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Evaluating the Effect of BMIs on Wound Complications After the Surgical Closure of Pressure Injuries

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Abstract: Background/Objectives: Pressure injuries (PIs) are injuries to the skin and underlying tissue localized over a bony prominence. Surgical complications following the closure of a PI include ulcer recurrence, wound dehiscence, hematomas, and infection, which pose significant morbidity issues to patients. The objective of this study is to characterize the relationship between BMI and early and late wound outcomes following surgical closure through a secondary analysis of a previous study examining the effect of two support surfaces on PI healing. Methods: A single institution study on patients with a stage 3/4 pressure injury admitted for surgical closure was conducted. The subjects were monitored for 14 days post-closure (POD-14) so that an assessment of their early wound status and complications, including moisture, maceration, drainage, dehiscence, epidermolysis, necrosis, and demarcation, could be conducted. Results: In total, 68 patients were included. Out of these, 13% of patients were underweight, 29% were normal-weight, 35% were overweight, and 22% were obese. POD-14 complications occurred in 22% of underweight patients, 15% of normal-weight patients, 38% of overweight patients, and 40% of obese patients. Of all recorded complications, 75% of patients were overweight or obese. Complication rates were not significantly different based on osteomyelitis status. The most common cultures identified in wounds were *P. aeruginosa*, *S. aureus*, and *E. coli*. Negative cultures were found in 22% of closed wounds and 13% of open wounds. Conclusions: Our findings suggest that BMIs may be correlated with early wound status and the incidence of postoperative complications, while it may not be correlated with osteomyelitis status. Future studies should further evaluate the effect of BMIs on pressure injury-associated complications. This may further guide preoperative planning and patient expectations.

Keywords: pressure injury; surgical closure; complications; BMI; osteomyelitis

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1. Introduction

Impacting over three million people in the United States annually, pressure injuries (PIs) are injuries to the skin and underlying tissue localized over a bony prominence. They are caused by prolonged and localized pressure that restricts blood flow and results in necrosis [1]. Traditional classification divides PIs into four stages based on severity and depth, with the most common locations being patients' buttocks, hips, and heels [2]. Based on the current literature, a higher BMI categorization has not been found to be a risk factor for either developing PIs or maintaining a longer time to heal [3,4].

In patients that require surgical intervention, major complications include injury recurrence, wound dehiscence, hematomas, and infection [5]. Moreover, a breadth of bacteria heterogeneity is often present in these wounds, varying between wound dimensions and the state of the microbiome. The most common species include *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Enterococcus faecalis* [6,7]. Bacterial infection poses significant morbidity to these patients, leading to poor outcomes, such as soft tissue and bone infections, including osteomyelitis [6]. Osteomyelitis is thought to affect 17–33% of PI patients [8,9]. This may act as an independent risk factor for wound dehiscence and may be associated with long-term failure following surgical closure, particularly in patients with an elevated BMI [5].

To prevent further postoperative complications, our group has previously studied wound management via both an air-fluidized bed (AFB) and a fluid immersion system (FIS) [10]. An AFB distributes pressure via silicone-coated ceramic beads that allow for air flow to "float" the PI patient [10,11]. An FIS aims to reach blood flow and tissue oxygen levels that are close to homeostatic levels. The device simulates a fluid environment with 3D technology to support pressure distribution while simultaneously adjusting for a patient's movement [11,12]. In our previous work, we found that both techniques have shown to provide viable support surfaces after pressure injury surgical flap closure with no significant differences regarding long-term clinical outcomes [10]. However, further sub-analysis reveals that a patient's BMI may predispose them to different wound outcomes based on the type of device used. There remains a need to investigate whether an elevated BMI poses a risk factor for PI complications and wound healing in the setting of clinically controllable factors, such as osteomyelitis and wound cultures. Therefore, the purpose of this study is to further analyze the effects of a patient's BMI on early and late wound outcomes after the surgical closure of pressure injuries, via a post hoc analysis of a previous study which examined the use of two different support surfaces and outcomes on PI healing [10]. This article was previously presented as a meeting abstract at the 2023 American College of Surgeons Clinical Congress on 22–26 October 2023.

