Does Sacrococcygeal Skeletal Morphology and Morphometry Influence Pressure Injury Formation in Adults?

Barbara Delmore, PhD, RN, CWCN, MAPWCA, IIWCC-NYU, FAAN, Senior Nurse Scientist, Center of Innovations in the Advancement of Care, NYU Langone Health; Clinical Assistant Professor, Hansjörg Wyss Department of Plastic Surgery, NYU Grossman School of Medicine, New York, New York
Stephen Sprigle, PhD, PT, Professor of Bioengineering, Rehabilitation Engineering and Applied Research Laboratory, Georgia Institute of Technology, Atlanta, Georgia
Mohammad Samim, MD, MRCS, Assistant Professor, Division of Musculoskeletal Radiology, Department of Radiology, NYU Langone Health/NYU Orthopedic Hospital, New York, New York
Allyson R. Alfonso, MD, Integrated Plastic Surgery Resident Physician, Former Research Fellow, Hansjörg Wyss Department of Plastic Surgery, NYU Grossman School of Medicine, New York, New York
Lawrence Lin, MD, Resident Physician, Department of Orthopedic Surgery, NYU Grossman School of Medicine, New York, New York
Ernest Chiu, MD, FACS, Medical Director, Helen L. & Martin S. Kimmel Hyperbaric and Advanced Wound Healing Center, NYU Langone Health; Professor, Hansjörg Wyss Department of Plastic Surgery, NYU Grossman School of Medicine, New York, New York

CME
1 AMA PRA
Category 1 Credit™

NCPD
ANCC
2.5 Contact Hours

GENERAL PURPOSE: To present a study that investigated sacrococcygeal skeletal structure as a possible nonmodifiable intrinsic risk factor for pressure injury and identify possible issues caused by its morphology.

TARGET AUDIENCE: This continuing education activity is intended for physicians, physician assistants, nurse practitioners, and nurses with an interest in skin and wound care.

LEARNING OBJECTIVES/OUTCOMES: After participating in this educational activity, the participant will:

1. Recognize the background information the authors considered when planning and conducting their study of sacrococcygeal skeletal structure as a possible pressure injury risk factor.
2. Identify the characteristics of the two groups of study participants.
3. Choose the results of the study clinicians may consider when implementing evidence-based practice.

ABSTRACT

OBJECTIVE: To determine if sacrococcygeal skeletal morphology and morphometry characteristics were possible pressure injury (PI) intrinsic risk factors; determine the exact location of these PIs; and generate hypotheses and determine methodological considerations required for future larger studies.

METHODS: This case-control pilot study compared 30 patients who had an MRI scan—15 patients had a PI and 15 patients did not. Key sacrococcygeal morphology and morphometry parameters were assessed.

RESULTS: On average, patients with PIs had less of a lumbosacral and sacrococcygeal angle and a greater sacral curvature and intercoccygeal angle than did patients without a PI. Patients with PIs had more variable coccyx types. Tissue and bone destruction precluded several measurements in some patients. The most common area of destruction was located distally.

CONCLUSION: Sacrococcygeal measurements differed in patients with PIs, and PIs were predominately located distally. Authors recommend replicating this study on a larger scale because certain key attributes warrant further investigation to determine their influence on sacrococcygeal PIs. Sacrococcygeal morphology and morphometry parameters have not been previously studied as possible intrinsic risk factors for PIs; yet, this is the most common location for their occurrence. Knowledge regarding possible injury mechanisms due to the forces from overlying skeletal structures with respective tissue loading over the sacrococcygeal area has the potential to inform practice; preventive strategies; and equipment, products, and technology developed.

Acknowledgments: The authors acknowledge the contributions of Linda Rolnitzky, MS; Daniel Smith, MA; and Jasmine Chau, MPH. This work was funded in full by the Plastic Surgery Foundation (award ID 567779). All authors, faculty, and staff have no relevant financial relationships with any ineligible organizations regarding this educational activity.
To earn CME credit, you must read the CME article and complete the quiz online, answering at least 7 of the 10 questions correctly. This continuing educational activity will expire for physicians on October 31, 2024, and for nurses September 5, 2025. All tests are now online only; take the test at http://cme.lww.com for physicians and www.NursingCenter.com/CE/ASWC for nurses. Complete NCPD/CME information is on the last page of this article.

KEYWORDS: morphology, morphometry, pressure injury, pressure ulcer, risk factors, sacrococcygeal

ADV SKIN WOUND CARE 2022;35:586–95.

