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Predictive Role of Subcutaneous Pressure Measurement in Determining Early Surgical Intervention for Cellulitis of the Leg

Dr. Kolasani Venkata Padmavathi[1], Dr. A.Y. Kshirsagar[2]

[1]Dept. of General Surgery, Krishna Institute of Medical Sciences, Krishna Vishwa Vidyapeeth, "Deemed To Be University", Karad, Malkapur, Karad (Dist. Satara), Maharashtra, India. PIN – 415539.
dr.padmavathikolasani@gmail.com

[2]Professor, Dept. of General Surgery, Krishna Institute of Medical Sciences, Krishna Vishwa Vidyapeeth, Deemed To Be University", Karad, Malkapur, Karad (Dist. Satara), Maharashtra, India. PIN – 415539.
kshirsagarashok007@gmail.com

KEYWORDS

Cellulitis, Subcutaneous Pressure, Compartment Syndrome, Surgical Intervention, Diagnostic Tool, Lower Limb Infection, Inflammation, Real-Time Monitoring, Evidence-Based Medicine, Predictive Marker

ABSTRACT

Cellulitis, a common bacterial skin infection, primarily affects the lower limbs and can escalate into serious complications, including compartment syndrome, if not managed promptly. Traditional assessment methods rely on clinical observation, but these can be subjective and may not always accurately predict the need for surgical intervention. This study investigates subcutaneous pressure measurement as an objective, quantitative method for evaluating cellulitis severity and predicting early surgical intervention requirements. Conducted at Krishna Vishwa Vidyapeeth, Karad, this prospective observational study included 52 patients with unilateral cellulitis of the leg below the knee. Subcutaneous pressure measurements were collected from affected and unaffected legs using the Stryker intracompartmental pressure monitor. Results indicated significantly elevated subcutaneous pressure in cellulitis-affected limbs, with statistical analysis showing a meaningful difference ($p < 0.001$) compared to normal limbs. The study supports existing literature suggesting that high subcutaneous pressure correlates with severe inflammation and increased risk for compartment syndrome, underscoring its potential as a predictive marker for early surgical intervention. Subcutaneous pressure measurement offers a promising, real-time diagnostic tool that enhances traditional clinical assessment and supports evidence-based decision-making. By incorporating this measurement into cellulitis management protocols, clinicians could improve diagnostic accuracy, identify high-risk cases earlier, and ultimately reduce morbidity associated with cellulitis-related complications. Future studies should aim to establish standardized pressure thresholds and validate protocols for widespread clinical use, potentially transforming how cellulitis severity and treatment needs are assessed.

I. Introduction

Cellulitis is a common yet potentially severe bacterial skin infection, characterized by inflammation, redness, swelling, warmth, and tenderness, commonly affecting the lower limbs. This condition often arises from an infection by bacteria such as Streptococcus pyogenes and Staphylococcus aureus, which can enter through even minor skin injuries or breaches. Although cellulitis can typically be managed with antibiotics, some cases require more intensive intervention, especially when complications arise. In severe cases, cellulitis can rapidly progress to cause systemic infection, sepsis, or compartment syndrome, all of which pose significant health risks [1]. For clinicians, managing cellulitis effectively requires not only prompt treatment but also the ability to detect early signs of severe complications and decide whether surgical intervention is necessary. One emerging area of research in this context is the role of subcutaneous pressure as a potential predictive marker for surgical intervention.

The pathophysiology of cellulitis is rooted in bacterial invasion of the dermis and subcutaneous tissues, where inflammation leads to fluid accumulation and edema, often escalating internal pressure within the affected tissue. When this pressure exceeds the vascular perfusion pressure, it may result in a dangerous reduction of blood flow, which, if left unaddressed, can lead to ischemia and tissue necrosis [2]. In cases where inflammation becomes severe, this process can progress into compartment syndrome, a condition marked by excessive pressure within a closed tissue space, causing compromised circulation and increasing the risk of tissue death. Prompt surgical intervention, such as a fasciotomy to release the pressure, can be life-saving in such cases.