2. Materials and Methods

2.1. Subject Recruitment and Criteria

Subjects who were at least 18 years old, had a stage-three or -four pressure injury (according to the National Pressure Ulcer Advisory Panel system), were deemed compliant by investigators, and had not participated in another clinical trial in the past 30 days were eligible for the study. They were admitted as inpatients at Northwestern Memorial Hospital for the surgical closure of their pressure injury and had a 30-day wound history on record (Table 1). Exclusion criteria included a life expectancy of less than 12 months, an inability to undergo surgery due to poor health, a history of radiation therapy, an inability to comply with the study, more than three prior surgical closures for the same pressure injury, a history of bleeding disorders, or severe fecal incontinence [13]. The recruitment process took place between January 2016 and November 2019. Subjects were informed of the study by the principal investigator (R.D.G.), and those who agreed to participate signed an informed consent form. This study was reviewed and approved by Northwestern University's Institutional Review Board (STU00200584).

Table 1. Inclusion and exclusion criteria.

Criteria	Details
Inclusion Criteria	
Age	≥18 years old
Pressure injury stage	Stage 3 or 4 (based on the National Pressure Ulcer Advisory Panel system)
Prior clinical trials	No participation in another clinical trial within the past 30 days
Admission	Inpatient admission at Northwestern Memorial Hospital for surgical closure
Wound history	30-day documentation of wound history
Exclusion Criteria	
Life expectancy	<12 months
Surgical candidacy	An inability to undergo surgery due to poor health
Radiation history	A history of radiation therapy
Surgical history	>3 prior surgical closures for the same pressure injury
Bleeding disorders	A history of a bleeding disorder

2.2. Data Collection

Data were gathered through the subjects' hospitalization and electronic medical records, and each participant was assigned a unique screening number. Only one wound per subject was considered in the study. For subjects with multiple wounds, the principal investigator assessed the wounds and selected the most appropriate wound to include in the study. For participants with more than one PI, pressure injuries not selected as the study wound received institutional-standard wound care. Medical and surgical history, physical exam results, and wound history were documented with a focus on the wounds. Measurements were taken manually following NPUAP guidelines (length, width, and depth). After surgical debridement, wound cultures were taken using a standardized method under sterile conditions and throughout the wound depth, and the wound was irrigated with 5 L of normal saline and re-measured. If appropriate, surgical closure was performed immediately and support devices (the AFB or the FIS) were initiated.

2.3. Postoperative Course

Subjects stayed in the hospital or a step-down facility for at least 14 days after their final surgery (Figure 1). The 14-day time point was selected based on studies demonstrating significant changes in the inflammatory environment and protease activity during this stage of healing, marking the transition from the inflammatory phase to the proliferative phase [14]. After closure, subjects were randomly assigned to receive AFB or FIS therapy for 14 days, regardless of hospital stay length. Closure success and complications were documented during this time. The study then followed patients monthly for 365 +/− 20 days to assess complications and the need for additional treatments. While in the hospital, standard-of-care interventions (wound dressings, topical treatments, and adjunctive therapies like vacuum-assisted closure) were carried out. The principal investigator decided if additional surgical debridement was necessary based on injury appearance and culture results. If a flap failed postoperatively, the subject was removed from the study and switched to standard wound care. Given that all participants were hospitalized for a minimum of 14 days post-surgery, they were also monitored during the 14-day post-closure period for the assessment of wound complications, including moisture, maceration, drainage, dehiscence, epidermolysis, necrosis, and demarcation. Postoperative care included standard wound care protocols, pain management, daily laboratory monitoring, and antibiotics tailored to culture results. The appropriate continuation of home medications, which varied per patient, was also provided. Additionally, follow-up evaluations were conducted at one month, six months, and one year after closure to determine the status of the wound, as reported in medical records, and self-reported by the subjects.