DOI: 10.1097/01.ASW.0000874180.84660.8b

INTRODUCTION

Despite decades of patient care advances, pressure injuries (PIs) remain a pathophysiologic and management concern.[1] It has been estimated that the US spends approximately $28 billion a year on facility-acquired PIs.[2] Facility-acquired PI occurrence is associated with possible reimbursement penalties, legal ramifications, iatrogenic complications, and poor quality of life and patient outcomes including premature death.[3]

Pressure is the single most important etiologic factor causing PIs but is compounded by the complexity of multiple contributory modifiable and nonmodifiable intrinsic and extrinsic risk factors.[1,4–6] The possible relationships between PI occurrence and these risk factors are a relatively new field of research and require more examination.[1,4,6–8] One intrinsic risk factor that has been discussed and studied is skeletal morphology. Skeletal shapes created by the morphology of the sacrum, coccyx, ischial tuberosities, and heels can contribute to pressure-related issues.[9–11] Pressure from extrinsic mechanical loads damages the underlying tissue, vessels, and bony structures.[9–14] This point is illustrated with tissue or bony deformation that can occur when a patient is seated or supine. Further, the complexity of the situation can increase based on individual characteristics.[9]

The literature regarding skeletal morphology largely discusses the effects of the seated position, as seen in plegia (quadriplegia, paraplegia) or other conditions requiring wheelchair use. However, patient conditions and positions create different displacements and stressors on the tissues and skeletal structures involved. The seated position can affect the ischial tuberosities, whereas supine positions can affect the sacrococcygeal region.[9,12] The added effect of conditions such as plegia, immobility, or higher body mass index (BMI) can cause pathoanatomic changes, such as different tissue and fat distribution.[13,15–19] These factors all add to the complexity of PI occurrence in a specific anatomical site.

This research departs from the majority of previous skeletal morphology works in that it specifically focuses on the skeletal sacrococcygeal influences on PI occurrence in the supine position. The objectives of this work were to investigate the sacrococcygeal skeletal structure as a possible nonmodifiable intrinsic risk factor and identify possible issues caused by its morphology. Sacrococcygeal skeletal structure is defined at birth and undergoes various changes through a person's life based on growth and development, trauma, and the aging process. Most PIs occur in the sacrococcygeal anatomic region,[20–22] but as a risk factor, the sacrococcygeal skeletal structure in the supine position has been addressed in a limited capacity.

Background

The sacrum is uniquely shaped and articulates with the lumbar spine, pelvis, and coccyx; it serves as a load-bearing keystone.[23,24] The lumbosacral junction, where the lumbar meets the sacrum, is one of the most variable areas including sacral fusion patterns.[24,25] The lumbosacral angle (sacro-horizontal angle, sacral angle, sacral lumbosacral angle, Ferguson's angle) is considered clinically important in diagnosing conditions and is an area where injuries frequently occur.[25–28] Sacral curvature is another anatomical parameter that gives the human pelvis its unique shape.[29] An erect posture makes the sacrum horizontal and influences it posteriorly. A supine posture exerts pressure on the lower sacrum and coccyx and influences it in a ventral direction.[29]

The coccyx, often viewed as a vestigial, rudimentary, and "irrelevant" structure, is known for its variable morphological nature[30] and its triangular bone that diminishes in size.[30,31] One of its important functions is to serve as an attachment point for the muscles and ligaments that build the perineum.[30] The number of segments can vary,[30,32] but the coccyx usually consists of three to five vertebrae, with four vertebrae segments presenting in approximately 70% to 80% of the population.[33–37] The coccyx's first segment is the largest with transverse processes. It curves in an anterior and inferior manner in most adults and may fuse with the sacrum in later life.[30,33,34,38] Unlike the sacral area, coccygeal movement occurs with change in posture affecting the sacrococcygeal angle and other parameters.[35,39] There are six coccyx types, with types I and II tending to be most common.[31,32,36,40] Type I is the straightest coccyx type; type II coccyx or greater may be more predisposed to certain conditions.[31,32,40,41]

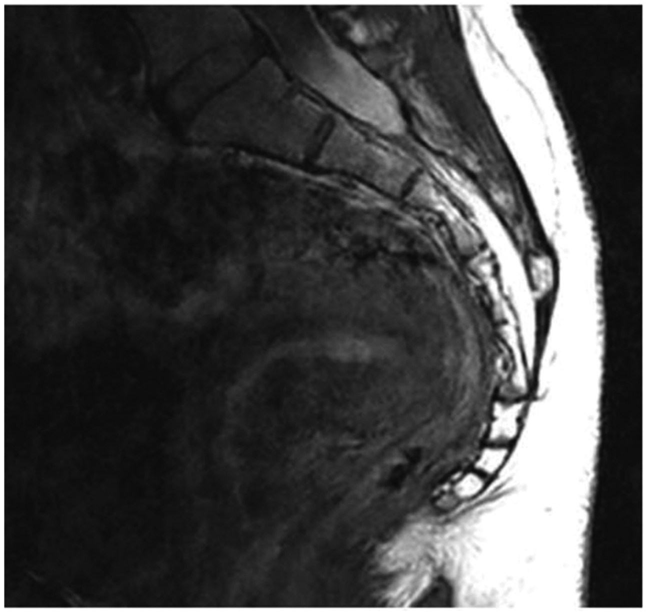
Morphology and morphometry of the sacrococcygeal region, including coccyx types, may be linked to various conditions.[27,28,31–33,35,38,40–42] Morphology and morphometry studies have not been linked to PIs, yet the sacrococcygeal area is the most common PI site.[20–22] The exact mechanisms for internal loading and subsequent physiologic responses leading to a PI are not well understood; however, current evidence suggests that damage can result directly from deformation or blood flow impairment by tissue deformation under load.[43–46] The sacrococcygeal area becomes more susceptible to damage because of its unique circulation, lower density of elastic fibers delaying tissue recovery, adiposity, patient factors, and extended recumbent or sitting positions.[20,47–49] The loading that occurs especially on the adipose tissue and how it becomes dispersed are influenced by a patient's position and the tissue strain that is caused.[19] Of note, while in bed (supine), it is considered best practice to elevate the head of the bed no more than 30° to avoid increased pressure on the sacrococcygeal area.[50]