However, timely decision-making for surgery is challenging, as the clinical signs of severe cellulitis overlap with those of other conditions, and the disease progression is often unpredictable.

Recent studies have highlighted the need for quantitative methods to assist in evaluating the severity of cellulitis and to provide objective criteria for surgical intervention. Currently, clinical observation remains the primary approach, with some reliance on imaging and laboratory markers to support diagnosis and assess severity. However, these methods often lack specificity and may delay treatment [3]. As a result, there is a growing interest in identifying measurable, real-time indicators that can aid in assessing the risk of complications in cellulitis. Subcutaneous pressure measurement offers one such promising approach. The rationale is based on the idea that elevated pressure within the subcutaneous tissue can serve as an early warning sign for impending complications, guiding timely surgical intervention.

Measuring subcutaneous pressure involves using devices such as the Stryker intracompartmental pressure monitor, a tool commonly used in diagnosing compartment syndrome. By adapting this technology to measure pressure in cases of cellulitis, healthcare providers can potentially gain a quantifiable insight into tissue health, offering a way to objectively assess whether surgical intervention may be warranted [4]. This quantitative approach to cellulitis management aligns with the principles of evidence-based medicine, aiming to supplement clinical judgment with data-driven indicators and reduce the variability in treatment decisions that arise from subjective assessment alone.

Objectives

1. To measure and compare subcutaneous pressure levels in cellulitis-affected legs and normal legs.

2. To analyze the correlation between elevated subcutaneous pressure and the severity of cellulitis.

3. To determine specific subcutaneous pressure thresholds that may indicate the need for surgical intervention.

4. To evaluate the effectiveness of subcutaneous pressure as an adjunct diagnostic tool for identifying high-risk cellulitis cases requiring surgical management.

5. To reduce the rate of undiagnosed compartment syndrome and subsequent complications through early identification using subcutaneous pressure monitoring.

In this study, the focus is on examining the utility of subcutaneous pressure as an adjunct to clinical evaluation, specifically to determine its effectiveness in predicting the need for fasciotomy or other surgical interventions in cellulitis patients. By integrating pressure measurement into the decision-making process, this research aims to enhance diagnostic accuracy, improve patient outcomes, and reduce the rates of severe complications in cellulitis cases. This exploration could lead to standardized protocols that incorporate subcutaneous pressure monitoring, providing a significant advancement in the clinical management of cellulitis and potentially other infectious and inflammatory conditions affecting the limbs.

II. Literature Review

Cellulitis, a bacterial skin infection primarily caused by Streptococcus pyogenes and Staphylococcus aureus, is a frequently encountered condition in healthcare. It often affects the lower extremities, presenting with symptoms such as erythema, swelling, warmth, and pain in the infected area [5]. If left untreated, cellulitis can rapidly progress, causing complications like abscess formation, sepsis, and, in severe cases, necrotizing fasciitis. The primary approach to treating cellulitis involves antibiotic therapy, which typically suffices in mild to moderate cases. For more severe infections, hospitalization and intravenous antibiotics may be necessary to control the spread of the infection. Effective management depends heavily on timely diagnosis and intervention, as delays can lead to critical outcomes. Given the infection's potential to advance quickly, clinical evaluation and appropriate intervention are essential in preventing these complications.

