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Effect of Negative Pressure Wound Therapy on Post-traumatic Wound Healing

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Abstract: **Patients with complex wounds constitute a significant workload burden for health care institutions. Complex wound is the term used to describe group those well-known difficult or complicated wounds, either acute or chronic, that challenge medical and nursing staff. They difficult to managed using simple or traditional dressing technique and currently have a major socioeconomic impact. Wound healing is a complex, dynamic overlapping process it includes an immediate sequence of cell migration leading to repair and closure. Wound healing refers to complete or partial healing. Complete healing is healthy granulation tissue formation with fibrous scar and complete epithelialization of wound. Partial healing is healthy granulation tissue formation with incompletely formed fibrous scar, and decrease of wound size and depth without formation of scar tissue. When wounds do not adequately heal with traditional standard treatment, additional modalities may be required, one of advanced wound care therapies is Negative Pressure Wound Therapy (NPWT) also known as Vacuum Assisted Closure (VAC). It is an advanced dressing technique using sub-atmospheric pressure to wound bed, using a sealed wound dressing connected to a vacuum suction device. Negative pressure wound therapy recently used worldwide to manage a multiple wounds indications such as acute traumatic wounds, chronic wounds, diabetic ulcer, pressure ulcer, burn, delayed and non-healing wounds.**

Keywords: **Negative Pressure, Post-traumatic wound, Vacuum Assisted Closure, Wound Healing.**

I. INTRODUCTION

Negative pressure wound therapy (NPWT) considered one of advanced treatment modalities that have been proved to be efficient in treating post-traumatic wounds. Post-traumatic wounds refer to open contaminated and/or infected wounds according to it's degree of cleanliness including; post traumatic raw areas and delayed primary closure.It has been difficult to manage wounds with sepsis associated with open wounds and tissue defect result from road traffic accidents or traumatic injuries. Reliable and efficacious therapy should not be able to decrease wounds infection only but also faster the healing process for these wounds (Zhou et al., 2013; Gupta et al., 2016). There are four primary and six secondary mechanisms of action .The four primary mechanisms of action have been proposed which include macro-deformation, micro-deformation, fluid or exudate removal and edema management and creation of the favorable environment for wound (Armstrong, Lavery & Diabetic Foot Study, 2005).Six secondary mechanisms includes hemostasis, inflammation reduction, mechanical stress causing granulation tissue formation and angiogenesis , reverse tissue expansion or skin stretching , neurogenesis and reduction of bacterial levels or counts (Bayer, 2018). Macro-deformation refers to reduction in the wound surface due to wound shrinkage caused by collapse or compression of the pores of foam and centripetal forces over the wound surface (Scherer et al., 2008; Kairinos, Solomons & Hudson, 2017). Micro-deformation occurs on internal wound surface by the porous filler material when exposed to suction force. Cellular deformation and related cell stretch caused by negative pressure wound therapy induce cell proliferation, migration, and differentiation; thereby positively influence wound healing (Orgill et al., 2009). The aim of this study was to assess the effectiveness of negative pressure wound therapy on post-traumatic wound healing. Sample of this study comprised a convenience sample of 25

adult patients with post-traumatic wounds admitted to Plastic Surgery Department at Alexandria Main University Hospital (EL AMIRY). One tool was used for data collection in this study was Wound Healing Assessment Tool (WHAT).

II. BODY OF ARTICLE

Aim of the study

The present study aimed to:

Assess the effectiveness of negative pressure wound therapy on post-traumatic wound healing.

Research Hypothesis:

Patients who receive negative pressure wound therapy will exhibit faster wound healing on post-traumatic wounds.

Research Methodology

Materials

Research design:

A quasi-experimental research design, one-group posttest only was used to conduct this study.

Setting:

The study was conducted at the Plastic Surgery Department of the Alexandria Main University Hospital (EL AMIRY).
Subjects:

Sample of this study comprised a convenience sample of 25 adult patients with post-traumatic wounds admitted to Plastic Surgery Department at Alexandria Main University Hospital (EL AMIRY).

Inclusion criteria:-

- Adult patients age from 18 to 60 years.
- Both genders (male and female).
- Healthy Patients without co-morbid conditions such as diabetics or peripheral vascular diseases.
- Having post-traumatic wounds such as open contaminated and/or infected wounds with delayed primary closure.
- Not on medication that may interfere with healing process as steroids, anti-inflammatory drugs and chemotherapy.

Tool of data collection: One tool was used for data collection in this study was Wound Healing Assessment Tool (WHAT).This tool was adapted from El-Shatby (2003), Desokey (2008) and Ibrahim (2018). It was used to assess wound healing process for adult healthy patients using negative pressure wound therapy technique. It was consisted of three parts as follows:-

Part I: Patient's socio-demographic data:- It included personal data such as patient's serial number, age, gender, level of education, occupation, marital status, area of residence and date of entry to the study.

Part II: Patient's clinical data:- It included: patient's history for associated medical diseases or previous surgeries, date of injury, mechanism of injury, site of injury. Patient body temperature and hematological laboratory investigations such as hemoglobin, albumin and anthropometric measurements including patient's weight, height and body mass index as criteria of nutritional assessment. White blood cells, C-reactive protein, erythrocyte sedimentation rate and microbiological wound culture if indicated as criteria for assessing local and systemic infection. Coagulation profile as criteria for assessing bleeding tendency.

Part III: Wound healing observation checklist for patients with traumatic wounds: This observation checklist was used for initial assessment of the wound pre NPWT application and posttest after NPWT application with weekly follow-up, through ongoing wound assessment of the healing process for (3-4 weeks) regarding the effect of NPWT on wound healing. Wound healing was assessed for morphology and description of wound condition against certain parameters such as type of open post-traumatic wound , wound size in centimeters, depth of wound ,exposure of inner structures as well as wound conditions which includes granulation and epithelial tissue formation, type of wound drainage or exudates, amount

of wound drainage or exudates ,,wound edges, odor, signs of wound infection, necrotic tissue, surrounding the wound and extent of wound healing as complete healing, partial healing or non-healing which mean as failure to progress through an ordinary sequence of wound repair process in a timely fashion and no improvement in wound characteristics.

Scoring system:

Scoring system for wound healing observation checklist scored as follows:

- Type of open post-traumatic wound assessed and scored as follows:-

0 =clean wound: wounds in which occurring in absence of infection. These wounds usually heal without complications.

1 =contaminated wound: wounds are open, post-traumatic wounds in which occurring in the presence of microorganisms. These wounds have acute non-purulent inflammation present.

