A single-center prospective study on the efficiency of negative pressure wound therapy versus conventional wound therapy in the postoperative management of devitalized and infected wounds

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INTRODUCTION: *In this study, we aim to present the benefits of using negative pressure wound therapy, particularly with respect to the speed up of recovery time of devitalized and infected post-operative wounds, cost-effectiveness of local healing, pain relief during treatment, and returning to work and resuming normal daily activities at an earlier time.*
MATERIALS AND METHODS: *This was a prospective study performed in General Surgery Clinic, between 2016–2018. The study comprised 67 patients divided into two groups: A (29 patients who underwent negative pressure wound therapy) and B (38 patients who underwent conventional wound therapy).*
RESULTS: *The average age of patients included in group A was 64.2 ± 12.3 years and in group B, 63.2 ± 9.7 years (p=0.440). The wounds were located on the foot, thigh, abdomen, and other areas, and the average length of stay in hospital was 33 ± 18 days for group A versus 17 ± 14 days for group B (p=0.042) but with an average local healing time of 12 ± 5 days in group A versus 44 ± 17 days in group B (p<0.001). The average cost of hospitalization was higher in group A: 17,868 ± 9,560 RON (3,834 ± 2,051 euros) compared to group B: 6,025 ± 4,137 RON (1,292 ± 887 euros) (p=0.443) but the average cost of local healing was lower in group A: 5,437 ± 2,238 RON (1,166 ± 480 euro) compared to group B: 6,840 ± 3,520 RON (1,467 ± 755 euro) (p=0.005).*
CONCLUSIONS: *The treatment of devitalized and infected post-operative wounds by using negative pressure wound therapy reduces local and complete healing time by approximately 30%, local healing costs by 26%, and allows better pain management during treatment with minimal complications.*

KEY WORDS: Negative pressure wound Therapy, Conventional wound therapy, Local healing, average cost

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Introduction

Negative pressure wound therapy (NPWT) has been used for over 20 years in medical practice 1, but in low- and middle-income countries with a low budget for health care services, this technique [3] is only used for 4–5 years

ABBREVIATION

NPWT: Negative Pressure Wound Therapy
RON: Romanian New (Romanian Currency)
ROC: Receiver Operating Characteristics
AUC: Area Under the Curve
ANOVA: Analysis of variants

because of the high cost of the negative pressure wound therapy unit and the necessary kits to perform local treatment. Hence, even today, physicians often opt for the conventional treatment of devitalized and infected post-operative wounds [1,2].
The use of negative pressure wound dressings was initially introduced for infected post-operative wounds of the lower limb. Positive results have encouraged their use for the treatment of wounds with any kind of localization, subsequently adapting kits inclusively to open abdominal wounds [3]. Literature studies that discuss this procedure are constantly in disagreement due to apparently high costs. But only a prospective study that tracks post-hospitalization expenses can adequately evaluate the cost-benefit ratio of NPWT compared to conventional treatment [3,4].
The present prospective study aims to contribute new data to the specialty literature by comparing the cost-effectiveness ratio of NPWT and conventional treatment methods performed at the Second Surgery Clinic, Emergency County Clinical Hospital, Tirgu Mures, Romania.

