.8 ± 2.99	7.21 ± 3.38	8.41 ± 4.69	8.77 ± 4.45
	3. day	5.09 ± 2.39	6.68 ± 4.16	6.49 ± 2.48	9.5 ± 4.26	9.15 ± 5.3
	6. day		5.92 ± 3.04	6.19 ± 2.63	7.09 ± 3.08	8.71 ± 4.03
	9. day			7.17 ± 3.5	7.99 ± 4.23	7.75 ± 4.36
	12. day				8.16 ± 6.21	7.94 ± 6.95
	15. day					8.72 ± 11.17
	p	0.079	0.514	0.609	0.312	0.346
	adj-*p**	0.343	0.963	0.147	0.944	0.6

Continued

Table III *(Continued)*. Follow-up changes of hematological parameters according to number of VAC changes.

		Number of VAC changes				
		1	2	3	4	5
Neu/lym ratio	n	13	21	19	16	30
	Baseline	3.76 ± 1.95	8.28 ± 7.4	6.46 ± 5.04	15.76 ± 20.19	12.43 ± 14.19
	3. day	4.67 ± 8.64	9.12 ± 14.31	5.29 ± 4.51	10.68 ± 14.77	9.02 ± 7.53
	6. day		4.3 ± 3.44	4.56 ± 3.69	7.52 ± 6.49	7.09 ± 5.21
	9. day			6.7 ± 9.62	7.43 ± 5.43	5.97 ± 4.55
	12. day				11.5 ± 14.6	6.26 ± 5.95
	15. day					8.25 ± 10.25
	p	0.68	0.014	0.071	0.307	0.022
	adj-*p**	0.469	0.544	0.626	0.464	0.783
Platelet (K/μL)	n	13	21	20	16	31
	Baseline	309.08 ± 103.31	261.65 ± 104.08	306.5 ± 125.51	269.56 ± 93.43	304.37 ± 169.93
	3. day	274.54 ± 72.94	287.3 ± 149.26	366.25 ± 147.85	292.73 ± 112.69	309.86 ± 173.83
	6. day		312.19 ± 170.36	400.8 ± 184.14	359.03 ± 205.92	328.28 ± 173.07
	9. day			335.28 ± 150.17	300.41 ± 123.54	333.66 ± 168.64
	12. day				292.94 ± 143.1	327.76 ± 172.06
	15. day					317.28 ± 204.79
	p	0.096	0.109	0.098	0.427	0.803
	adj-*p**	0.782	0.203	0.35	0.34	0.305
Total protein (g/L)	n	2	2	1		
	Baseline	5.8 ± 0.14	5.15 ± 2.47	6.8		
	3. day	6.15 ± 0.35	5.55 ± 3.18	6.4		
	6. day		5.35 ± 2.9	7		
	9. day			7.9		
	12. day					
	15. day					
	p					
	adj-*p**					
White blood cell (K/μL)	n	13	21	20	16	
	Baseline	10.06 ± 5.78	9.09 ± 3.95	9.64 ± 3.41	10.35 ± 4.85	11.24 ± 5.52
	3. day	8.09 ± 3.15	9.06 ± 3.94	9.1 ± 2.86	11.98 ± 4.28	12 ± 6.28

*adj-*p*: Adjusted *p*-value: the *p*-value calculated by the Bonferroni method to eliminate type 1 error for the *p*-value determined by statistical methods. Mean Platelet Volume (MPV), vacuum-assisted closure (VAC).

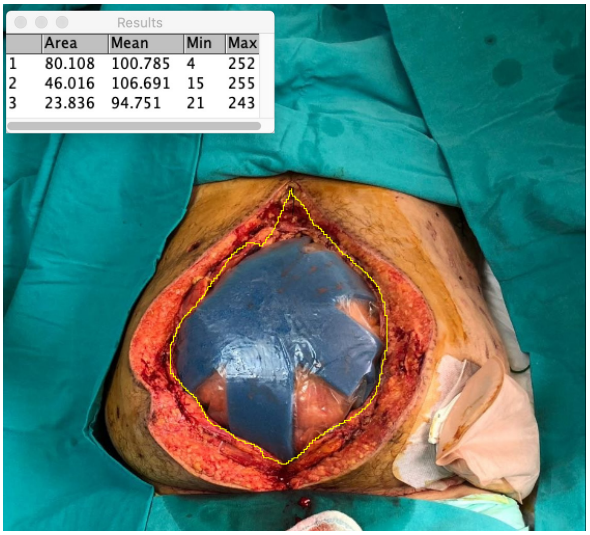

Figure 1. First VAC application of patient 1.