The paucity of research led the authors to ask the question: "Do skeletal sacrococcygeal morphology and morphometry influence PI occurrence in the supine position?" This question is illustrated in Figure 1, which shows MRI scans of two women in the supine position with a simulation of a 30° head-of-bed elevation. Participant A presents with a type I coccyx and a lumbosacral angle of 45°, whereas participant B presents with a type III coccyx and lumbosacral angle of 58°. A clear difference exists between the individuals with respect to tissue loading. The coccyx of participant B protrudes into the adipose tissue and is driven more superficially with respect to the skin. An inference can be made that this position induces increased tissue strain in participant B compared with participant A. Figure 1 illustrates the value of research studying sacrococcygeal morphology and morphometry differences, as well as indicating differences in tissue strains and therefore PI risk.

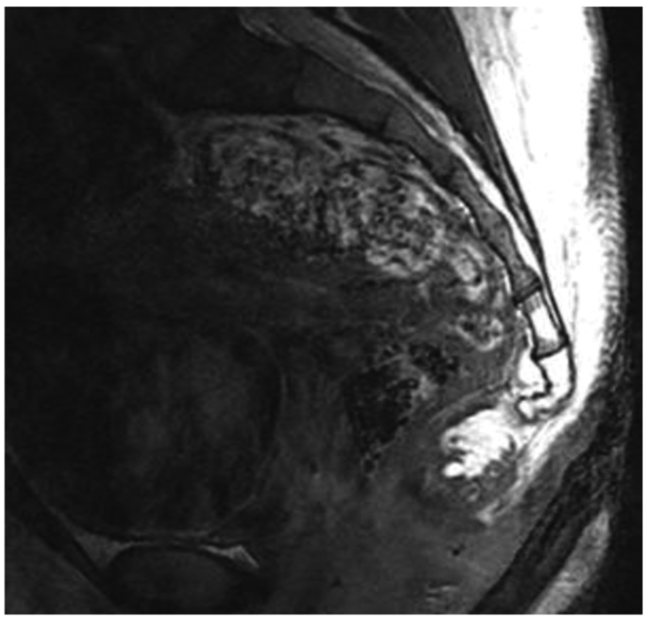
Understanding the possible injury mechanisms due to forces from overlying skeletal sacrococcygeal structures and other contributing characteristics is important because it can inform prevention strategies. In addition, it can inform the design of pressure redistribution products (eg, support surfaces) that work to mitigate extrinsic factors and protect this region from PI occurrence. In this article, the authors report research findings that explored sacrococcygeal morphology and morphometry as possible PI intrinsic risk factors. Because these factors have not been studied previously, the authors also present hypotheses and methodological considerations for future research.

Figure 1. MAGNETIC RESONANCE IMAGES OF TWO WOMEN IN THE SAME POSITION AND A SIMULATED 30° HEAD-OF-BED ELEVATION

Participant A presents with a type I coccyx and a lumbosacral angle of 45°, whereas participant B presents with a type III coccyx and lumbosacral angle of 58°. The image demonstrates a clear difference between participants in the loading of adipose tissue.



Participant A



Participant B

METHODS

Design

The design was a retrospective, case-control study conducted at an urban, tertiary medical center located in New York City. This research received expedited (category 5) approval from the institutional review board.

Aims

The first aim of this study was to assess sacrococcygeal morphology and morphometry in patients with and without full-thickness PIs, hypothesizing that there would be a difference between these groups. The rationale was that because gravitational forces on tissues are imparted through the bony skeleton, by extension, the morphology of skeletal structures may impact the direction and magnitudes of normal and shear forces.[43,51] The second aim was to determine the precise anatomical locations of full-thickness sacrococcygeal PIs. Investigators hypothesized that full-thickness PIs more commonly occur over the distal sacrococcygeal region. The rationale was that the relative anatomical location of PIs overlying the sacrum and coccyx will help improve understanding of possible mechanisms of injury due to forces from overlying skeletal structures. The third aim was to identify hypotheses and methodological considerations when using radiographic images to study anatomy in persons with and without PIs for future studies.

Participants

Inclusion criteria for cases and control participants were patients older than 18 years (skeletal maturity reached[39]) with a supine MRI of the sacrococcygeal region. For cases only, patients had a full-thickness PI as defined by the National Pressure Injury Advisory Panel's staging definitions (stage 3, stage 4, and unstageable).[4] Exclusion criteria included patients with known pathologies such as large masses (malignancy), pelvic disease, and pelvic surgery, including extensive reconstructive efforts.[35,41] Patients with disabilities causing poorly formed skeletal morphology (spina bifida, spinal cord injury) were excluded because "sitting-related" PIs can develop from equipment used (eg, toilets, beds, cars, bathtubs) because of their disability.[16–18]

Procedures

Using the medical center's electronic medical record, cases (with PIs) and control participants (without PIs) were selected using a series of *International Classification of Diseases* (*ICD*) ninth and tenth revision codes to determine if a patient had an MRI (supine position) in the sacrococcygeal region (eg, pelvic, sacrum) between 2013 and 2019.