Materials and Methods

Type of Study

This was a prospective study performed at the Second General Surgery Clinic, Mures County Emergency Clinical Hospital, Tirgu Mures during 01.01.2016–01.01.2018. The study comprised 67 patients with devitalized and infected post-operative wounds, which were most often located at the level of the leg, abdomen, inguinal, and subinguinal region, below- and above-the-knee amputation sites.
The 67 patients were divided into two groups. We included in group A 29 patients who underwent negative pressure wound therapy and in group B 38 patients who underwent conventional wound therapy for devitalized and infected post-operative wounds.
All patients who were applied negative pressure wound therapy signed an informed consent form, and subsequently, they were explained the use of the device, the technique of applying the dressings, and the importance of monitoring correct functioning.
General inclusion criteria comprised all devitalized and infected post-operative wounds which underwent necrectomy and debridement and with the possibility of wound healing. Exclusion criteria were: patient's refusal to use negative pressure wound dressings, local bleeding, and clotting disorders.
Characteristically, inclusion criteria for the two subgroups were:
– Group A: patients with wounds comprising prosthetic materials, patients who were treated conventionally in previous hospital presentations with no results and patients with wounds involving a wide area (more than 5 cm diameter);
– Group B: patients without prosthetic materials, with small wounds (less than 5 cm diameter).
We considered the following data for both groups: demographic segmentation, wound localization, duration and cost of hospitalization, duration and cost of local healing, and survival to complete healing.
To perform this study, we first obtained the approval of the Hospital Research Ethics Committees, the Board of the County Emergency Clinical Hospital Tirgu Mures, and the Head of the Second General Surgery Clinic.

Description of the Device

The negative pressure was generated by a portable mobile unit with a battery and power supply that enables the functioning of the device and recharging of the battery. The touchscreen of the device, which locks automatically in 30 seconds or manually, displays the following parameters: charge level of the battery, touchscreen locked/ unlocked, used pressure, continuous/ intermittent pressure, pressure control buttons, and a start/stop button. After switching on the device, a rotating indicator displays the green, yellow, or red color depending on the effectiveness of the negative pressure, with green indicating maximum efficiency and red minimal efficiency. The second component of the NPWT unit comprises dedicated kits containing a special film to isolate the wound and protect the skin from the negative pressure, a mesh soaked in silver nitrate with an antimicrobial effect that is applied to the wound, a sponge with high absorption capacity, an insulating plastic film applied externally, a port with a drainage tube that makes the connection between the wound, and the fluid collection reservoir attached to the unit that provides the negative pressure.
All patients were informed that the device was mobile and they could move whenever required and that when the battery charge level was low, it had to be connected to a power source.
Patients who received conventional dressings were informed that they would be bandaged once or twice daily; some of them required chloramine baths and after

discharge, they would need to be bandaged at home and then they would be followed up in the medical office of the Outpatient Clinic.

Surgical Technique

From a surgical point of view, the bandaging technique applied to the two groups differed significantly and required specific training for negative pressure wound dressings.

Both groups A and B patients were subjected to wound revision or necrectomy prior to treatment. During the first days, patients in group A were bandaged conventionally and then they were applied negative pressure wound therapy using dedicated kits. After the kit was set, the applied pressure was between -70 and -125 mmHg depending on the amount of wound secretion and the degree of patient tolerability. Negative pressure was achieved by applying continuous or intermittent pressure, switched automatically by the device, -40 mmHg for three minutes then -70 mmHg for the next three minutes in the case of intermittent pressure. In case the drainage tube became obstructed or the dressing was not correctly sealed, the device made audible signals until the problem was remedied. The special kit comprised items for three dressings that were changed every three days. The fluid collection reservoir was replaced at the same time. Some patients required two or three kits to obtain a clean and granulating wound. Patients in group B benefited from treatment with conventional dressings, using hydrogen peroxide and betadine or chloramine baths, that were changed once or twice daily, depending on the amount of secretion. All these patients required bandaging after discharge from the hospital. They were followed up at the local dispensary or medical office of the Outpatient Clinic.

Caring for and monitoring patients in hospital and after discharge

All patients were monitored daily for both wounds and secretions as well as for clinical and paraclinical (laboratory tests) evolution during the entire hospitalization period. According to the type of bacteria involved in post-operative wound suppuration, patients received antibiotic treatment based on antibiotic susceptibility testing. To correctly estimate the pain and define the correct analgesic treatment, both during and in between wound dressing applications, we used the Visual Analogue Scale. We obtained a mean value of 3.8 for group A and 5.4 for group B.