rates have been reported[7,8]. Methods such as skin closure and the Bogota bag application, which were very common historically, are still used today, but VAC systems are increasingly applied. In a study[14] of 239 patients, the rate of primary fascia closure was higher in patients who had undergone skin closure alone than in those who had undergone other procedures, but this method was preferred for patients with lower trauma scores; VAC application was preferred for patients who underwent damage-control surgery and had more severe trauma. In another study[15], the rate of primary fascia closure after VAC application was 31%. Apart from abdominal closure, VAC systems are useful for the evacuation of exudate from the wound area, reduction of edema, increase in tissue oxygenation, reduction of the bacterial load, increase in angiogenesis *via* increases

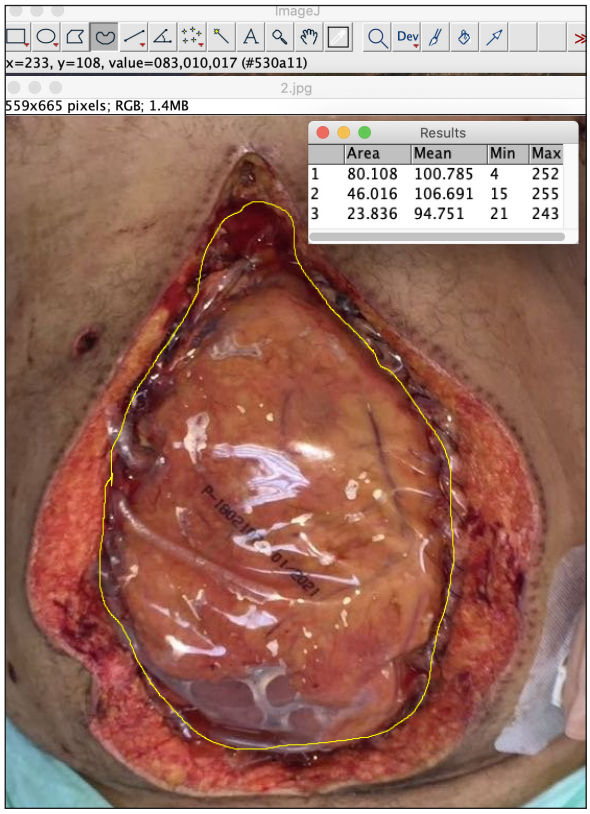

Figure 2. Mid-treatment of patient 1.

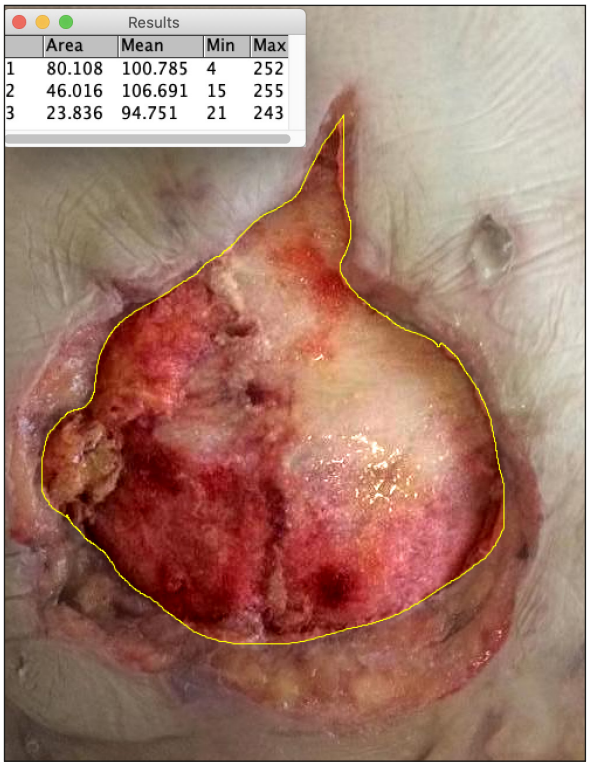

Figure 3. Before the wound closure of patient 1.

in the local concentrations of interleukin-8 and vascular endothelial growth factor, and acceleration of granulation tissue development and wound contraction[16,17]. In our clinic, VAC application is the first choice for patients who undergo OA procedures; skin closure or Bogota bag application is performed only when a VAC system cannot be used for various technical reasons.

The WBC count is a useful parameter for the prediction of prognosis and mortality in many clinical situations, such as in the context of acute coronary syndrome, acute cerebral ischemia, or acute appendicitis, and for the prediction of kidney loss in patients with diabetes mellitus[18-21]. The Neu/Lym ratio, mean Plt volume, Plt number, and Hb, Alb, and CRP concentrations are among the parameters whose predictive ability in various clinical situations has been investigated[22-29]. These parameters have been used to predict mortality in patients with pneumonia, the progression of various gastrointestinal malignancies, and the activation of ulcerative colitis and to diagnose testicular torsion. In our study, the significant differences found between groups of patients who underwent different numbers of VAC changes could not be used to predict the number of VAC changes or to determine the timing of abdominal closure because the patients in

Table IV. Wound area calculation by using the ImageJ.