Sample Size

The sample size was 5,400 patient encounters in which 401 were cases and 4,999 were control participants. The intent was to randomly select 15 cases and 15 control participants to achieve an adequate sample size of 30.[52,53] For this type of analysis, a sample size can successfully be as low as 12 participants per group,[54,55] but the investigators decided to use 15 per group for a total of 30. The aim was not to perform statistical testing of these data but simply to derive descriptive information that can be used in the development of larger studies. A power analysis was not appropriate in the absence of statistical comparison of the two groups.

As seen in Figure 2, various issues arose in the ability to randomly select cases, but a sample size of 15 was achieved by purposive selection. Random selection of control participants was more successful.

Data Collection

Sacrococcygeal morphology and morphometry measurements were collected as defined in Table 1 and exemplified in Figure 3. Sacral measurements were included because the sacrum orients the coccyx; therefore, lumbar-sacral angle and sacral curvature may be highly influential in "pointing" the coccyx. The sacral area was also included because the distinction of ulcers over the sacrum versus the coccyx may not be clear as ulcers may cross over regions. With this in mind, vertebral ranges were used to enable multiple locations to be considered. Using a combination of *ICD* codes and chart information, data were also collected on demographics (age, sex, height, weight, BMI, race/ethnicity, parity data, admitting diagnosis, medical history) and exact location of the PI using a combination of *ICD* codes, electronic medical record data, and MRI scans.

After receiving mentoring by the academic partner and radiologist on the team, an attempt was made to conduct an interrater reliability analysis process. It quickly became apparent that each case had to be reviewed, measured, and verified using the consensus process because nearly half of the patients with PIs had severe bone and/or soft

Figure 2. SELECTION PROCESS FOR CASES AND CONTROLS FROM 5,400 ELIGIBLE PATIENT ENCOUNTERS

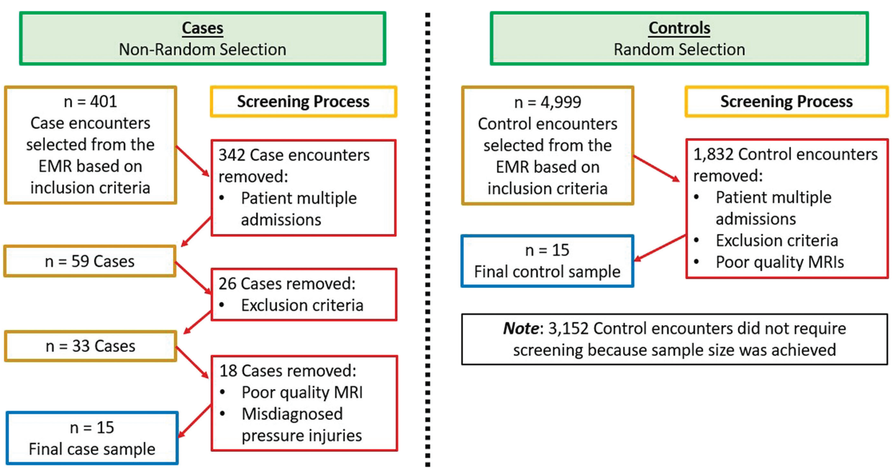


Table 1. SELECTED SACROCOCCYGEAL VARIABLES WITH DEFINITIONS

Variable/Measure	Definition
Lumbosacral angle,°	Angle formed between the long axis of the lumbar vertebrae and superior margin of the sacrum (rationale: influential in "pointing" the coccyx)
Sacral curvature,°	Angle created by measuring from upper S1 border to S5 inferior border lengths anteriorly and posteriorly and averaging (rationale: influential in "pointing" the coccyx)
Sacrococcygeal angle,°	Angle formed by the intersection of the line between the midpoint of S1 and C1 upper borders and the line between the latter and tip of coccyx
Intercoccygeal angle,°	Angle caused by the lines parallel to the first and the last segment of coccyx
Coccyx types	Type I—coccyx slightly curved pointing downward (angle less than 30°) Type II—coccyx more curved and points forward (angle larger than 30°) Type III—coccyx with a sharp angulation at the first or second intercoccygeal joint Type IV—coccyx has an anterior subluxation at the sacrococcygeal or first intercoccygeal joint Type V—coccyx has a retroverted tip Type VI—scoliotic deformity
Tissue thickness measurements (rationale: sacrococcygeal area is a load-bearing region, which is significant because a pressure injury can result from localized tissue loading resulting in a series of pathophysiologic responses to deformation)	
S3-S4 tissue thickness, mm	Tissue thickness (load bearing) from S3 to S4
S4-S5 tissue thickness, mm	Tissue thickness (load bearing) from S4 to S5
S5-C1 tissue thickness, mm	Tissue thickness (load bearing) from S5 to C1
C1-C2 tissue thickness, mm	Tissue thickness (load bearing) from C1 to C2

tissue destruction to the sacrococcygeal area (Figure 4). The consensus process was between two team members for verification. Measurements were accomplished using supine MRI scans in the midsagittal plane to the sacrum and coccyx. Sagittal T1 (relaxation times of tissues) displays were used to view osseous structures, which are better for measurement in certain conditions.[38] Various tissue thickness measurements were obtained from the skin (epidermis, dermis), subcutaneous (adipose) tissue, muscle layers, and bone (Table 1).