The duration of hospital stays in patients using negative pressure wound dressings was longer due to the complexity of wounds and associated comorbidities, but they were surgically healed when discharged from the hospital. Only group B patients required wound therapy and monitoring after discharge from hospital at the local dispensary or in an outpatient setting for different periods of time, varying from case to case.

It is important to mention that we had three death cases due to comorbidities, two in group A (sepsis, diabetes with unbalanced glucose levels) and one death case in group B (NYHA III-IV heart failure, chronic ischemic heart disease, chronic renal failure). All patients received anticoagulant medication and we did not have any death or major bleeding because of this regimen.

Statistical Analysis

Data analysis was performed using IBM SPSS 17.0 software. Data were reported as the number of cases/patients, relative frequencies as qualitative variables (male or female, location of wound), and mean and standard deviation of continuous variables. We used the Chi-square test to compare the acquired data for the two treatment options. A p-value<0.05 was considered statistically significant for all tests.

To interpret the results of the two groups, we calculated the Pearson parameter correlation coefficient. We used the ANOVA tables and Student's t-test to compare mean values (duration of hospitalization, local healing, and complete healing respectively in terms of the cost of hospitalization and local healing).

For graphical representation of predictive variables, we used the IBM SPSS 17.0 ROC Curves for each significant variable: area under the curve, standard error, asymptomatic significance, and lower and upper limits for 95% CI. We plotted comparative graphical representations for both types of treatment based on the ROC Curve assay and AUC (area under the curve)> 0.5 (50%).

Results

Gender distribution of patients in Group A (N=29), who benefited from negative pressure wound therapy, showed male predominance (62%) with an average age of 64.2 ± 12.3 years. Gender distribution in group B was relatively even, with an average age of 63.2 ± 9.7 years. Wound localization was relatively uniform in the two groups, but abdominal wounds appeared with a higher frequency in group B and wounds in other locations appeared more often in group A. We found that neither of the previously quantified variables was statistically significant, as shown in Table I.

Most patients in group A were treated and considered healed after a longer stay in the hospital, on average 33 ± 18 days. Patients in group B had less complex devitalized or infected post-operative wounds and stayed in hospital for a shorter time, on average 17 ± 14 days. Longer stay in hospital and treatment during this time

TABLE I - *Patient distribution by gender, age, wound location in the two studied groups.*

Variable	Negative pressure wound therapy Group A N= 29 patients	Conventional treatment Group B N= 38 patients	p-value
Gender			
Masculine (%)	62%	53%	0.440*
Feminine (%)	38%	47%	
Age	64.2 ± 12.3	63.2 ± 9.7	0.301*
Wound location			
Leg (%)	38%	34%	0.581*
Abdomen (%)	28%	40%	
Thigh (%)	10%	13%	
Other (%)	24%	13%	

*Chi square test

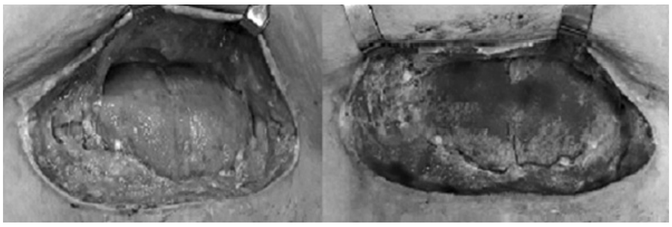

Fig. 1: The initial appearance of an abdominal infected wound after cesarean delivery and after ten days of NPWT (1 kit).

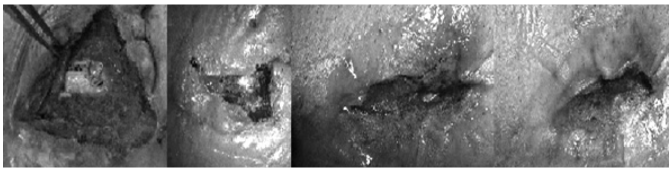

Fig. 2: The initial appearance of a subinguinal infected wound after femoral artery aneurysm resection respectively after ten days (1 kit) and 20 days of NPWT (2 kits).

involve higher costs, thus in the case of group A, the average cost of hospital stay was 17,868 ± 9,560 RON (3,834 ± 2,051 euros) compared to group B with an average cost of 6,025 ± 4,137 RON (1,292 ± 887 euros) ($p<0.001$).