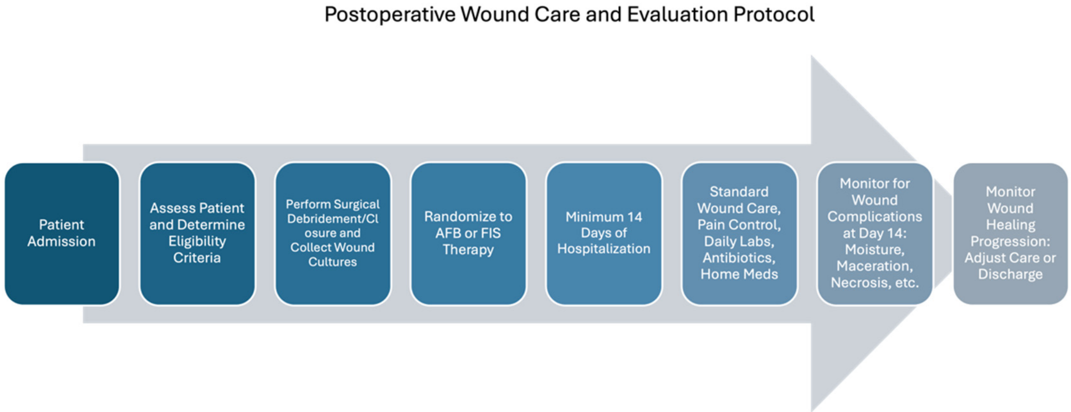

Figure 1. Postoperative wound care and evaluation protocol.

2.4. Data Analysis

Complications and wound status at postoperative day 14 (POD-14) were analyzed and compared based on the BMI, osteomyelitis status, and wound culture groups. The BMI was determined using the standard calculation of weight in kilograms divided by height in meters squared (kg/m^2). The BMI categories used in analyses were defined as follows: underweight—BMI: <18.5, normal-weight—BMI: 18.5–24.9, overweight—BMI: 25.0–29.9, obesity class 1—BMI: 30.0–34.9, obesity class 2—BMI: 35.0–39.9, and obesity class 3—BMI: ≥40.0. Chi-squared analyses were performed for assessing differences between the following categorical variables: BMIs, osteomyelitis status, and wound cultures.

3. Results

A total of 80 were included in the study. The average age of patients was 48.5 years (Table 2). Of those patients, 66% were male and 34% were female. Moreover, 59% of patients were White, 31% were Black, 9% were Hispanic, and 1% had other ethnicities. However, 12 patients withdrew from the study due to insufficient follow-up or death in the first 14 days, and an additional 4 patients withdrew after one year. Death was considered an exclusion criterion rather than listed as a complication of procedure given the lack of confirmatory evidence for causal relationship, especially considering patient-specific confounding factors and comorbidities. Of the 68 patients who remained enrolled 14 days after surgery, 39 had a high BMI (overweight or obese), and 7 of these had comorbid diabetes mellitus. Of the 29 patients with a normal or low BMI, 4 had comorbid diabetes.

Table 2. Demographic information.

Demographic	
Age (year)	48.3
%Male	68%
Race	
White	41
Black	19
Hispanic	7
Other	1

Table 2. *Cont.*

Demographic	
Smoking	
Current	8
Never	34
Past	25
Diabetes Status	
Type I	1
Type II	10
Negative	56
Medical History	
Paraplegia	14
Spinal cord injury	8
Trauma	4
Quadriplegia	3
Multiple sclerosis	3
Spina bifida	3
Gunshot wound	2
Hip dislocation	1
Prolonged hospitalization	1

3.1. Complications

In total, 20 patients (29%) experienced 32 postoperative complications by two weeks (Table 3 and Figure 2). Furthermore, 75% of all 32 complications were in overweight or obese patients. There was a significant difference between POD-14 complication rates across the underweight, normal-weight, and elevated BMI groups ($p = 0.002$). There was no difference in the complication rates between patients with and without diabetes mellitus ($p = 0.58$). A total of 66 patients reported data regarding osteomyelitis status. Complication rates were not significantly different across acute, chronic, and negative osteomyelitis statuses.