2 =infected wound: dirty and infected wounds are open, post-traumatic wounds with retained dead tissue in which a large number of microorganisms where purulent drainage was present.

- Wound size assessed and scored in centimeters for length and width: The linear dimensions of wound surface are measured with measuring tape in centimeters.

- Depth of wound assessed and scored as follows:-

0 = healed.

1 = superficial epithelialization.

2 = partial thickness skin loss that involves epidermis and/ or dermis.

- Exposure of inner structure (muscle, tendon and bone) assessed and scored as follows:-

0 = absent.

1 = present.

- Wound condition assessed and scored as follows:-

a. Granulation tissue formation including type, color& amount:

0 = normal: 100% wound covered, surface intact or partial thickness wound.

1= bright, beefy red, 75% -100% wound fills &/or tissue over growth.

2 = bright, beefy red, < 75% & > 25% of wound fills.

3 = pink&/or dull, dusky red/or fills ≤ 25%of wound.

4 = no granulation tissue present.

b. Epithelial tissue (If yes specify):

0 =100% wound was covered and surfaces are intact.

1 = 75% to < 100% wound is covered &/or epithelial tissue extends > 0.5 cm into wound bed.

2 = 50% to < 75% wound is covered &/or epithelial tissue extends < 0.5 cm into wound bed.

3 = 25% to 50 wound covering.

4 = < 25 wound covering.

5 =No epithelial tissue present.

- Type of wound drainage or exudates assessed and scored as follows:-

0 = none.

1 = bloody: thin, bright red.

2 = serosanguineous: thin, watery, pale red/pink.

3 = serous: thin, watery, clear.

4 = purulent: thin or thick, opaque, tan/yellow, with or without odor.

- Amount of wound drainage or exudates assessed and scored as follows:-

0 = none.

1 = scant (<100 ml of drainage).

2 = small (≥100 to ≤ 200 ml of drainage).

3 = moderate (> 200 %to ≤ 300 ml of drainage).

4 = profuse (>300 ml of drainage).

- Wound edges assessed and scored as follows:-

0 = attached.

1 = not attached.

2 = edematous.

- Odor assessed and scored as follows:-

0 = none.

1 = foul.

- Signs of wound infection assessed and scored as follows :-

0 = absence of local signs of wound infection.

1 = presence of local signs of wound infection (redness, hotness, tenderness, purulent discharge and swelling).

2 = presence of systemic signs of wound infection (fever, elevated WBCs, elevated ESR, elevated CRP).

- Necrotic tissue assessed and scored as follows:-

0 = absent.

1 = present.

- Surrounding wound assessed and scored as follows:-

0 = absence of inflammation signs (redness, hotness, tenderness and swelling).

1 = presence of inflammation signs (redness, hotness, tenderness and swelling).

- Extent of wound healing assessed and scored as follows:-

a. Complete healing (If yes specify / Not Applicable):

0 = presence of healthy granulation tissue formation with combination of new blood vessels, fibroblast and epithelial cells which is bright pink to red in color and fibrous scar tissue formation.

1 = complete epithelialization of entire wound.

b. Partial healing:

0 = presence healthy granulation tissue formation and repaired of connective tissue but not completely forming a fibrous scar.

1= decrease of wound size and depth without formation of scar tissue.

c. Non healing:

0 = No granulation tissue formation or repair of connective within the wound space.

1 = No decrease of wound size and depth.

2 = No formation of fibrous scar tissue.

Part IV: Photographic pictures: - Photographic pictures taken to record and compare different stages of wound healing process by healthy granulation tissue formation to be ready for closure by tertiary intention or skin graft, if indicated.

Method

1. An approval from the ethical committee, Faculty of Nursing Alexandria University was obtained.

2. An official letter was issued from the Faculty of Nursing, Alexandria University to the study settings to obtain permission to collect necessary data.

3. An official permission was obtained from the directors and head of the departments of the selected hospital setting after explanation of the aim of the study.

4. Tool was adapted by the researcher after reviewing of the recent related literature.

5. The adapted tool was tested for content validity, completeness and clarity of the items. The tool was revised by two experts in the field of Plastic Surgery and three experts in the field of Medical Surgical Nursing and necessary modification were carried out.

6. Reliability of the tool was tested using appropriate test.

7. A pilot study was conducted on (10%) of the subjects of study who were excluded from the study sample for testing, the feasibility and applicability of the developed tool and to identify the difficulties that may encountered during data collection and of modifications was done accordingly.

8. The initial wound assessment was done pre Negative pressure wound therapy application (NPWT).

9. Photo for wound was taken at the initial wound assessment for patients who fulfilled the inclusion criteria.

10. An initial assessment for patient's wound morphology was done at dressing room of plastic surgical department or in the operating room when massive wound debridement was required and according to severity of pain.

11. Measurement of the actual wound size measured with measuring tape in (centimeters) in the initial wound assessment before application of NPWT and every week for 3-4 weeks.

12. Negative pressure wound therapy consists of convenient materials and supplies such as sterile foam, sterile dressing, connecting tube, occlusive surgical adhesive tapes. The negative pressure was applied to the wound by a portable suction device connected to some form of wound dressing via tubing to the wound base a sub-atmospheric pressure, usually in the range of 50 to 200 mmHg according to severity of pain and wound condition was applied.

13. **Application Method of Negative Pressure Wound Therapy:-**

A-Wound preparation: Empirical antibiotics were given after patient admission in the ward or in the operating room under general anesthesia if massive surgical debridement was needed. Under aseptic technique, any old dressings from the wound are removed and discarded. If required, a culture swab for microbiology may be taken. Necrotic tissue should be surgically removed (surgical debridement) and adequate hemostasis achieved. For patients experiencing pain with dressing changes, 1% lidocaine solution may be introduced either via the tubing or injection into the wound as flushing or washing. Irrigation for wound and it's surrounding with normal saline 0.9% then dryness of wound and it's surrounding followed by disinfection by betadine 10%. In case of old dressing carful and gradual removal of old dressing and foam to avoid irritating the periwound skin by using normal saline solution to loosen the foam for removal from the wound bed.

B-Placement of foam: Sterile, open-cell foam dressing is gently placed into the wound surface or cavity. Any areas of undermining or tunneling should also be filled with foam pieces and packed into the wound. Foams are used as they are

the most effective at transmitting mechanical forces across the wound and provide an even distribution of negative pressure over the entire wound bed to aid in wound healing. There are many different types of foam available such as, black foam (applied into the wound) or white foam (applied over the wound). Black foam or polyurethane ether (PU), has larger pores, is lighter, easily collapsible and hydrophobic. It is used when stimulation of granulation tissue and wound contraction is required.