Patients in group B were followed-up both during hospitalization as well as after discharge from hospital because they had surgical wounds that were not completely healed and required wound treatment at home or an outpatient clinic for a period of 18 to 41 days, in contrast to patients in group A who underwent NPWT and needed one or two dressings on discharge and suture removal but did not require follow-up (Figs. 1, 2).

The assessment of statistical data showed that the average length of stay in hospital was shorter in the case of patients who received conventional dressings and that this association had statistical significance ($p = 0.042$). The average time of local healing in group A (the number of days when the patients benefited from NPWT) was 12 ± 5 days and it was much lower compared to 44 ± 17 days of conventional wound therapy applied in group B (number of days of wound therapy during hospitalization and after discharge) until complete wound healing, which also showed statistical significance ($p <0.001$).

Based on the above-presented data, the price of the number of used NPWT kits in addition to the price of the number of days spent in the hospital, we calculated the average cost of local healing for group A as: 5,437 ± 2,238 RON (1,166 ± 480 euros). The average cost of local healing for group B was 6,840 ± 3,520 RON (1,467 ± 755 euros), which totals the hospitalization costs and the price of conventional wound therapy at home or in the outpatient setting. Thus, the average cost of local healing in group A proved to be less than in group B, and also statistically significant ($p = 0.005$). All data used in this statistic analysis were taken from the medical informatics system of the County Emergency Clinical Hospital Tirgu Mures and are presented in Table II.

To interpret the results of the two groups, we calculated Pearson's correlation coefficient and found for group A a direct and strong correlation between hospital costs and length of stay in hospital (0.778) and between the duration of local wound healing and complete wound healing (0.726). For patients in group B, we found a strong and direct correlation between the duration of hospitalization and local wound healing (0.900) and between the cost of hospitalization and the cost of local healing (0.741).

From the above-presented data, it can be stated that patients who underwent NPWT had a longer hospital stay and hospitalization costs than patients who benefit-

TABLE II - *Duration of hospitalization and overall hospital costs, duration and costs of local wound healing.*

Variable	Negative pressure wound therapy Group A - N= 29	Conventional treatment Group B - N= 38	p-value
Duration of hospitalization (number of days)	33 ± 18	17 ± 14	P=0.042*
Overall hospital costs (RON)	17868± 9560	6025 ± 4137	p<0.001**/***
Duration of local wound healing (number of days)	12 ± 5	44 ± 17	p<0.0011*
Costs of local wound healing (RON)	5437 ± 2238	6840 ± 3520	P=0.005*

*Chi square test; **Mann – Whitney test; ***Kolmogorov-Smirnov test

TABLE III - *Study of group A/group B and the determination of p-value for the duration of hospitalization, duration of local wound healing and complete wound healing and overall hospital costs.*

Variable	Groups	Sum of Squares	Df*	Mean Square	F**	p-value
Duration of hospitalization	Between Groups	4463.631	1	4463.631	18.130	p<0.001
(no. days)	Within Groups	16003.474	65	246.207		
Study of group A/group B	Total	20467.104	66			
Duration of local wound healing	Between Groups	16110.344	1	16110.344	88.243	p<0.001
(no. days)	Within Groups	11866.850	65	182.567		
Study of group A/group B	Total	27977.194	66			
Duration of complete wound healing	Between Groups	1886.811	1	1886.811	6.008	p=0.017
(no. days)	Within Groups	20413.816	65	314.059		
Study of group A/group B	Total	22300.627	66			
Overall hospital costs (RON)	Between Groups	2.307E9	1	2.307E9	46.977	p<0.001
Study of group A/group B	Within Groups	3.192E9	65	4.911E7		
	Total	5.499E9	66			