The severity of cellulitis can escalate, leading to compartment syndrome, particularly in cases with extensive swelling and inflammation. Compartment syndrome is a serious condition where increased pressure within a closed anatomical space, such as muscle compartments in the leg, compromises blood supply, leading to ischemia, necrosis, and even nerve damage. This condition requires immediate intervention; delaying can result in irreversible muscle and nerve damage or even limb amputation in severe cases. Fasciotomy, a surgical procedure that involves cutting the fascia to relieve compartment pressure, is often performed in cases of acute compartment syndrome. Identifying patients who need this intervention, however, remains challenging, as clinical symptoms alone may not reliably indicate the presence of compartment syndrome, particularly when cellulitis is the underlying cause. Studies have shown that typical signs, such as disproportionate pain, are not always sufficient, as they can overlap with symptoms of cellulitis itself. [6][7]

As cellulitis cases with severe inflammation can mimic or even precipitate compartment syndrome, there is a strong clinical interest in identifying objective indicators that can help predict the need for surgical intervention. Subcutaneous pressure measurement is one such emerging method, offering a potential diagnostic tool for determining when compartment syndrome may be developing in cellulitis cases. By

measuring the pressure within the subcutaneous tissue, clinicians can gain quantifiable data on tissue health, allowing them to make more informed decisions regarding the need for surgical decompression. Studies have found that subcutaneous pressure measurement can aid in detecting elevated interstitial pressures that are precursors to tissue ischemia and necrosis [8]. This method has traditionally been used in trauma cases but is gaining traction in cellulitis management, as it provides a more precise assessment than clinical observation alone.

The role of subcutaneous pressure as a predictor for surgical intervention has been supported by recent studies demonstrating its effectiveness in diagnosing early-stage compartment syndrome. Devices such as the Stryker intracompartmental pressure monitor, commonly used for diagnosing compartment syndrome in trauma, are now being applied to cellulitis cases to assess whether increased pressure indicates a need for surgical intervention. A study by Spinnato et al. (2022) indicated that subcutaneous pressure measurements, when elevated beyond certain thresholds, correlated with a higher likelihood of requiring fasciotomy. Similarly, Makedonov et al. (2020) suggested that pressure monitoring could serve as an early diagnostic measure, allowing for quicker response times in preventing the progression to full-blown compartment syndrome.

Although promising, the use of subcutaneous pressure as a routine diagnostic tool in cellulitis cases requires further research to establish standardized thresholds and protocols. Some studies have found that while elevated subcutaneous pressures are associated with complications, there is variability in the specific thresholds that warrant surgical intervention. Therefore, while subcutaneous pressure monitoring holds potential, further validation is necessary to refine its role in clinical practice. As research progresses, this method may become a standard part of cellulitis management, offering an evidence-based approach to improving outcomes by guiding timely and appropriate surgical interventions.

III. Materials and Methods

a. Study Design, Location, and Duration

This study is a prospective observational analysis conducted within the Department of General Surgery at Krishna Vishwa Vidyapeeth in Karad, Maharashtra. The research aimed to investigate the role of subcutaneous pressure as a predictive indicator for surgical intervention in cellulitis of the lower limb. The study spanned from March 2022 to September 2023, during which patients presenting with unilateral cellulitis of the lower leg, below the knee, were evaluated. The prospective design allowed for systematic observation and real-time data collection on the patients' clinical presentations and their subcutaneous pressure measurements, providing an in-depth understanding of how these measurements correlate with the need for surgical intervention.

b. Participant Criteria, Sample Size, and Selection Process

The study included a carefully selected cohort of 52 patients, each meeting specific inclusion and exclusion criteria to ensure consistency and reliability in the data. The inclusion criteria were:

1. Patients aged between 14 and 65 years.

2. Diagnosis of unilateral cellulitis localized below the knee.

Exclusion criteria were set to avoid confounding variables that could interfere with the study's outcomes. These included:

1. Patients with bilateral pedal edema or bilateral cellulitis, as these conditions could skew subcutaneous pressure readings.

2. Cases of necrotizing fasciitis or filarial leg, which require different treatment protocols.

3. Patients with underlying conditions such as deep vein thrombosis, tibial or fibular fractures, or diabetic foot ulcers with skin necrosis.