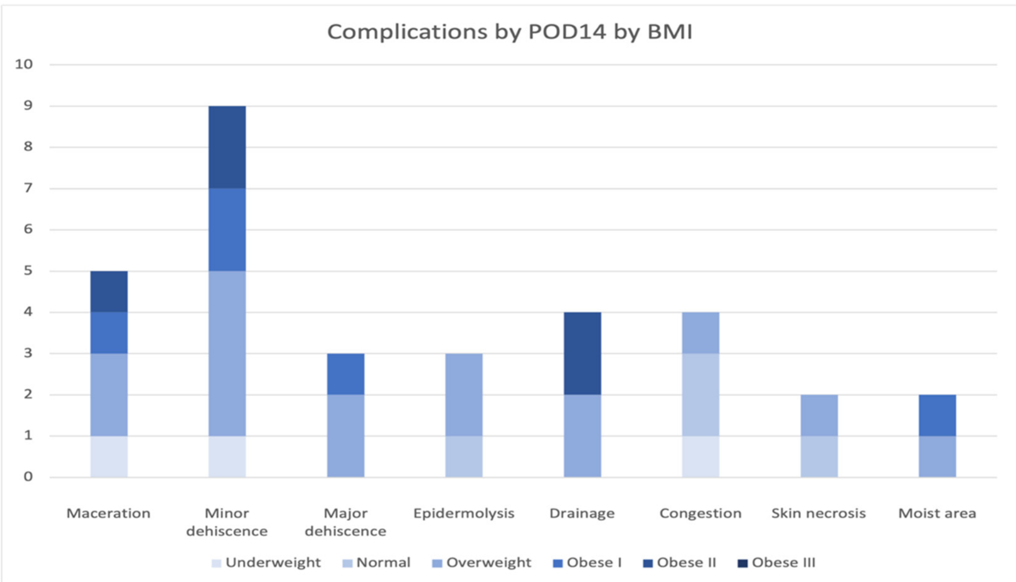

Figure 2. Complications based on BMIs.

Table 3. Complications based on POD-14.

	Maceration	Minor Dehiscence	Major Dehiscence	Epidermolysis	Drainage	Congestion	Skin Necrosis	Moist Area	Total No. of Complications	No. Pts with Complications	Total No. of Pts (%)	% Pts with Complications *
BMI												
Underweight	1	1	0	0	0	1	0	0	3	2	9 (11)	22%
Normal	0	0	0	1	0	2	1	0	4	3	27 (34)	11%
Overweight	2	4	2	2	2	1	1	1	15	9	27 (34)	33%
Obese I	1	2	1	0	0	0	0	1	5	4	11 (14)	36%
Obese II	1	2	0	0	2	0	0	0	5	2	3 (4)	67%
Obese III	0	0	0	0	0	0	0	0	0	0	3 (4)	0%
Total	5	9	3	3	4	4	2	2	32	20	80	25%
Osteomyelitis Status												
Acute	1	2	0	0	0	1	0	1	5	3	12 (18)	25%
Acute and Chronic	0	1	0	0	0	1	1	0	3	2	4 (6)	50%
Chronic	0	2	1	3	2	1	1	0	10	7	25 (38)	28%
Negative	4	4	2	0	2	1	0	1	14	8	25 (38)	32%
Total	5	9	3	3	4	4	2	2	32	20	66	30%

* The OR of complication occurrence for elevated BMIs vs. normal BMIs = 4.14, RR = 3.07, and ARR = 23%. OR = odds ratio. RR = relative risk. ARR = absolute risk reduction.

3.2. Wound Status and Culture

Fifty-nine patients had closed wounds and nine had open wounds at POD-14 (Table 4 and Figure 3). There was no significant correlation between a patient's BMI or osteomyelitis status and wound status. Comorbid diabetes mellitus also had no impact on the wound closure rates at any time point. The most common cultures identified in wounds were *P. aeruginosa*, *S. aureus*, and *E. coli* (Table 5). Negative cultures were found in 22% of closed wounds and 13% of open wounds. The cultures did not vary significantly between open and closed wounds ($p = 0.68$). There was a significant difference in the bacterial culture incidence between patients with complications vs. without complications ($p < 0.001$).

Table 4. Postoperative wound status.

	Total No. Pts at POD 14 (%)	POD 14 Open (%) *	1 mo Open (%)	6 mo Open (%)	1 Year Open (%)	Total No. Pts at 1 Year (%)
BMI						
Underweight	9 (13)	0 (0)	1 (11)	0 (0)	2 (22)	9 (14)
Normal	20 (29)	1 (5)	4 (20)	6 (30)	8 (40)	20 (31)
Overweight	24 (35)	4 (17)	9 (38)	4 (17)	3 (13)	24 (38)
Obese I	11 (16)	3 (27)	5 (45)	2 (22)	3 (43)	7 (11)
Obese II	2 (3)	1 (50)	1 (50)	1 (50)	1 (50)	2 (3)
Obese III	2 (3)	0 (0)	0 (0)	0 (0)	1 (50)	2 (3)
Total	68	9 (13)	20 (29)	13 (20)	18 (28)	64
Osteomyelitis Status						
Acute	12 (18)	1 (8)	2 (17)	2 (17)	2 (20)	10 (16)
Acute and Chronic	4 (6)	1 (25)	0 (0)	1 (25)	1 (25)	4 (6)
Chronic	25 (38)	3 (12)	9 (36)	6 (25)	10 (42)	24 (39)
Negative	25 (38)	4 (16)	9 (36)	3 (13)	3 (13)	24 (39)
Total	66	9 (14)	20 (43)	12 (23)	16 (35)	62