*degree of freedom; **F test value

TABLE IV - *Student's t-test for pairs of samples - Study of group A/group B and the determination of p-value*

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t*	df**	p-value
Pair I	Study of group A/group B Costs of local wound healing (RON)	-6231.358	3520.794	430.133	-7090.147	-5372.569	-14.487	66	p<0.001

*t student value; **degree of freedom

ed from conventional wound treatment due to comorbidities and the fact that most patients were treated 10–12 days postoperatively without being discharged. However, the costs and duration of local healing were lower in the case of NPWT compared to conventional wound therapy, with the data being statistically significant, as shown in Table III.

Due to the small groups of patients being analyzed in this study, we used Student's t-test for pairs of samples to test the average cost of local healing, and obtained statistically significant data (p <0.001), as shown in Table IV.

To calculate and graphically represent the predictive variables, we used the IBM SPSS 17.0 ROC Curves for each statistically significant variable calculated separately for groups A and B. We tested both null (AUC = 0.5) and alternative hypotheses (AUC different 0.5) for all variables. The results of the ROC Curve analysis confirmed the results of the other statistical methods. We observed that, although both hospitalization costs and duration of hospitalization had higher mean values in group A, the duration of local healing was significantly shorter in comparison with group B (only 12 days on average compared to 43 days, approximately 3.6 times higher efficiency), followed by the duration of complete healing (an average of 33 days in group A versus 43 days in group B, approximately 30% shorter). The cost efficiency of local healing in case of NPWT was also confirmed (approximately 26% more efficient) (Figs. 3, 4).

Discussions

Today, the mechanism of action of negative pressure applied to infected or poorly oxygenated wounds is well known. Negative pressure wound therapy stimulates local angiogenesis, vascularization, and oxygenation, and reduces edema by eliminating wound exudate, pus collection, and significantly lowering bacterial concentration. [5-8] Consequently, it favours wound granulation and considerably reduces healing time, as well as potentially saving patients from disabling operations [7,9-12]. Changing bandages less often should reduce both exposure to contamination and discontinuation of the wound healing process [13,14].

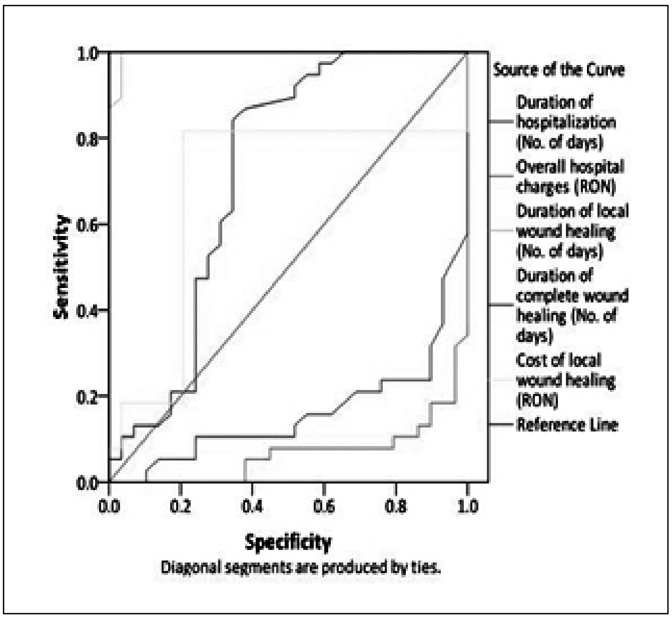

Fig. 3: Group A ROC Curves.