Patient	First VAC application (cm^2)	In the middle of the treatment process (cm^2)	Before wound closure (cm^2)	The ratio of the latest area of the wound to the first area calculated before treatment (cm^2)
1	80.108	46.016	23.836	0.30
2	89.607	52.512	36.738	0.41
3	35.403	28.104	12.038	0.34
4	51.798	36.048	13.985	0.27
5	45.529	41.314	20.488	0.46

our study had OAs and thus were quite different from those included in other studies in which these parameters were evaluated. These parameters have generally been used to determine the presence or absence of single clinical conditions or to predict prognosis. In contrast, patients with OAs have more than one clinical issue that requires follow-up in an intensive care setting. Moreover, maintenance processes performed in these patients can be quite long and include blood and blood product (e.g., thrombocyte and Alb) transfusion. Thus, these laboratory parameters may not be useful for the evaluation of the degree of wound healing.

The absence of peritonitis, the sufficiency of the abdominal domain after fascia closure and the absence of visceral edema should be considered when making decisions about fascia closure[13,30]. In our clinic, the decision to terminate VAC and close a patient's OA is made after systemic investigation for sepsis, determination that the abdominal domain is sufficient, and consideration of granulation tissue development and the wound reduction rate. Thus, the decision is based on clinical experience.

Wound area calculation using computer programs and medical treatments for open wounds have been described in the literature, and positive results have been reported. However, the results reported[31,32] for wound area measurement have been limited to the nonsurgical maintenance of open wounds (i.e., diabetic ulcers, pressure sores, and those caused by venous obstruction); no data on the use of this method in patients with OAs are available. With this method, wounds are evaluated according to evidence-based medicine. Treatment effectiveness is observed and recorded objectively, and this method enables easy comparison of the same types of wound[33]. However, the calculation of wound area entails a certain amount (10-44%) of error. Methods such as digital planimetry and the use of three-dimensional cameras have been developed to reduce this margin of error[11,31], but their application in patients with OAs during all VAC changes does not seem to be convenient in terms of cost and sterility requirements. Photographs can be transferred easily to the ImageJ program, and the ratio of reduction from the initial wound state can be determined by measuring the wound area. The advantages of this method are that it entails no additional cost, that many images can be obtained, and the most appropriate ones can be selected. Most importantly, errors made in area calculation are negligible, as we use the shrinkage rate instead of the net wound area. However, clinical decision-making cannot rely on artificial intelligence. Clinical experience, treatment and care opportunities of the medical facility, patient conditions such as co-morbidities and immune status, and pathophysiology of the wound and infection should also be evaluated. As the use of computerized systems and artificial intelligence is gradually increasing in all fields of life, it is inevitable that they will be used in the medical field. However, the integration of such systems will be easier and more efficient when patient and disease factors are adopted into the algorithms of the computer systems. In the design of such interpretive technological algorithms or systems, objective measurements are the most dependable variables. On the other hand, the individuality of the patient and the uniqueness of the disease should never be underestimated[34-36]. From this point of view, the major limitation of scientific research is the question of whether other variables related to the patient and disease are not included in the algorithm. Another limitation of this study is that the study is retrospective; therefore, photographs in which the area measurement can be made in a reliable way could be obtained in a small number of patients.

Conclusions

The concept of a wound reduction ratio calculated using a computer program may be in the early days, and yet, it cannot replace the wound closure eligibility criteria determined by clinical experience. However, it is very promising, and if patient and disease factors are adopted into the algorithm, it may be a useful tool for clinical decision-making.

Conflict of Interest

The authors declare that they have no conflict of interests.

Funding

This research received no external funding.

Informed Consent

The data of patients are obtained from our patients anonymously. Informed consent was obtained from all patients. The data does not contain sensitive data. All authors signed informed consent when enrolled in the hospital.

Ethics Approval

This study was approved by the Faculty of Medicine, Sakarya University. Ethics Committee approval No: 71522473/0.50.01.04/78.

Authors' Contribution

AS, EG: study concept and design, acquisition of data, analysis and interpretation of data, drafting and revision of the article, final approval for the submission. ZB: acquisition of data, drafting and revision of the article, final approval for the submission. YA: acquisition of data, drafting and revision of the article, final approval for the submission. KO: acquisition of data, critical revision of the article, final approval for the submission. BM: acquisition of data, revision of the article, final approval for the submission. RC: acquisition of data, revision of the article, final approval for the submission. NF: acquisition of data, revision of the article, final approval for the submission. FA: acquisition of data, revision of the article, final approval for the submission.

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