* The OR of open wound status at POD-14 for elevated BMIs vs. normal BMIs = 4.90, RR = 4.10, ARR = 16%, and chi-squared analysis $p = 0.18$.

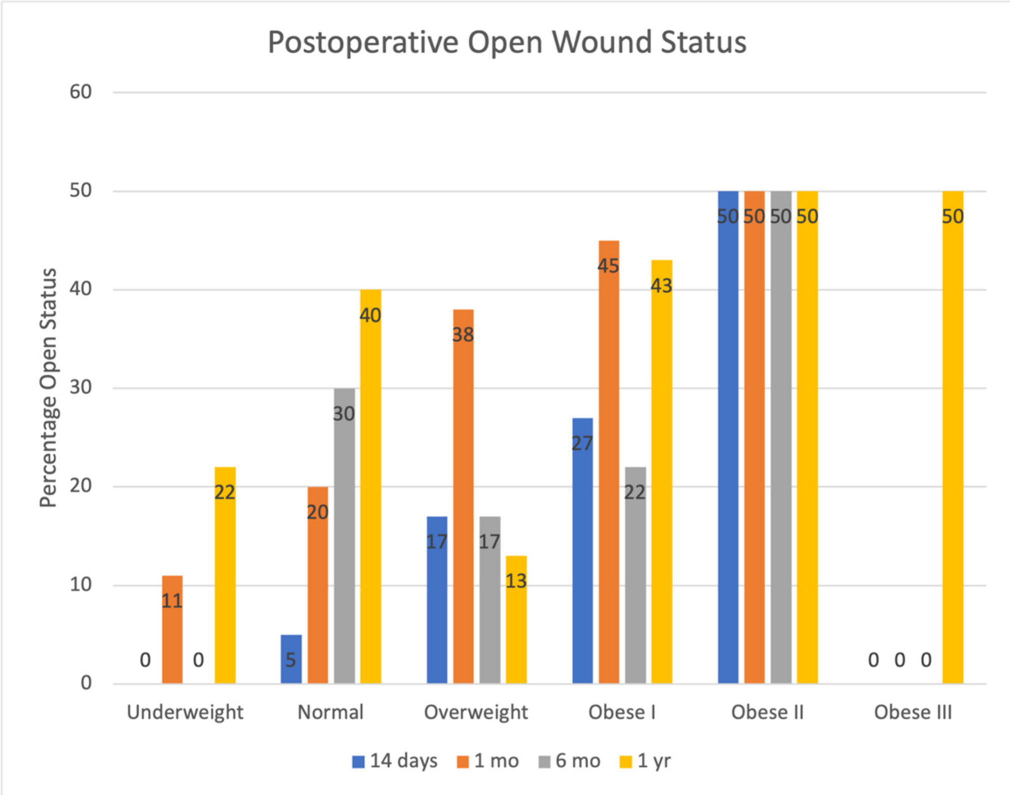

Figure 3. Postoperative open wound status.

Table 5. Culture results.