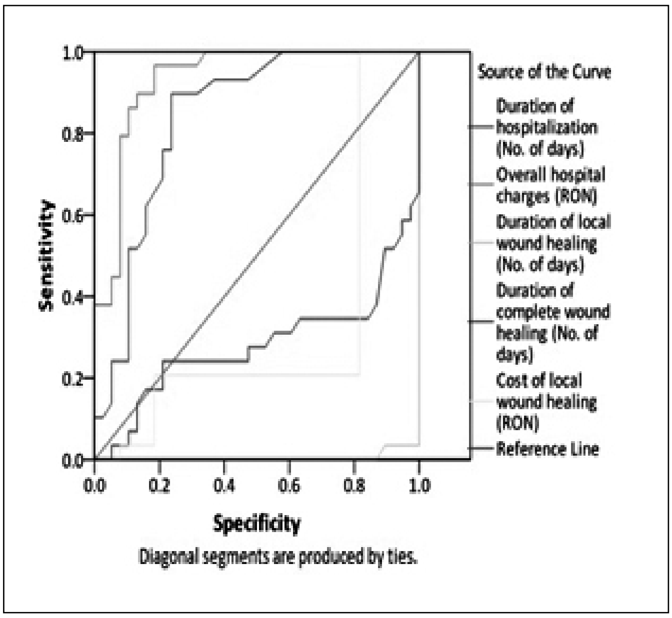

Fig. 4: Group B ROC Curves.

When surgeons started using negative pressure in the treatment of devitalized and infected post-operative wounds, 20 years ago, this technique was viewed with suspicion, due to high costs and questionable reports in the literature. Today, NPWT has become the gold standard for acute or chronic wound dehiscence at any level, pressure ulcers, orthopedic traumas, and even in the therapy of complications of abdominal surgical wounds [15-19].

Authors do however disagree about the cost-effectiveness ratio of this technique. In 2009, de Leon, when comparing the evolution of complicated wounds in patients who underwent NPWT vs. conventional treatment, observed a significant reduction in wound volume in the first group and lower cost per cubic centimeter. However, the assessment of the overall costs did not confirm the benefit of using NPWT; the author concluded that further studies were necessary [19].

Braakenburg and colleagues compared NPWT with conventional wound treatment (hydrocolloids, alginate, acetic acid, and sodium hypochlorite) in a retrospective study although acetic acid and sodium hypochlorite are no longer recommended as wound care products. They observed that the group of patients who underwent NPWT healed more quickly, had a greater reduction in wound size, and reduced time investment. Regarding total cost, although statistical calculations proved insignificant, they found the use of conventional dressings to be more favorable [20]. Vuerstaek et al. also found NPWT to be more favorable, reporting faster healing and hence more rapid wound preparation for grafting and lower costs [21].

Although the NPWT device and kits are more expensive, their longer application on wounds and less frequent change of dressings reduces the total cost. However, it is essential to correctly quantify the costs in groups of patients undergoing conventional treatment, given the fact that the majority of costs are produced after discharge from hospital and cannot be considered in most of the studies.

Hence, these are the sources of controversies in the literature on the evaluation of pertinent parameters such as the cost/benefit analysis [16,19].

Thus, a doctor's ability to collect the data after discharge patient time represents a key element in assessing the correct costs of wound healing [22]. Another element to be considered prior to deciding to use NPWT is the patient's decision. Patients need to assess their ability and willingness to use the device that should be carefully monitored, and they also need to be aware of possible errors, to accept regular exchange of local kits, and that their quality of life should not to be affected by corroborating these factors. Studies conducted by Augustin and Zschocke [23] measured the results prior to and after the use of NPWT and reported a significant increase in the quality of life. It is essential to include patients in the decision-making process on available treatment options – "the shared decision-making will become a norm: no decision about me without me". Patients' dissatisfactions were related to the aspect of the exudate in the canister, embarrassment, noise, and pain [24].

There are also costs that can be reduced by evaluating less obvious issues. The involvement of patients in the preparation of dressing and monitoring the device saves the time and effort of qualified staff, thus reducing additional costs. Meanwhile, health care providers can perform other activities, which increases service productivity.