This foam acts as a sort of filter to keep any large particles such as blood clots or dead, sloughed off tissue. An evacuation tube embedded in the foam, which is connected to vacuum suction that contains a fluid collection canister.

Depending on the defect size, one or more drainage tubes are inserted into the foam When the system is to be changed on the inpatient ward, placement of the drainage tubes on the skin is recommended. It is preferred to the subcutaneous placement of the drainage tubes in the operating room, because a more effective vacuum is produced**.**

C-Sealing with drapes: The wound is covered with the transparent non-permeable adhesive membrane sheet to ensure an airtight seal. The site is sealed with sheet of plastic adhesive drape. Drapes should cover the foam and tubing and at least three to five centimeters of surrounding healthy tissue to ensure a seal. Prior to application of the drape, it is essential to prepare the peri-wound skin and ensure that it is dry.

D-The application of negative pressure: Intermittent negative pressure is uniformly applied to all tissues on the inner surface of the wound. The foam dressing should compress in response to the negative pressure. Recheck if any leakage present and cover the source of leakage by drapes .The suction pump delivers intermittent negative pressure during the day, ranging from 50 to 200 mmHg according to the severity of pain. The intermittent negative pressure mode cycle one hour suction pump on and one hour off.

A-Wound preparation

B-Placement of foam

C-Sealing with drapes

D-The application of negative

Figure (1)

14. The frequency of dressing was done using NPWT about one dressing weekly for (3-4) weeks.

15. The patient is assessed for wound healing process post NPWT application three times; initially at the first vacuum dressing, next at the middle of dressing course and the last time at the end of dressing course (after 3- 4 weeks) in each time photo was taken and size was measured using a measuring tape.

16. The dressing is changed every 7 days for 3-4 weeks. The duration of therapy is dependent on the size and extent of the wound. Small wounds may heal with negative pressure therapy alone. Larger wounds may require skin grafting once a granulation bed is produced.

17. Negative-pressure wound therapy or the vacuum sealing technique was judged to be successful when the initial dimensions of the wound were reduced and granulation tissue covered the wound bed in the absence of any clinical signs of infection.

18. Wound assessment recorded during dressing times and clinical photographs were obtained to assess and compare different stages of wound healing process.

19. Negative pressure wound therapy continued until the next following vacuum dressing.

20. The role of NPWT on wound healing process ended when satisfactory results were achieved that are indicated by formation of healthy granulation tissue in absence of wound infection signs. Partial wound healing was occurring and wound was ready for closure by tertiary intention or skin graft if indicated according to wound conditions.

21. Data collection for this study was conducted by the researcher using the study tool "Wound Healing Assessment Tool".

22. Data was analyzed using the appropriate statistical tests.

Statistical analysis of the data: Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. Qualitative data were described using number and percent Quantitative data were described using mean, standard deviation. Significance of the obtained results was judged at the 5% level.

Ethical considerations:

- A written informed consent from the study subjects was obtained after explaining the aim of the study.
- Confidentiality of data was maintained.
- The subjects were assured that they have the right to withdraw from the study, at any time.

III. RESULTS

Table (1): Distribution of patient's according to socio-demographic data (n=25)

Socio-demographic data	No.	%
Age (years)		
18 <40	18	72.0
40 <60	7	28.0
Gender		
Male	17	68.0
Female	8	32.0
Level of education		
Illiterate	14	56.0
Educated	11	44.0
Marital status		
Single	4	16.0
Married	19	76.0
Divorced	0	0.0
Widow	2	8.0

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Occupation		
Manual work	14	56.0
Clerk work	5	20.0
Not working	1	4.0
Housewives	5	20.0
Retired	0	0.0
Residence		
Urban	15	60.0
Rural	10	40.0

As regard age, it was noticed that (72%) of studied patients were within the age group that ranged from 18 to less than 40 years. More than quarter (28%) of patient's age ranged from more than 40 years to less than 60 years. More than two third (68%) of patients were males. In relation to level of education, (56%) of the studied patients were illiterate while, (44%) were educated. Concerning marital status, the results revealed that more than three quarters (76%) of studied patients were married, (16%) of them were single and minorities of them (8%) were widows.

Regarding occupation, it is found that (56%) of studied patients were manual workers, (20%) of them were clerical workers, (20%) of them were housewives and only (4%) of them were not working. Moreover, it was found that more than half of the studied patients (60%) were from urban areas.

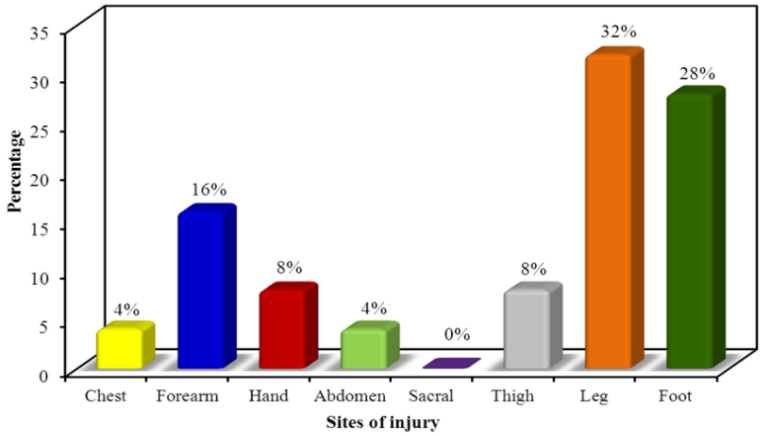

Figure (2): Distribution of patient's according to sites of injury (n=25)

Regarding sites of injury, the most common anatomical site of the post-traumatic wound was in the lower limb (32%) of studied patients had wound in the legs, (28%) of studied patients had wound in the feet ,(16%) of studied patients wound in the forearm , (8%) of studied patients had wound in the hand ,(%8) of studied patients had wound in the thigh, (4%) had wound in the chest and (4%) of studied patients had wound in the abdomen as shown in figure (2).

Table (2): Effect of negative pressure wound therapy on open post-traumatic wound type, size, depth and exposure of inner structure at the different studied periods.