4. Individuals who had already completed an antibiotic course for cellulitis.

Patients were recruited from the outpatient clinic and emergency department of Krishna Vishwa Vidyapeeth and were screened based on the above criteria. Those who fit the inclusion criteria and provided informed consent were enrolled in the study. This selection process ensured a representative sample of cellulitis cases without complicating factors that could affect subcutaneous pressure independently of cellulitis.

c. Detailed Methodology for Subcutaneous Pressure Measurement and Data Collection

To obtain accurate subcutaneous pressure measurements, a standardized protocol was followed for each patient. First, the circumference of both the affected and unaffected legs was measured using a standard inch tape, providing a baseline for evaluating any differences due to cellulitis-related swelling. To minimize patient discomfort during the procedure, a local anesthetic gel containing lignocaine and prilocaine was applied to the measurement area. The exact location on the leg was marked with a skin marker to ensure precision and repeatability of measurements.

Prior to pressure measurement, the skin was prepared with a 7.5% Povidone Iodine solution to maintain a sterile field and prevent infection. Subcutaneous pressure measurements were taken using the Stryker intracompartmental pressure monitor, a device known for its accuracy in measuring compartmental pressures. The Stryker device was equipped with an 18G side port needle connected to a prefilled saline

syringe and a pressure diaphragm. The side port needle, as opposed to a straight needle, was selected to reduce the risk of overestimating pressure, providing more reliable readings. Measurements were taken at a consistent distance of 10.5 cm from the tibial tuberosity, which was identified as a stable reference point for pressure monitoring across patients.

Data collection encompassed both demographic and clinical data. Patient characteristics, including age, gender, and relevant comorbidities, were documented. Clinical data included detailed subcutaneous pressure readings from various regions (anteromedial, anterolateral, posteromedial, and posterolateral) of the affected leg. Pressure values were recorded systematically to track variations and identify any potential association between elevated pressures and the severity of cellulitis.

Statistical analyses were conducted to explore significant differences in subcutaneous pressure between the affected and unaffected legs. The collected data underwent descriptive statistical analysis to characterize the sample and summarize findings, while inferential statistics, including t-tests and ANOVA, were used to assess differences and validate the study's hypothesis regarding the predictive value of subcutaneous pressure for surgical intervention. By employing this structured methodology, the study aimed to rigorously evaluate the utility of subcutaneous pressure measurement in guiding clinical decisions for cellulitis management.

IV. Procedure and Methodology

1. Study Design and Setting

This prospective observational study was conducted in the Department of General Surgery at Krishna Vishwa Vidyapeeth, Karad, Maharashtra, from March 2022 to September 2023. The study focused on patients presenting with unilateral cellulitis of the lower leg, examining the role of subcutaneous pressure as a predictive marker for early surgical intervention.

2. Participant Selection and Criteria

Inclusion Criteria

- Patients aged between 14 and 65 years.
- Diagnosed with unilateral cellulitis of the lower leg (below the knee).

Exclusion Criteria

- Bilateral pedal edema or bilateral cellulitis.
- Patients with necrotizing fasciitis, filarial leg, deep vein thrombosis, tibial or fibular fractures, or diabetic foot ulcers with skin necrosis.
- Patients who had already completed an antibiotic course for cellulitis.

Eligible patients were recruited from the outpatient and emergency departments, screened based on the criteria, and informed consent was obtained. A total of 52 participants meeting the inclusion criteria were enrolled in the study.

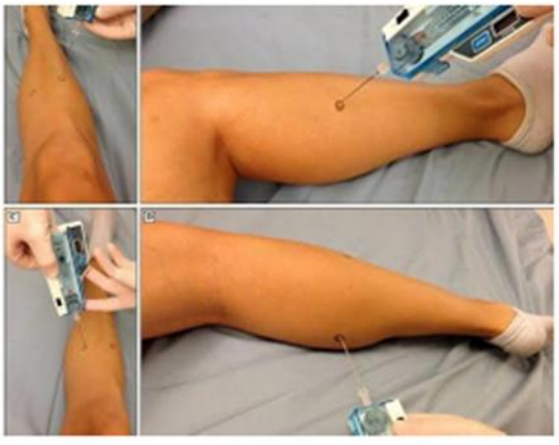

Figure 1. Stryker Intracompartmental pressure monitor

3. Data Collection Procedure

3.1 Demographic and Clinical Data

For each participant, demographic information (age, gender) and clinical characteristics (presence of pain, swelling, fever, and relevant comorbidities) were documented.