Data Analysis

Data analysis for this study had two goals: (1) perform preliminary tests using the small sample and (2) provide information that can be used to design more complex studies. Because of the sample size, comparisons between groups were made by examining the data rather than by statistical testing. Note that all test results were performed for the sole purpose of providing descriptive information for further studies.

To describe this sample of 30 patients by PI status (15 PI cases, 15 non-PI control participants), patient demographic and patient physical characteristics, including morphology and morphometry, were presented. Means and SDs, along with upper and lower data limits, were used to describe continuous variables by PI status. Proportions accompanied by odds ratios (ORs) or Fisher exact test (coccyx type analysis) described categorical variables. The OR represents the odds that a PI will occur given a particular patient characteristic compared with the odds of a PI occurring without that characteristic. Fisher exact test was used to compare the distribution of patients' coccyx types between the PI and non-PI groups. It was used in lieu of the χ^2 test because of the data distribution of this small sample.

Figure 3. SAMPLE SACROCOCCYGEAL MEASUREMENTS

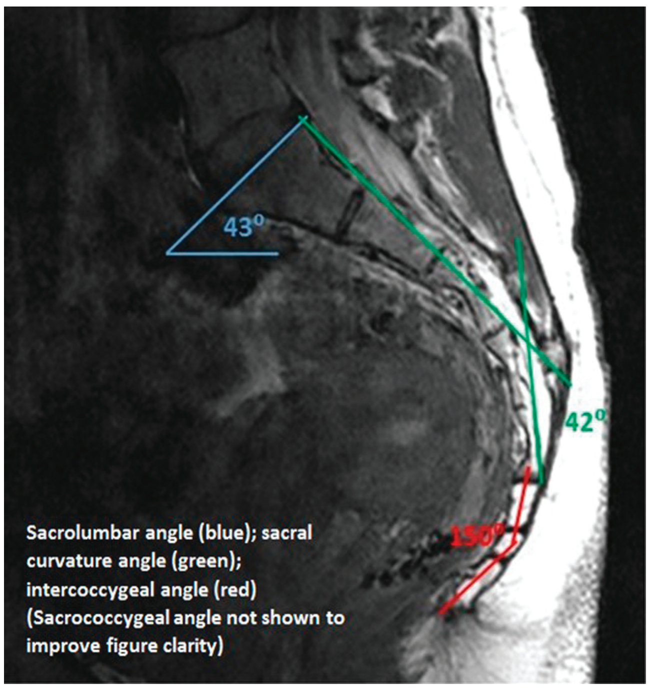
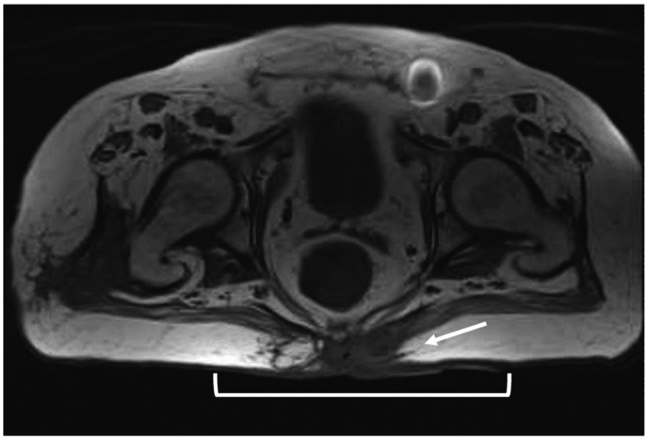


Figure 4. MAGNETIC RESONANCE IMAGES OF TWO DIFFERENT PATIENTS WITH STAGE 4 PIs

Note the extent of tissue and/or bone destruction. In the top image (sagittal view), the patient's PI encompasses the sacrococcygeal area. In the bottom image (axial view), the patient's PI is located in the coccyx area.



Abbreviation: PI, pressure injury.

The odds that a PI will occur was estimated for the following patient characteristics: sex (male vs female), race (White vs non-White), and for all "yes" versus "no" variables. An OR of greater than 1 indicates that the PI is more likely to occur in a patient characteristic; an OR of less than 1 indicates that PI is less likely to occur in a patient characteristic.

RESULTS

Aim 1

To determine if patients with PIs displayed different morphology and morphometry characteristics, patients with and without PIs were compared (Table 2). Tissue destruction precluded obtaining measurement in all tissue thickness categories (Table 2). Of note, although tissue thickness varied widely in both groups, the average tissue thickness was greater in patients with PIs at the three proximal locations: between S (sacrum) 3 to S4, S4 to S5, and S5 to C (coccyx) 1.