Culture	Total Count	Open Count	Closed Count	Complications (−)	Complications (+)
Psuedomonas	16 (20)	3 (33)	12 (20)	12 (22)	4 (21)
Negative	15 (19)	1 (11)	11 (19)	12 (22)	4 (21)
S aureus	12 (15)	1 (11)	9 (15)	7 (13)	5 (26)
E coli	11 (14)	2 (22)	8 (14)	7 (13)	4 (21)
E faecalis	9 (11)	2 (22)	5 (8)	5 (9)	4 (21)
Coryneabacterium	9 (11)	0 (0)	8 (14)	7 (13)	2 (11)
Strep Group B	7 (9)	1 (11)	4 (7)	6 (11)	1 (5)
Proteus	6 (8)	2 (22)	4 (7)	5 (9)	2 (5)
B hemolytic Strep	5 (6)	0 (0)	4 (7)	4 (7)	3 (5)
Klebsiella	4 (5)	0 (0)	3 (5)	3 (6)	4 (5)
Strep Group C	3 (4)	1 (11)	1 (2)	2 (4)	5 (5)
E cloacae	3 (4)	0 (0)	2 (3)	2 (4)	6 (5)
A baumanii	3 (4)	1 (11)	1 (2)	2 (4)	7 (5)
S epidermidis	1 (1)	0 (0)	1 (2)	1 (2)	0 (0)

4. Discussion

In our group's previous work, we studied AFB and FIS therapy for the care of buttock PIs and found that both were equally effective off-loading methods [10]. In this study, we further analyzed risk factors that may affect patients predisposed to postoperative complications of moisture, maceration, drainage, dehiscence, epidermolysis, necrosis, and demarcation, as well as open wound status. While the postoperative care of PIs is well established, identifying variables that may increase a patient's risk of developing complications can help inform more specialized care and improve outcomes, including a patient's BMI. Overall, we found an increased rate of postoperative complications in patients who were overweight or had class I-III obesity. Furthermore, we found that complication rates were not significantly different across the clinically controlled variables of osteomyelitis status and wound bacteria. Bacteria found in wounds predominantly consisted of *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Escherichia coli*.

4.1. Association Between Increased BMIs and Wound Healing Complications

In our study, we found that patients who were overweight or had class I-III obesity had a 3.1-fold increase in complications and a 4.1-fold increase in the risk of developing open wound status following the surgical closure of their pressure injuries. This may be due to several factors, including increased cardiac workload, impaired ventilation, venous insufficiency, decreased mobility, and the presence of skin folds. Important factors in the healing of chronic or postoperative wounds include the perfusion and prevention of moisture. In overweight or obese patients, there is an increased amount of adipose tissue, which is considered avascular at wound sites. Patients with higher BMIs also experience decreased tidal volume and hypoventilation due to a higher abdominal volume. Venous insufficiency is another comorbidity commonly seen in obesity, and it can also impair oxygen diffusion from capillaries to the wound. Furthermore, a well-known consequence of obesity is increased demand on the heart to perfuse tissues. The combination of increased adipose tissue, respiratory changes, venous insufficiency, and increased cardiac workload leads to poor perfusion at the wound site, increasing the risk of developing necrosis [15,16].

Poor perfusion may also inhibit collagen deposition, impairing wound closure and scar formation, especially in patients with comorbid diabetes mellitus. Previous studies have shown that fibroblasts require 15 mmHg of oxygen pressure to properly lay collagen [17]. However, in obese patients, oxygen pressures at wound sites can be close to zero [17]. This can lead to a decrease in collagen deposition, which may predispose obese patients to poor wound closure. It is thought that obese patients have increased tension at wound fascial edges, further impairing perfusion and wound closure. Thus, poor perfusion may also increase rates of dehiscence and drainage [16,18].

Obesity additionally leads to a variety of chronic, low-grade, inflammatory processes within adipose tissues. Studies have repeatedly demonstrated that visceral adipose tissue in central obesity has an increased expression of cytokines, including TNF-alpha, TGF-beta, and IL-6, and an increased infiltration of macrophages [15]. Although these patients are in a chronic inflammatory state, they often have an impaired immune response to infection and wounds. In normal wound healing, M2 macrophages are critical to the transition from the inflammatory stage to the proliferative stage, where anti-inflammatory cytokines promote the formation of granulation tissue via fibroblasts and growth factors [19]. In obese patients, anti-inflammatory M2 macrophages are switched to the proinflammatory M1 state [16,20]. As a result, chronically present proinflammatory cytokines are uninhibited, impairing the production of growth factors and leading to delayed wound healing [15].

Finally, previous studies have shown that it can be difficult to maintain an adequately dry environment at wound sites for overweight patients. This can occur due to decreased mobility, which makes it more difficult for obese or overweight patients to shift positions. Additionally, these patients are more likely to have skin folds, which may harbor moisture [16]. While appropriate moisture levels are important for wound healing, excess moisture may lead to maceration, dermatoses, inflammation, and an increased risk of developing infection [21].