3.2 Subcutaneous Pressure Measurement

To assess subcutaneous pressure, the following steps were taken:

1. Preparation:

o The circumference of both the affected and unaffected legs was measured using an inch tape to establish a baseline for comparison.

o Local anesthetic gel (Prilox cream containing lignocaine and prilocaine) was applied to the target measurement area to minimize discomfort.

o The exact site for pressure measurement was marked with a skin marker to ensure consistency.

2. Skin Preparation:

o The marked area was sterilized using a 7.5% Povidone Iodine solution to minimize contamination risk.

3. Pressure Measurement:

o Subcutaneous pressure measurements were taken using the Stryker intracompartmental pressure monitor, equipped with an 18G side-port needle and a prefilled saline syringe.

o The side-port needle configuration was chosen to enhance accuracy and minimize overestimation risks, as it has shown improved precision in measuring subcutaneous and compartment pressures.

o Measurements were taken at a standardized distance of 10.5 cm from the tibial tuberosity, identified as a stable reference point across patients.

o Readings were taken from multiple sites within the affected leg (anteromedial, anterolateral, posteromedial, and posterolateral regions) to capture regional pressure variations.

4. Data Analysis

Collected data were entered into a database and analyzed statistically using descriptive and inferential techniques.

4.1 Statistical Methods

1. Descriptive Analysis:

o Demographic characteristics and clinical symptoms were summarized to characterize the study sample.

o Mean and standard deviations for subcutaneous pressure readings across different regions were calculated for both affected and unaffected legs.

2. Comparative Analysis:

o Independent t-tests were conducted to assess differences in subcutaneous pressure between normal and cellulitis-affected legs.

o Statistical significance was set at a p-value of <0.05.

3. Correlation Analysis:

o To evaluate the relationship between elevated subcutaneous pressure and cellulitis severity, correlation analyses were performed.

4. Threshold Analysis:

o Potential pressure thresholds indicating the need for surgical intervention were analyzed by evaluating the sensitivity and specificity of various subcutaneous pressure values.

5. Quality Control

To ensure consistency and accuracy, each pressure measurement was conducted by a trained clinician following a standardized protocol. Measurements were taken at consistent anatomical locations, and readings were cross-checked to verify reliability.

6. Ethical Considerations

The study protocol was approved by the institutional ethics committee of Krishna Vishwa Vidyapeeth, Karad. All patients provided informed consent before participation, and patient confidentiality was maintained throughout the study.

V. Observations and Results

a. Demographic Distribution and Symptom Analysis

The study included a total of 52 patients who met the inclusion criteria. Demographically, the majority of patients were within the 50-59 age group, which represented 28.8% of the total cohort. Gender distribution showed a slight predominance of males (53.8%) over females (46.2%).

Table 1: Age and Gender Distribution of Participants

Age Group (years)	Number of Patients	Percentage (%)
20-29	5	9.6
30-39	9	17.3
40-49	12	23.1
50-59	15	28.8
60+	11	21.2
Total	52	100
Gender	Number of Patients	Percentage (%)
Male	28	53.8
Female	24	46.2
Total	52	100

Symptom Distribution: Common symptoms observed included swelling (80.8%), pain (67.3%), and fever (38.5%).