Wound Healing Observation Checklist	Initial wound assessment Pre vacuum dressing		The first vacuum dressing After 1st week		The middle vacuum dressing After 2nd-3rd weeks		The last vacuum dressing After 3rd - 4th weeks		Test of sig.	p
	No.	%	No.	%	No.	%	No.	%		
1-Type of open post-traumatic wound										
Clean wound	0	0.0	13	52.0	25	100.0	25	100.0	Fr= 58.862*	<0.001*
Contaminated wound	11	44.0	10	40.0	0	0.0	0	0.0		
Infected wound	14	56.0	2	8.0	0	0.0	0	0.0		
p_1			**0.004***		**<0.001***		**<0.001***			

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2-Wound size in centimeters for length and width (cm)										
Length										
Min. – Max.	5.0 – 45.0		4.0 – 43.0		3.0 – 42.0		3.0 – 38.0		F= 53.850*	<0.001*
Mean ± SD.	19.46 ± 11.86		18.88 ± 11.86		17.82 ± 11.78		16.56 ± 10.94			
p_1			**0.001***		**<0.001***		**<0.001***			
Width										
Min. – Max.	3.0 – 15.0		3.0 – 13.0		2.50 – 12.0		2.0 – 12.0		F= 71.201*	<0.001*
Mean ± SD.	8.0 ± 3.63		7.76 ± 3.50		7.06 ± 3.29		6.42 ± 3.06			
p_1			**0.091**		**<0.001***		**<0.001***			
3- Depth of wound										
Healed	0	0.0	0	0.0	0	0.0	0	0.0		
Superficial epithelialization	0	0.0	1	4.0	10	40.0	12	48.0	Fr= 45.348*	<0.001*
Partial thickness skin loss that involves epidermis and/ or dermis	25	100.0	24	96.0	15	60.0	13	52.0		
p_1			**0.827**		**0.028***		**<0.001***			
4- Exposure of inner structure (muscle, tendon and bone)										
Absent	15	60.0	15	60.0	23	92.0	24	96.0	Fr= 24.943*	<0.001*
Present	10	40.0	10	40.0	2	8.0	1	4.0		
p_1			**1.000**		**0.080**		**0.049***			

F: F test (ANOVA) with repeated measures, Sig. bet. periods was done using **Post Hoc Test** (**Bonferroni**)

Fr: **Friedman test**, Sig. bet. periods was done using **Post Hoc Test** (**Dunn's)**

p: p value for comparing between **the different studied periods**

p_1: p value for comparing between **Pre vacuum dressing** and **each other periods**

*: Statistically significant at $p \leq 0.05$

Regarding type of open post-traumatic wound in initial wound assessment it was found that (56%) of studied patients had infected wound, while (44%) of them had contaminated wound .As regards to the first vacuum dressing after 1st week the results showed that more than half (52%) of studied patients had a clean wound, while (40%) of patients had contaminated wound and only (8%) of patients had an infected wound. While in the middle vacuum dressing after 2nd-3rd weeks and The last vacuum dressing after 3^{rd}-4^{th} weeks (100%) of studied patients had a clean wound in the follow up dressing period. Also, there was a statistical significant differences after the last vacuum dressing after 3rd-4th weeks (p <0.001). Significant difference were present between the three vacuum dressing as p value was (0.004, <0.001, <0.001 respectively).

In relation to wound size in centimeters for length and width (cm) in initial wound assessment pre vacuum dressing ,the longest length of the wounds ranged from (5– 45cm) ,with mean length of (19.46 ± 11.86) and the longest width of the wounds ranged from (3 – 15cm) with a mean width of (8.0 ± 3.63). While wound size in centimeters for length and width (cm) in The last vacuum dressing after 3rd - 4th weeks ,the smallest length of the wounds were ranged from(3– 38cm) ,with mean length of (16.56 ± 10.94) and the smallest width of the wounds ranged from (2– 12cm) with a mean width of (6.42 ± 3.06). Moreover the findings showed that there were statistical significant reduction in wound size in centimeters for length and width (cm) during three times follow up vacuum dressing as p value was (<0.001).

Regarding depth of wound the table revealed significant differences in the depth of wound after the first vacuum dressing after 1st week and after the middle vacuum dressing , after The last vacuum dressing after 3rd-4th weeks in the follow up periods as p value was (p <0.001) and furthermore ,this table represented that (100%) of studied patients had partial thickness skin loss that involves epidermis and/ or dermis before vacuum dressing, while (96%) of patients had partial thickness skin loss that involves epidermis and/ or dermis after the first vacuum dressing after 1st week. On the other

hand, after the middle vacuum dressing (60%) of patients had partial thickness skin loss that involves epidermis and/ or dermis while (40%) of patients had superficial epithelialization. (48%) of patients had superficial epithelialization in the last vacuum dressing after 3rd-4th weeks of follow up period (p <0.001).

Concerning exposure of inner structure muscle, tendon and bone (60%) of patients had absent exposure of inner structure in initial wound assessment pre vacuum dressing and same after the first vacuum dressing after 1st week (92%) of patients had absent exposure of inner structure after the middle vacuum dressing and (96%) of patients had absent exposure of inner structure after The last vacuum dressing after 3rd-4th weeks of follow up period (p <0.001).

Table (3): Effect of negative pressure wound therapy on wound condition: granulation tissue formation and epithelial tissue formation at the different studied periods.

Wound Healing Observation Checklist	Initial wound assessment Pre vacuum dressing		The first vacuum dressing After 1st week		The middle vacuum dressing After 2nd-3rd weeks		The last vacuum dressing After 3rd - 4th weeks		Fr	p
	No.	%	No.	%	No.	%	No.	%		
1- Wound condition:-										
a) Granulation tissue formation:										
Normal: 100% wound covered, surface intact or partial thickness wound.	0	0.0	0	0.0	0	0.0	18	72.0		
Bright, beefy red, 75% –100% wound fills &/or tissue over growth	0	0.0	0	0.0	15	60.0	4	16.0		
Bright, beefy red, <75% & >25% of wound fills	0	0.0	14	56.0	10	40.0	3	12.0	71.182*	<0.001*
Pink&/or dull, dusky red/or fills ≤ 25%of wound	0	0.0	11	44.0	0	0.0	0	0.0		
No granulation tissue present	25	100.0	0	0.0	0	0.0	0	0.0		
p_1			**0.003***		**<0.001***		**<0.001***			

Fr: **Friedman test**, Sig. bet. periods was done using **Post Hoc Test** (**Dunn's)**

p: p value for comparing between **the different studied periods**

p_1: p value for comparing between **Pre vacuum dressing** and **each other periods**

*: Statistically significant at $p \leq 0.05$

The result showed that (56%) of studied patients had bright, beefy red, <75% & >25% of wound fills by granulation tissue formation while (44%) had pink&/or dull, dusky red/or fills ≤ 25%of wound after the first vacuum dressing after 1st week. Then in the middle vacuum dressing (60%) of them had bright, beefy red, 75% –100% wound fills. while (40%) of patients had bright, beefy red, <75% & >25% of wound fills. The result showed that in The last vacuum dressing after 3rd-4th weeks this percent was increased to (72%) of patients who had normal wound healing: 100% wound covered, surface intact or partial thickness wound. This table also showed that (16%) of patients had bright, beefy red, 75% –100% wound fills &/or tissue over growth and statistical significant difference in granulation tissue formation was present where p value<0.001 before vacuum dressing and after follow up dressing periods.