The use of NPWT in the home care environment is relatively limited due to financial restrictions [24]. Some UK health authorities provide a list of specific wounds in which they consider NPWT indicated, which often limits the individualization of treatment [25].
Adapting NPWT is an important step. NPWT is often perceived to be more expensive than conventional wound care, due to unit price considerations in comparison with the total costs of the treatment. It is important to acknowledge that there may be cases where a new treatment is clinically and financially beneficial in the long term (such as in local recurrent rectal cancer after the Milles procedure [26]), but it is difficult to initiate due to the related start-up costs [27].

Conclusions

The chronic treatment of devitalized and infected post-operative wounds is a time- and resource-consuming process. Analyzing conventional treatment, it has proven to be effective with shorter hospitalization time and lower hospitalization costs but requires wound care after discharge from the hospital until complete wound healing.
Regarding the treatment of devitalized and infected post-operative wounds with negative pressure dressings, despite the apparently longer healing time and higher in-hospital costs, after processing the statistical data complete wound healing proved to be more effective regarding local and complete healing time with lower local healing costs.
The healing of devitalized and infected post-operative wounds by using NPWT compared to conventional wound therapy proved to be an innovative technique that reduces local healing costs by 26% and complete healing time by 30% with minimal complications.

Riassunto

Il trattamento a pressione negativa (TPN) è stata usata per oltre 20 anni nella pratica medica, ma nei paesi con un basso budget per i servizi medici ospedaliera è in uso da soli 4-5 anni a causa degli elevati costi della TPN e dei kit necessari per il trattamento locale.
In questa ricerca, vogliamo presentare i benefici dell'utilizzo della TPN, con particolare attenzione ai tempi di guarigione post-operativa di una ferita infetta e devitalizzata, al rapporto costo-efficienza, a una terapia meno dolorosa possibile e a un ritorno rapido al lavoro e alle attività quotidiane.
Materiali e metodo: Lo studio effettuato è di tipo prospettico, eseguito tra il 2016 ed il 2018 nella Clinica di Chirurgia Generale, Clinica di Emergenza di Tirgu Mures, riguardante 67 pazienti divisi in due gruppi: gruppo A, con 29 pazienti sottoposti alla terapia a pressione negativa, e gruppo B, con 38 pazienti sottoposti alla terapia convenzionale.
I criteri dei due sottogruppi erano i seguenti: Gruppo A – pazienti con ferite che includevano protesi, pazienti precedentemente sottoposti a una terapia convenzionale senza alcun risultato e pazienti con ferite di grande diametro (> di 5 cm di diametro); Gruppo B – pazienti senza protesi e con ferite di dimensioni inferiori ai 5 cm di diametro.
Risultato: Dopo un'analisi statistica dei dati ottenuti dai pazienti sono stati ricavati e seguenti risultati. L'età media dei pazienti del gruppo A era di 64.2 ± 12.3 e nel gruppo B, 63.2 ± 9.7 anni (p=0.440). Le ferite erano sulle gambe, cosce, addome e altre zone, e in media la permanenza in ospedale era di 33 ± 18 giorni per il gruppo A rispetto ai 17 ± 14 giorni per il gruppo B (p=0.042) ma con una media di guarigione locale di 12 ± 5 giorni nel gruppo A rispetto a 44 ± 17 giorni nel gruppo B (p<0.001). La media dei costi di ricovero era più alta nel gruppo A: 17,868 ± 9,560 RON (pari a 3,834 ± 2,051 euro) paragonata al gruppo B: 6,025 ± 4,137 RON (pari a 1,292 ± 887 euro) (p=0.443) ma il costo in media della guarigione locale era inferiore nel gruppo A: 5,437 ± 2,238 RON (pari a 1,166 ± 480 euro) rispetto al gruppo B: 6,840 ± 3,520 RON (pari a 1,467 ± 755 euro) (p=0.005).
Conclusioni: Il trattamento di ferite infette e devitalizzate post operatorio usando un trattamento a pressione negativa riduce il periodo di guarigione locale e completa di circa il 30%, ed i costi della guarigione locale del 26%, e permette una migliore gestione del dolore durante il trattamento con complicazioni minime.

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