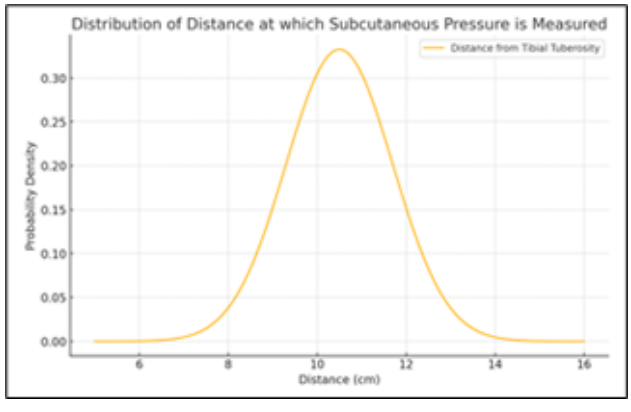

Figure 2. Distance at which Subcutaneous Pressure Measured from Tibial Tuberosity in cm

Table 2: Symptom Distribution

Symptom	Number of Patients	Percentage (%)
Swelling	42	80.8
Pain	35	67.3
Fever	20	38.5

b. Comparative Pressure Readings Between Normal and Cellulitis-Affected Legs

Subcutaneous pressure measurements revealed significant differences between the cellulitis-affected and normal legs across different regions (anteromedial, anterolateral, posteromedial, and posterolateral). The affected leg consistently showed elevated pressures, with the highest mean pressure recorded in the anteromedial region.

Table 3: Comparative Subcutaneous Pressure Readings (mmHg)

Measurement Region	Normal Leg (Mean ± SD)	Cellulitis-Affected Leg (Mean ± SD)
Anteromedial	2.1 ± 2.4	9.8 ± 1.7
Anterolateral	2.1 ± 2.4	8.9 ± 2.1
Posteromedial	2.1 ± 2.4	9.0 ± 1.7
Posterolateral	2.1 ± 2.4	9.5 ± 2.0

c. Statistical Analysis and Significance of Findings

Statistical analysis confirmed significant differences in subcutaneous pressure between normal and affected legs. An independent t-test comparing normal and cellulitis-affected legs indicated a highly significant difference ($p < 0.001$), supporting the hypothesis that elevated subcutaneous pressure is associated with cellulitis severity.

Table 4: Statistical Comparison of Subcutaneous Pressure (Normal vs. Affected Legs)

Group	Median Pressure (mmHg)	Z-statistic	p-value
Normal Leg	2.1	2.79	<0.001
Cellulitis-Affected Leg	9.3		

The findings highlight that elevated subcutaneous pressure measurements could serve as an objective indicator to assess cellulitis severity and potentially guide surgical intervention decisions in severe cases.

VI. Discussion

The results of this study demonstrate a significant elevation in subcutaneous pressure in cellulitis-affected legs compared to normal legs, aligning with findings from existing literature that suggest high interstitial pressure as a marker for severe inflammation and infection. In cellulitis, where the infection and inflammation spread rapidly, the resultant edema can increase interstitial pressure, compromising blood flow and tissue viability. This study supports the growing body of evidence suggesting that subcutaneous pressure could serve as an early warning indicator for complications, such as compartment syndrome, thereby justifying prompt surgical intervention in severe cases. Previous research by Spinnato et al. (2022) and Makedonov et al. (2020) similarly identified elevated tissue pressure as an early indicator for surgical decompression in compartment syndrome, providing a clinical foundation for using pressure measurements as part of cellulitis management strategies. These results reinforce the relevance of subcutaneous pressure measurement in guiding clinical decision-making. Traditional assessment of cellulitis severity relies largely on clinical signs and symptoms, such as erythema, swelling, and tenderness. However, these signs can overlap with other conditions, such as deep vein thrombosis or lymphedema, leading to diagnostic ambiguity. Subcutaneous pressure measurement offers an objective, quantitative assessment tool, potentially enhancing the accuracy of clinical evaluation. In the present study, patients with cellulitis consistently displayed elevated subcutaneous pressure levels, distinguishing affected limbs from normal ones. This suggests that incorporating subcutaneous pressure measurement into routine cellulitis assessment could aid clinicians in identifying cases at higher risk for complications, allowing for timely intervention. This approach aligns with evidence-based medicine, where quantitative data are integrated into clinical judgments to support more consistent and accurate decision-making.