Moreover the result showed that (84%) of the patients had no presence of epithelial tissue after the first vacuum dressing while (76%) of them had no presence of epithelial tissue in the middle vacuum dressing, and (24%) of them had< 25 wound covered by epithelial tissue. Also, the finding revealed that (52%) of patients had no presence of epithelial tissue at the end of the last vacuum dressing after 3rd-4th weeks, while (40%) of studied patients had < 25 wound covering.

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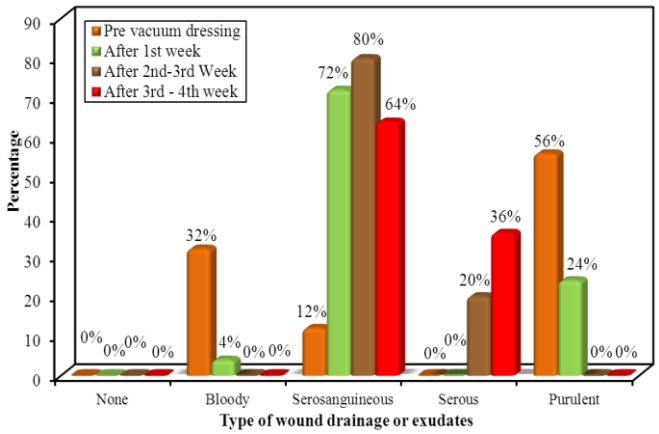

Figure (3): Effect of negative pressure wound therapy on open post-traumatic wound according to type wound drainage or exudates at the different studied periods.

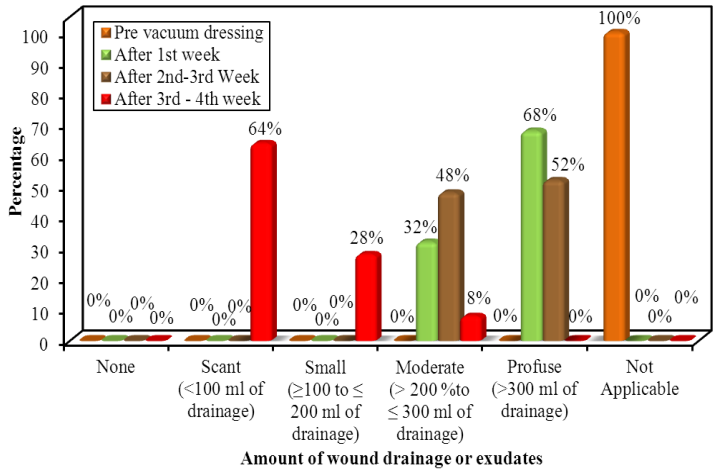

Figure (4): Effect of negative pressure wound therapy on open post-traumatic wound according to amount of wound drainage at the different studied periods.

In relation to type of wound drainage or exudates, the table illustrated that before dressing (56%) of studied patients had purulent discharge: thin or thick, opaque, tan/yellow, with or without odor , while (32%) of studied patients had bloody: thin, bright red in initial wound assessment pre vacuum dressing. Moreover, the table showed that (72%) of studied patients had serosanguineous: thin, watery, pale red/pink in the first vacuum dressing after 1st week, while decreased in percent to (24%) of patients who had purulent discharge: thin or thick, opaque, tan/yellow, with or without odor. Only (4%) of the patients had bloody: thin, bright red. Furthermore, the same table showed that (80%) of studied patients had serosanguineous: thin, watery, pale red/pink in the middle vacuum dressing. At the end of The last vacuum dressing after 3rd-4th weeks it was found that (64%) of patients had serosanguineous: thin, watery, pale red/pink. Only (36%) of the patients had serous: thin, watery, and clear. And statistical significant difference were found between different vacuum dressing period where p1 value (<0.476, 0.014, <0.001 respectively).

Concerning amount of wound drainage or exudates (68%) of studied patients had profuse (>300 ml of drainage) in the first vacuum dressing after 1st week, only (32%) of them had moderate (> 200 %to ≤ 300 ml of drainage) .While more than half (52%) of studied patients had profuse (>300 ml of drainage) in the middle vacuum dressing. Also, the findings revealed that (64%) of the studied patients had scant (<100 ml of drainage), while (28%) of studied patients had small (≥100 to ≤ 200 ml of drainage) in The last vacuum dressing after 3rd-4th weeks and only (8%) of them had moderate (> 200 %to ≤ 300 ml of drainage). Highly statistical significant difference were present between the different vacuum dressing periods where p value<0.001 as shown in figures (3, 4).

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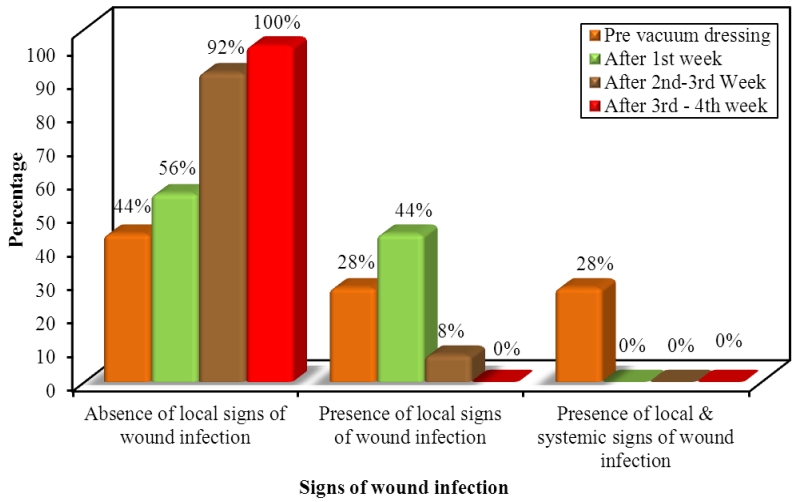

Figure (5): Effect of negative pressure wound therapy on open post-traumatic wound according to signs wound infection at the different studied periods.