4.2. Bacterial Culture of Wounds

In our cohort, we found that the most common pathogens detected on pre-closure wound culture were *S. aureus*, *E. coli*, and *P. aeruginosa*. These results are in line with previous studies, which also report *S. aureus* and *P. aeruginosa* among the most popular bacteria in pressure injuries [6,22]. Other studies have reported that staphylococci, *P. aeruginosa*, and *E. coli* are the pathogens that are most likely to cause biofilm formation on chronic wounds [23]. Biofilm production is a well-described factor that converts acute wounds into chronic wounds [23]. As all the patients in this study had stage-three or -four pressure injuries, the presence of species that form biofilms and increase the chronicity of wounds is not surprising. These results suggest that the targeted use of antimicrobial therapy early in wound care could help prevent biofilm formation and thus prevent the progression of pressure injuries. It has been shown that debridement is also an essential step in removing biofilms from chronic wound sites [24].

4.3. Association Between Osteomyelitis and Wound Healing Complications

Osteomyelitis is a common infectious complication of pressure injuries, and stage-four injuries with bony involvement are often assumed to have osteomyelitis. Most cases of pressure injury-related osteomyelitis are chronic, lasting more than 6 weeks. Chronic osteomyelitis is more likely to require surgical intervention and have a 20–30% chance of recurrence compared to acute osteomyelitis [25]. Osteomyelitis has previously been shown to pose a great cost burden (approximately USD 60,000 per patient, not including surgical charges) [26]. When undetected and untreated, it can cause serious complications, such as deep abscesses and sinus tract formation, increasing the time to wound closure, the length of stay, and the rate of complications from surgical closure [27]. Thus, diagnosing and appropriately treating osteomyelitis is crucial to the management of pressure injuries.

However, when diagnosed and treated appropriately, osteomyelitis has been shown to have no effect on the healing of pressure injuries. A systematic review concluded that osteomyelitis does not increase the risk of developing wound complications or recurrence [28]. Another study investigated the length of hospital stay and readmissions in patients with pressure injury-related pelvic osteomyelitis.

Our study found that there were no differences in the risk of developing wound complications based on osteomyelitis status. All wounds investigated in this work were surgically debrided, after which most patients underwent six weeks of antibiotic treatment. This regimen was likely more than sufficient to address the risk of developing complications posed by underlying osteomyelitis. Thus, the osteomyelitis and wound culture results may suggest that such clinically controlled variables may not significantly impact pressure injury wound outcomes.

5. Limitations

Our study is not without its limitations. This study offers a post hoc analysis utilizing the patient data documented in our group's prospective RCT with the aim of comparing the performance of the Dolphin Fluid Immersion Simulation System (manufactured by Joerns Healthcare) to that of the Clinitron Air-Fluidized Therapy Bed (manufactured by Ethos Therapy Solutions) by pooling together the two treatment arms to examine wound outcomes. Thus, half of the patients were randomly assigned to receive an FIS and the other half received an AFB. However, there were no significant differences in wound status outcomes between the FIS and the AFB at any time point after surgery. Patients were not matched based on comorbidities, which is a limitation of this study. Furthermore, the small sample size in this study limited the power of statistical analyses and the ability to draw conclusions. Future studies may analyze risk factors for flap failure in PI patients.

This study found that patients who are overweight or have class I-III obesity are at an increased risk of developing several early wound healing complications. Many of the consequences of obesity that lead to impaired wound healing are well documented, but the need to apply our knowledge of these mechanisms to provide more targeted therapy for patients with increased BMIs and reduce complications remains. Future studies should evaluate the effects of infection prevention, nutrient supplementation, incisional negative pressure wound therapy, and weight reduction to improve pressure injury-associated outcomes. This may further guide preoperative planning and patient expectations.

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Informed Consent Statement: Subjects were informed of the study by the principal investigator (R.D.G.), and those who agreed to participate signed an informed consent form.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: No financial assistance was received in support of the study. Robert Galiano has the following disclosures: Peri and MTF Biologics. The funders had no role in the design of the study; in the collection, analyses, or interpretation of the data; in the writing of the manuscript; or in the decision to publish the results. No disclosures were made by any of the other authors.

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