When compared with other predictive markers and diagnostic techniques, subcutaneous pressure measurement offers unique advantages. Common diagnostic methods for assessing cellulitis severity include laboratory markers (e.g., white blood cell count, C-reactive protein, erythrocyte sedimentation rate) and imaging techniques such as ultrasound or MRI. While these methods are valuable, they each present limitations. Laboratory markers indicate general inflammation but lack specificity for cellulitis or compartment syndrome. Elevated white blood cell count or C-reactive protein levels may indicate infection severity but cannot provide real-time data on tissue pressures, which is critical in deciding when surgical intervention may be required. Imaging techniques, such as ultrasound, have shown utility in differentiating cellulitis from abscesses and other fluid collections, and they help in diagnosing conditions like deep vein thrombosis. However, imaging can be costly, time-consuming, and may not always be readily available in emergency settings. Furthermore, ultrasound and MRI are primarily diagnostic tools rather than real-time monitoring solutions, whereas subcutaneous pressure measurement offers immediate feedback on tissue status, allowing clinicians to monitor pressure changes dynamically.

Moreover, this study's findings suggest that subcutaneous pressure measurement could complement existing diagnostic techniques. In cases where clinical presentation or laboratory results are inconclusive, pressure monitoring could serve as an adjunct tool, helping determine if elevated tissue pressure warrants surgical decompression. By quantifying the extent of pressure buildup, this method can reduce reliance on subjective assessment, which can vary among clinicians and contribute to inconsistent treatment decisions. Overall, while subcutaneous pressure measurement is still emerging as a tool for cellulitis management, it holds considerable promise as a complementary diagnostic approach, particularly in cases where cellulitis threatens to progress into compartment syndrome. The results suggest that routine use of this technique could improve outcomes by providing timely, data-driven insights into cellulitis severity, supporting early intervention in high-risk cases. Future research should focus on validating specific pressure thresholds to refine its clinical applicability further and on standardizing protocols for incorporating pressure

measurement into cellulitis treatment frameworks. With such advancements, subcutaneous pressure monitoring may become a standard part of cellulitis management, improving both the precision of diagnosis and the effectiveness of care.

VII. Conclusion

This study highlights the potential role of subcutaneous pressure measurement as a valuable tool in assessing the severity of cellulitis and guiding clinical decision-making for surgical intervention. The significant differences in pressure between normal and cellulitis-affected legs suggest that elevated subcutaneous pressure could serve as an early indicator of complications, such as compartment syndrome, which require prompt intervention. By providing an objective, quantifiable assessment, subcutaneous pressure monitoring could enhance traditional diagnostic methods and aid in identifying cases that necessitate timely surgical management. Compared to traditional assessment techniques, subcutaneous pressure measurement offers a rapid, real-time indicator of tissue health, reducing the dependence on subjective symptom evaluation alone. This method could complement existing diagnostic approaches, such as laboratory markers and imaging, which, while useful, may lack specificity or immediacy in detecting compartmental pressure changes related to cellulitis. Integrating subcutaneous pressure measurement into standard cellulitis assessment protocols could improve diagnostic accuracy, optimize patient outcomes, and reduce the risk of severe complications. Future research is needed to establish standardized pressure thresholds and refine clinical protocols for subcutaneous pressure measurement in cellulitis cases. As more evidence becomes available, subcutaneous pressure monitoring may become a critical component of cellulitis management, supporting clinicians in making timely, evidence-based decisions that ultimately enhance patient care and reduce morbidity associated with advanced cellulitis.

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