Regarding signs of wound infection, More than half (56%) of patients had infection (28%) of them presence of local signs of wound infection (28%) of them and presence of local & systemic signs of wound infection in the initial wound assessment pre vacuum dressing, while (44%) of patients had absence of local signs of wound infection. In the first vacuum dressing after 1st week it was found that more than half (56%) of patients had absence of local signs of wound infection, while (44%) of patients had presence of local signs of wound infection. Signs of wound infection were improved to absence of local signs of wound infection in (92%) of patients in the middle vacuum dressing while after the last vacuum dressing after 3rd-4th weeks (100%) of patients had absence of local signs of wound infection as shown in figure(5).

Table (4): Effect of negative pressure wound therapy on open post-traumatic wound according to extent of wound healing at the different studied periods.

Wound Healing Observation Checklist	Initial wound assessment Pre vacuum dressing		The first vacuum dressing After 1st week		The middle vacuum dressing After 2nd-3rd weeks		The last vacuum dressing After 3rd - 4th weeks		Fr	p
	No.	%	No.	No.	No.	%	No.	%		
1-Complete healing (healthy granulation tissue formation with fibrous scar and complete epithelialization of wound) Healthy granulation tissue formation with fibrous scar and complete epithelialization of wound.	0	0.0	0	0.0	0	0.0	0	0.0	50.0*	<0.001*
2-Partial healing (healthy granulation tissue formation with incompletely formed fibrous scar, and decrease of wound size and depth without formation of fibrous scar tissue)	0	0.0	25	100.0	25	100.0	25	100.0		
3-No healing	0	0.0	0	0.0	0	0.0	0	0.0		
4-Not Applicable	25	100.0	0	0.0	0	0.0	0	0.0		
p_1			<0.001*				<0.001*			

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Fr: **Friedman test**, Sig. bet. periods was done using **Post Hoc Test** (**Dunn's)**

p: p value for comparing between **the different studied periods**

p_1: p value for comparing between **Pre vacuum dressing** and **each other periods**

*: Statistically significant at $p \leq 0.05$

This table showed that (100%) of studied patients had partial wound healing that started in the first vacuum dressing after 1st week and ended in The last vacuum dressing after 3rd-4th weeks, and no cases had complete healing.

Also, the result portrayed statistical significant differences that were found between the different vacuum dressing periods where p value <0.001, <0.001 respectively for three vacuum dressing periods.

Table (5): Relation between granulation tissue formation and patients socio-demographic& clinical data (n = 25)

	Granulation tissue formation													
	The first vacuum dressing After 1st week				**The middle vacuum dressing After 2nd-3rd weeks**				**The last vacuum dressing After 3rd - 4th weeks**					
	Bright, beefy red, <75% & >25% of wound fills (n = 14)		**Pink&/or dull, dusky red/or fills ≤ 25%of wound (n = 11)**		**Bright, beefy red, 75% – 100% wound fills &/or tissue over growth (n = 15)**		**Bright, beefy red, <75% & >25% of wound fills (n = 10)**		**Normal: 100% wound covered, surface intact or partial thickness wound. (n = 4)**		**Bright, beefy red, 75% – 100% wound fills &/or tissue over growth (n = 18)**		**Bright, beefy red, <75% & >25% of wound fills (n = 3)**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Age (years)														
18 <40	11	78.6	7	63.6	14	93.3	4	40.0	4	100.0	14	77.8	0	0.0
40 <60	3	21.4	4	36.4	1	6.7	6	60.0	0	0.0	4	22.2	3	100.0
χ^2(p)	**0.682(FEp=0.656)**				**8.466*(FEp=0.007*)**				**7.484*(MCp=0.015*)**					
Gender														
Male	9	64.3	8	72.7	12	80.0	5	50.0	4	100.0	13	72.2	0	0.0
Female	5	35.7	3	27.3	3	20.0	5	50.0	0	0.0	5	27.8	3	100.0
χ^2(p)	**0.202(FEp=1.000)**				**2.482(FEp=0.194)**				**6.894*(MCp=0.020*)**					
Date of injury														
1 day <7 day	10	71.4	7	63.6	11	73.3	6	60.0	2	50.0	13	72.2	2	66.7
7day<14 day	4	28.6	4	36.4	4	26.7	4	40.0	2	50.0	5	27.8	1	33.3
14 day<21 day	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
χ^2(p)	**0.172(FEp=1.000)**				**0.490(FEp=0.667)**				**1.114(MCp=0.791)**					
Patient body temperature														
Normal	10	71.4	4	36.4	9	60.0	5	50.0	2	50.0	10	55.6	2	66.7
Hyperthermia	4	28.6	7	63.6	6	40.0	5	50.0	2	50.0	8	44.4	1	33.3
Hypothermia	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
χ^2(p)	**3.074(FEp=0.116)**				**0.244(FEp=0.697)**				**0.436(MCp=1.000)**					

χ^2: Chi square test

MC: Monte Carlo FE: Fisher Exact test

p: p value for comparing between the studied categories

There were no statistical significant relations between granulation tissue formation and patients socio-demographic& clinical data, except for age, where (p) value = (0.007*), (p) value = (0.015*) and gender where (p) value = (0.020*) in different vacuum dressing periods. There were no statistical significant relations between granulation tissue formation and patient's clinical data as shown in table (5).

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Continue Table (5): shows the relations between granulation tissue formation and patient's clinical data.