All anatomical angles varied widely within groups. On average, patients with PIs had less of a lumbosacral and sacrococcygeal angle and a greater sacral curvature and intercoccygeal angle than patients without PIs. Type I was more prevalent in patients without PIs; patients with PIs had more variable coccyx types including type IV (subluxation). Although there was difficulty capturing all measurements because of PI osseous destruction, the more common missing measurements were distal (C1-C2) and intercoccygeal angles (Table 2).

Aim 2

For patients with PIs, MRI scans were viewed to determine the precise anatomical location of full-thickness PIs. Supporting the hypothesis, with the exception of one PI, all occurred distally and were confined to the coccyx or spanned between the lower sacrum (S4-5) and the lower coccyges.

DISCUSSION

The findings are discussed by aim. Aims 1 and 2 address morphology and morphometry findings. Aim 3 addresses methodological considerations for future research based on experience gained through conducting this study. Limitations are addressed by aim and discussed accordingly.

Aim 1

Patients with PIs had different morphology and morphometry characteristics demonstrating anatomical variation. Tissue thickness findings appear to describe the presence or lack of adipose tissue distribution required as a protective mechanism over load-bearing areas.[20–22] In an attempt to determine the rationale for this finding, the researchers reviewed cases and noted that 9 of the 15 patients with PIs had BMIs from 25 to 30 kg/m^2 (overweight) or greater than 30 kg/m^2 (obesity and class 3 obesity according to the CDC).[56] On the contrary, three patients with full-thickness PIs and thinner tissue between C1 and C2 had a BMI of less than 18.5 kg/m^2 (underweight, cachexia).[56]

By segments, the lumbosacral angle was lower, and the sacral curvature was greater; this may be a unique feature for this population. In the lower segments, patients with PIs had less of a sacrococcygeal angle and a greater intercoccygeal angle, which is also found in other conditions such as coccydynia.[41] More specifically, patients with PIs had a greater intercoccygeal angle that may be reflective of coccyx type II or greater and is also observed in other conditions.[41] Patients who gave birth were 3.5 times more likely to develop a PI, a possible risk factor because coccyx shapes may result from childbearing.[33,35]

The coccyx was indeed harder to measure because individuals have different numbers of segments, and any subluxation complicates intercoccygeal curvature measurements. Some

Table 2. PATIENT CHARACTERISTICS BY GROUP

Characteristic	PI (n = 15)		No PI (n = 15)		
Demographics	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	***P***
Age, y	71.9 (17.7)	38–92	60.3 (17.1)	30–86	.8
Height, cm	165.1 (10.9)	147.3–183.0	167.0 (9.1)	147.3–182.9	.6
Weight, kg	68.9 (14.4)	38.6–95.3	72.8 (15.9)	47.3–117.0	.5
Body mass index, kg/m^2	28.5 (8.1)	16.3–43.1	26.3 (7.2)	17.3–48.7	.5
	n (%)		**n (%)**		**OR[a]**
Male sex	6 (40.0)		8 (53.3)		1.7
Patients who gave birth (n = 10)	7 (46.4)		3 (20.0)		3.5
Race					
White	9 (60.0)		10 (66.7)		0.8[b]
Black	1 (6.7)		3 (20.0)		
Other	4 (27.0)		1 (6.7		
Chinese	1 (6.7)		0 (0)		
Asian—unspecified	0 (0)		1 (6.7)		
Admitting diagnosis					
Cancer	1 (6.7)		10 (66.7)		0.04
Infection	7 (46.7)		2 (13.3)		5.7
Pelvic concerns[c]	6 (40.0)		10 (66.7)		0.3
Other medical history					
Cerebrovascular accident	3 (20.0)		1 (6.7)		3.5
Diabetes	4 (26.7)		5 (33.3)		0.7
Malnutrition	4 (26.7)		1 (6.7)		5.5
Multiple sclerosis	2 (13.3)		1 (6.7)		2.2
Obesity	6 (40.0)		2 (13.3)		4.3
Perfusion issues	9 (60.0)		5 (33.3)		3.0
Measurements					
Tissue thickness,[d] mm	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	
S3-S4 (n = 12)	19.8 (11.3)	8.1–46.9	14.5 (7.9)	4.4–34.9	
S4-S5 (n = 11)	20.2 (10.7)	10.5–39.9	15.7 (7.6)	4.4–33.2	
S5-C1 (n = 11)	17.8 (8.2)	10.5–32.8	17.4 (7.5)	4.4–34.9	
C1-C2 (n = 9)	18.6 (6.9)	11.3–27.8	20.2 (9.4)	4.4–41.5	
Angles,[d] °					
Lumbosacral angle (n = 13)	40.7 (9.5)	24.4–55.4	43.0 (8. 6)	31.1–65.6	
Sacral curvature (n = 13)	65.2 (23.0)	33.3–95.6	49.0 (14.8)	31.1–89.4	
Sacrococcygeal angle (n = 9)	77.4 (13.0)	62.1–99.2	82.0 (9.2)	60.5–97.5	
Intercoccygeal angle (n = 10)	63.5 (26.5)	35.1–120.0	57.8 (13.8)	31.9–82.5	
Coccyx type	**n (%)[d]**		**n (%)**	**Fisher *P*[e]**	
Type I	8 (53.3)		11 (73.3)	.10	
Type II	1 (6.7)		4 (26.7)		
Type III	2 (13.3)		0 (0.0)		
Type IV (subluxed)	2 (13.3)		0 (0.0)		