	Granulation tissue formation													
	The first vacuum dressing After 1st week				The middle vacuum dressing After 2nd-3rd weeks				The last vacuum dressing After 3rd - 4th weeks					
	Bright, beefy red, <75% & >25% of wound fills (n = 14)		Pink&/or dull, dusky red/or fills ≤ 25%of wound (n = 11)		Bright, beefy red, 75% – 100% wound fills &/or tissue over growth (n = 15)		Bright, beefy red, <75% & >25% of wound fills (n = 10)		Normal: 100% wound covered, surface intact or partial thickness wound. (n = 4)		Bright, beefy red, 75% – 100% wound fills &/or tissue over growth (n = 18)		Bright, beefy red, <75% & >25% of wound fills (n = 3)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Hematological laboratory investigations include:														
-Hemoglobin														
Normal	9	64.3	3	27.3	12	80.0	0	0.0	4	100.0	8	44.4	0	0.0
Above normal	0	0.0	1	9.1	0	0.0	1	10.0	0	0.0	0	0.0	1	33.3
Below normal	5	35.7	7	63.6	3	20.0	9	90.0	0	0.0	10	55.6	2	66.7
χ^2(^{MC}p)	3.859(0.155)				16.640*(<0.001*)				10.198*(0.011*)					
-White blood count														
Normal	8	57.1	4	36.4	7	46.7	5	50.0	2	50.0	8	44.4	2	66.7
Above normal	6	42.9	7	63.6	8	53.3	5	50.0	2	50.0	10	55.6	1	33.3
Below normal	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
χ^2(p)	1.066(0.302)				0.027(^{FE}p=1.000)				0.718(^{MC}p=0.831)					
-C-reactive protein														
Normal	10	71.4	4	36.4	9	60.0	5	50.0	3	75.0	9	50.0	2	66.7
Above normal	4	28.6	7	63.6	6	40.0	5	50.0	1	25.0	9	50.0	1	33.3
Below normal	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
χ^2(p)	3.074(^{FE}p=0.116)				0.244(^{FE}p=0.697)				1.036(^{MC}p=0.821)					
-Erythrocyte sedimentation rate														
Normal	12	85.7	5	45.5	9	60.0	8	80.0	3	75.0	12	66.7	2	66.7
Above normal	2	14.3	6	54.5	6	40.0	2	20.0	1	25.0	6	33.3	1	33.3
Below normal	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
χ^2(p)	4.588(^{FE}p=0.081)				1.103(^{FE}p=0.402)				0.378(^{MC}p=1.000)					
-Albumin														
Normal	9	64.3	6	54.5	11	73.3	4	40.0	3	75.0	12	66.7	0	0.0
Above normal	0	0.0	1	9.1	0	0.0	1	10.0	0	0.0	0	0.0	1	33.3
Below normal	5	35.7	4	36.4	4	26.7	5	50.0	1	25.0	6	33.3	2	66.7
χ^2(^{MC}p)	1.351(0.817)				3.382(0.143)				7.816(0.068)					

χ^2: Chi square test

MC: Monte Carlo FE: Fisher Exact test

p: p value for comparing between the studied categories

This table represents that ,there were no statistical significant relations observed between granulation tissue formation and patients clinical data except for hemoglobin percent , as (p) values were (<0.001*) ,(0.011*) respectively in different vacuum dressing periods.

Initial wound assessment Pre vacuum dressing	The first vacuum dressing after 1st week	The last vacuum dressing After 3rd - 4th weeks

Figure (6): Case 1

Initial wound assessment Pre vacuum dressing	The first vacuum dressing after 1st week	The last vacuum dressing after 3rd - 4th weeks

Figure (7): Case 2

IV. DISCUSSION

The injuries caused by road traffic accidents (RTAs) become a major public health problem worldwide and a major cause of morbidity and mortality with a temporary or permanent disability. It has been difficult to manage wounds with severe soft tissue injures or defects result from high energy trauma, ischemia, constant pressure and burn associated with extensive contamination or infection and compromised viability. Reliable and efficacious management should be achieved through infection clearance from the wound which considered a key factor in healing process of wounds (Zhou et al., 2013; Gupta et al., 2016; Al-Zamanan et al., 2018).

In this study of a quasi-experimental research designed to test the hypothesis that patients with post-traumatic wound dress using negative pressure wound therapy had results that the majority of patients exhibited faster wound healing on post-traumatic wounds and the patients had a partial wound healing with healthy granulation tissue formation and reduction of wound infection. NPWT help to promote wound healing before definitive closure to be ready for skin graft or flaps. The study results demonstrated that there are significant differences between pre vacuum dressing and last vacuum dressing after four weeks.

This technique decreases duration of hospital stay and decreases the burden on the hospitals. Clinical applications of NPWT includes; soft tissue defects after trauma, diabetic foot infections, pressure ulcers, open abdominal wounds, sternal wounds, necrotizing fasciitis, extravasation injury, skin graft fixation and burns (Karthikeyan, 2019). The current study revealed that in relation to patient socio demographic data most of studied subjects were aged from 18 to less than 40 years. The highest percent of study cases were male patients. These results are in contrast with Al-Zamanan et al. (2018) who found that young adult were more at risk for traumatic injuries which represent the leading cause of disability and death.

Regarding gender, the results revealed that, the majority of patients were male. These findings are in accordance with Arjun (2018) who found that men are at risk for traumatic wound injuries. Concerning level of education and marital status, the results revealed that, the majority of patients were illiterate and married. Illiteracy might have lack of their knowledge and compliance about wound care and wound complication.

Regarding occupation and residence it was found that majority of patients were manual workers and they come from urban areas. This may be because of a lot of them as adult male workers that are at high risk for traumatic injuries as they come from urban due to unavailability of specialized hospitals as plastic surgery specialty in their residence areas.

Regarding sites of injury, the most common anatomical site of the post-traumatic wound was in the lower limb wound in the leg. This result is supported by Lee et al. (2009) who reported that NPWT facilitate the faster growth of healthy granulation tissue on open wounds in the lower limb especially the foot and ankle region.

Regarding type of open post-traumatic wound in initial wound assessment majority of patients had infected wound which improved to be a clean wound in the follow up NPWT. This may be due to majority of patients wounds caused by RTA with large raw areas which at risk to develop wound infection. The study findings are in agreement with Ludolph et al. (2018) who found a reduction in the number as well as in the amount of bacterial colonization or bioburden of wounds under the influence of NPWT.

Accordingly, Nain, Uppal, Garg, Bajaj and Garg (2011) reported that the surface area of the wounds in the vacuum assisted closure group was significantly decreased in wounds size and optimal contraction for wounds are achieved already at 75 mmHg and this may be appropriate suction force for most wounds. Moreover the study findings showed that there were statistical significant reduction in wound size in centimeters for length and width (cm) during three times follow up vacuum dressing as p value was (<0.001). Regarding depth of wound the findings revealed significant difference in the depth of wound after the first vacuum dressing after 1st week and after the middle vacuum dressing and after the last vacuum dressing after 3rd-4th week in the follow up periods as p value was (p <0.001).This result was supported by Jebakumar and Ezhil (2017) who added that patients treated with NPWT had increased rate of epithelial tissue growth and few percent of patients required repeat split thickness skin graft to the same site and significantly volume and depth reduction for the wound, and decreased healing duration.

Concerning exposure of inner structure muscle, tendon and bone the majority of patients showed absence exposure of inner structure during follow up period. This result was supported by DeFranzo et al. (2001) who found that vacuum-assisted closure therapy decreased wound surface area and rapid formation of profuse granulation tissue in lower-extremity wounds with exposed tendon, bone. The wounds were closed primarily and covered with split thickness skin grafts, or rotational flap into the granulating bed to fill the injured defect.