Abbreviations: OR, odds ratio; PI, pressure injury.
[a]OR > 1 indicates a positive association between patient characteristic and PI.
[b]Compares White to all others.
[c]Excludes pelvic disease, malignancy, and surgery.
[d]Missing data due to bone destruction from a PI.
[e]Fisher exact test used to compare the distribution of four coccyx types between groups.

segments of the coccyx were deviated to the right or left, which made the measurements on their midsagittal plane difficult. A possible solution for this situation could be oblique reconstruction along the long axis of the coccyx if it is not in the midline. Another possible solution is to perform these measurements on three-dimensional (3D) volumetric models, which take into account the deviation, subluxation, and so on. Classifying coccyx type is not straightforward. Both the literature and this study illustrate that clear angle thresholds of measurements do not exist (ie, one cannot define a hard threshold value that differentiates a type 1 from a type 2); thus, interrater assessment is needed, which can be guided by, but not solely dependent on, angle measurements.

Tissue destruction precluded measurements in all tissue thickness categories and may not be a useful measurement after a PI has caused extensive destruction. The extent of bone destruction also hampered assessment and measurements—a clinical reality. However, the findings provide insight for how protective equipment and devices may augment PI prevention.

Aim 2

The hypothesis for the second aim was confirmed, and the precise anatomical location determined: sacrococcygeal PIs commonly occurred distally. It is interesting, considering the size or area spanned by some of these PIs. The PIs ranged from the sacrum and extended to the coccyx (eg, S2-C1, S3-C3). Because the location of initial insult cannot be determined, necrosis may have originated in the lower anatomical regions. Not surprising, given that this was a retrospective study, the researchers encountered documentation and coding inaccuracies regarding PI location. The team had the advantage of viewing PIs at the bone level, which can certainly not be accomplished by a clinician who can only view the PI at the skin level or a coder relying on documentation.

Aims 1 and 2 Summary

The findings of both aims 1 and 2 have implications for PI causation, prevention, clinical monitoring, equipment, and products. Chai and Bader[48] found that existing preventive surfaces did not take into account variability in morphology and other intrinsic factors that increase patients' PI risk. Pressure injury risk derived from the supine position is due to the strain placed on the skeletal sacrococcygeal region, along with the loading and strain placed on tissues. This can be compounded by skeletal sacrococcygeal morphology.[9,17,19,57]

Understanding the morphology and morphometry of the sacrococcygeal area in individuals with PIs improves our understanding of the possible mechanisms of injury because of forces from overlying skeletal structures, tissue loading, and the relative anatomical locations of ulcers overlying the sacrum and coccyx. The findings of this study begin to provide knowledge that can better inform equipment and products used in PI prevention. An example is the design of support surfaces. Pressure redistribution surfaces help to mitigate deleterious factors for at-risk patients. How they are designed by manufacturers and subsequently used in the clinical area is important for effective PI prevention.

This work provides insight into individual PI risk due to the unique features of skeletal sacrococcygeal morphology. Understanding this individual risk, for example, can help set parameters for devices that provide alerts. Alert systems can be integrated into electronic medical records as an integral part of patient care.[58–60] They can provide cues to clinicians because of their ability to connect with the patient at the bedside. Individual risk can help determine an alert system's parameters, such as the patient's decreased pressure threshold based on their unique skeletal morphology. This, in turn, affects the individual's required PI prevention strategies such as needing more frequent turning and repositioning. Further, individual risk knowledge due to the skeletal sacrococcygeal morphology can become part of the risk assessment screening process.

Aim 3

Although there are inherent flaws in using a retrospective design and data, it was the most appropriate approach because this concept had never been explored. This observational approach also helped to generate hypotheses and reveal methodological issues to consider when replicating this work.

Although the findings were informative, they may have been diminished for several reasons. The selection process for the cases was intensive and exhaustive. The aim of finding viable PI cases with quality MRI scans proved to be more challenging than initially anticipated. This issue provided insight into the feasibility of achieving adequate sample sizes. The amount of bone destruction clearly hampered measurements in such a small sample. This challenge also did not allow for random selection or an interrater reliability analysis.

The decision to use MRI scans was based on Woon and colleagues,[38] who suggested that an MRI may be a better alternative for determining differences in the bony anatomy of the coccyx for certain conditions compared with a computed tomography (CT) scan. Perhaps it may have been more prudent to use CT scans because CT scans offer superior spatial resolution and the ability to view thin sections and obtain 3D models, which may have improved the researchers' ability to locate viable cases. In general, the accuracy of angle measurements can be impacted by the quality of images, including slice thickness and spacing, as well as the ability to clearly identify the margins of bony structures within a single slice, especially in the presence of underlying bone destruction. The quality of the images is reliant on various patient factors (eg, motion during scan, BMI, anatomical variations, degree of tissue destruction) versus various technical factors (eg, slice thickness, field of view and image contrast, spatial resolutions, and magnet strength for MRI scanners [1.5 vs 3 T]).