Also, the result showed that in the last vacuum dressing after 3rd-4th week the majority of patients had normal wound healing: 100% wound covered, intact surface or partial thickness wound at last vacuum dressing after 3rd-4th week. These results are in agreement with Arjun (2018) who found in his study that negative pressure wound therapy uses negative vacuum force to help in wound closure and has a positive effect on healing process by promoting granulation growth and wound repair.

In relation to type of wound drainage or exudates, the study findings showed that the majority of patients had purulent discharge in the first vacuum dressing after 1st week which indicate wound infection and exudate converted in the majority of patients to be serosanguineous at last vacuum dressing after 3rd-4th week. This because of the presence of purulent drainage associated with infected wounds which are the majority of studied samples. This is supported by

Cutting (2003) who reported that exudate can provide a vast amount of information about wound status or wound infection and the presence of exudate influences the process of wound healing.

Concerning amount of wound drainage or exudates more than two third of studied patients had profuse (>300 ml of drainage) in the first vacuum dressing after 1st week, and this amount of wound drainage decreased during the different vacuum dressing periods to be a scant amount (<100 ml of drainage) in the last vacuum dressing after 3rd-4th week. This is supported by Nain et al. (2011) who reported that negative-pressure wound therapy assists discharge removal from the wound which enhance the growth of granulation tissue. In wounds with excessive amount of drainage, higher pressure levels may be used for the initial therapeutic period.

Regarding signs of wound infection, the study findings found that more than half of patients had infection both local only, local and systemic signs of wound infection and presence of necrotic tissue in the initial wound assessment pre vacuum dressing. This may be due to presence of local signs of wound infection and systemic signs of wound infection, as evidenced by fever ,elevated WBCs, elevated ESR elevated CRP, purulent drainage and necrotic tissue which should be removed through debridement before healing and repair can occur. While follow up the last vacuum dressing after 3rd-4th week all patients had absence of local signs of wound infection and absence of necrotic tissue. This is supported by Hasan, Teo and Nather (2015) who reported that wounds managed with negative pressure wound therapy showed a more rapid inhibition in bacterial growth and multiplication and aids in bacteria clearance.

In addition ,the present study showed that all of the patients had partial wound healing characterized by healthy granulation tissue formation with incompletely formed fibrous scar, and decrease of wound size and depth without formation of fibrous scar tissue started in the first vacuum dressing after 1st week and ended in the last vacuum dressing after 3rd-4th week this in agreement with Karthikeyan (2019) who found that NPWT provide a beefy red granulation tissue is a good prognostic sign and a sign of a flourishing wound suitable for skin cover by either a flap or skin graft. In this line, Chiummariello, Guarro, Pica and Alfano (2012) reported that usage of negative pressure over wound environment provide vasodilatation for, so increasing the effectiveness of local perfusion, enhancing angiogenesis, which assists in granulation tissue proliferation.

Significant correlations have been found between granulation tissue formation and patient's age. This may be due to older patients wounds may slow healing than those in younger patients, mainly because of associated diseases that occur as result of ageing process. Elderly may have inadequate dietary intake, alteration in hormonal responses, dehydration, and compromised body system; immune and cardiorespiratory any of which can increase the risk of tissue breakdown and impaired healing process. This in accordance with Guo and DiPietro (2010) ; Sgonc and Gruber (2013) who reported that aging one of factors can affect wound healing which interferes wound healing phases, thus causing improper or impaired tissue repair.

Significant correlations have been found between granulation tissue formation and patient's gender. The majority of studied patients were male. This is contradicted by who stated that sex hormones play a role in wound healing process. Estrogen can improve impairment in healing, while androgens regulate cutaneous wound healing negatively. Estrogen affects healing process by regulation of many of genes associated with regeneration, matrix formation, epidermal function, inhibition of protease, and the genes primarily in relation with inflammation.

Furthermore, the study findings revealed no statistical significant relations between granulation tissue formation and patient's clinical data except for hemoglobin percent. This may be due to other patient's clinical data of hematological laboratory investigations and microbiological wound culture reflect presence or absence of wound infection not reflect granulation tissue formation, While significant correlations were detected between granulation tissue formation and hemoglobin percent despite that more than half of patients had below normal hemoglobin percent this may justified due to immediate post traumatic blood loss. Inadequate blood supply one of the important factors that delayed wound healing so, measuring level of hemoglobin helps to evaluate the blood oxygen carrying capacity; however, it may also be necessary to evaluate liver, kidney, and thyroid functions to determine healing capacity for patient. In this essence Janis and Harrison (2014), Minniti et al. (2014) stated that low hemoglobin levels are often associated with tissue ischemia and hypoxia that impair wound healing due to decrease in oxygen and nutrient supply.

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Negative pressure wound therapy as a part of a wound management modality results in reduced hospital stays, the need for less frequent dressing changes, reduction in morbidity and consequent decreased overall medical costs. In conclusion, negative pressure wound therapy is modern advanced therapy in the field of wound management with several applications in different types of wounds. Wherever feasible, Negative pressure wound therapy must be the treatment modality for selection in management of complex wounds. The study findings found negative pressure wound therapy a lifesaving method for open post-traumatic wounds management.

V. CONCLUSION

The current study seeks to assess the effectiveness of negative pressure wound therapy on post-traumatic wound healing. Based on the study findings, it can be concluded that all of studied patients had partial wound healing in the last vacuum dressing after 3rd-4th weeks. There were highly statistical significant differences between wound healing process related to wound cleanness, reduction in wound size and depth, absence of exposure of inner structure, presence of granulation tissue formation, scanty wound drainage or exudates, absence of wound odor, absence of local signs of wound infection and absence of necrotic tissue, absence of inflammatory signs, extent of partial wound healing and three sequential different vacuum dressing periods where p value <0.001. In addition, there were statistical significant relations between granulation tissue formation and age of patients, gender and hemoglobin percent. Negative pressure wound therapy (NPWT) may help to optimize wound conditions before definitive closure to be ready for skin graft or flaps. In conclusion, negative pressure wound therapy is a promising new advanced modality in management of wounds results in reduced hospital stays the need for less frequent dressing changes, reduction in morbidity and consequent decreased overall medical costs. Negative pressure wound therapy should be considered as a first line therapy for delayed and non-healing wounds and to be the choice for infected, difficult and not responding wounds to conventional dressing. The study obtained fulfilled the aim of the study; the proposal and hypothesis were tested and accepted.

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