The coccyx was hard to measure because individuals have different numbers of segments, and any subluxation complicates intercoccygeal curvature measurements. Some segments of the coccyx were not on the midsagittal plane (ie, deviated to the right or left), which made the measurements on their midsagittal plane difficult. A possible solution for this situation (using MRI or CAT scans) could be oblique reconstruction along the long axis of the coccyx if it is not in the midline. Another possible solution is to perform these measurements on 3D volumetric models, which take into account the deviation, subluxation, and so on.

Use of existing radiographic images has the benefit of being available for analysis but is encumbered by complications. For example, image quality and variation in slice thicknesses impacted the accuracy of measurements. The alternative of prospectively obtaining images also has complications in drastically increasing cost and time while exposing individuals to diagnostic imaging who might otherwise not have been referred for that procedure.

CONCLUSIONS

The sacrococcygeal area is the most common area for PI occurrence, yet morphologic and morphometric parameters had not previously been studied as possible intrinsic risk factors. In this study, key sacrococcygeal parameters were assessed to understand possible injury mechanisms due to forces from overlying skeletal structure. Patients with PIs had different sacrococcygeal morphology and morphometry measurements. It was also noted that these PIs were predominately located distally. Risk factors that contribute to a sacrococcygeal PI warrant further investigation to determine the required strategies and interventions needed to prevent their occurrence.

The implications for future research can best be grouped into three categories: sacrococcygeal measurements that may or may not influence PI formation, actual anatomical location of sacrococcygeal PIs, and methodological considerations. The findings lead to a better understanding of why obtaining measurements was a challenge in light of tissue and bone destruction. It also equates to the fact that severe PIs will undoubtedly require more care, and this care will be at a higher cost.[2] This is important as a means to devise personalized interventions to prevent PI occurrence, inform practice, and improve the development of preventive equipment, products, and technologies.

PRACTICE PEARLS

- Patients with PIs possessed different sacrococcygeal morphology and morphometry characteristics than patients without PIs.
- As compared with patients without PIs, patients with PIs particularly possessed morphology and morphometry differences in the lower segments that are also observed in patients with other conditions such as coccydynia.
- The majority of sacrococcygeal PIs were more distal—S4 to the coccyges—which has implications for the strategies, products, and technologies used to prevent PIs. ●

REFERENCES

1. Coleman S, Gorecki C, Nelson EA, et al. Patient risk factors for pressure ulcer development: systematic review. Int J Nurs Stud 2013;50:974-1003.
2. Padula WV, Delarmente BA. The national cost of hospital-acquired pressure injuries in the United States. Int Wound J 2019;(December 2018):1-7.
3. Padula WV, Pronovost PJ, Makic MBF, et al. Value of hospital resources for effective pressure injury prevention: a cost-effectiveness analysis. BMJ Qual Saf 2019;28(2):132-41.
4. Edsberg LE, Black JM, Goldberg M, McNichol L, Moore L, Sieggreen M. Revised National Pressure Ulcer Advisory Panel pressure injury staging system. J Wound Ostomy Continence Nurs 2016;43: 585-97.
5. Horn SD, Barrett RS, Fife CE, Thomson B. A predictive model for pressure ulcer outcome: the Wound Healing Index. Adv Skin Wound Care 2015;28:560-72.
6. Coleman S, Nelson EA, Keen J, et al. Developing a pressure ulcer risk factor minimum data set and risk assessment framework. J Adv Nurs 2014;70:2339-52.
7. Gould LJ, Bohn G, Bryant R, et al. Pressure ulcer summit 2018: an interdisciplinary approach to improve our understanding of the risk of pressure-induced tissue damage. Wound Repair Regen 2019:1-12.
8. Bogie KM, Zhang GQ, Roggenkamp SK, et al. Individualized clinical practice guidelines for pressure injury management: development of an integrated multi-modal biomedical information resource. J Med Internet Res 2018;7(9):1-11.
9. Sprigle S, Sonenblum S. Visualizing tissue strain under the sacrum and coccyx in different supine postures: a case series. Adv Skin Wound Care 2019;32:264-71.
10. Gefen A, Brienza DM, Cuddigan J, Haesler E, Kottner J. Our contemporary understanding of the aetiology of pressure ulcers/pressure injuries. Int Wound J 2021;(APII):1-13.
11. Gefen A. The biomechanics of heel ulcers. J Tissue Viability 2010;19(4):124-31.
12. Brienza D, Vallely J, Karg P, Akins J, Gefen A. An MRI investigation of the effects of user anatomy and wheelchair cushion type on tissue deformation. J Tissue Viability 2018;27(1):42-53.
13. Oomens CWJ, Broek M, Hemmes B, Bader DL. How does lateral tilting affect the internal strains in the sacral region of bed ridden patients? A contribution to pressure ulcer prevention. Clin Biomech 2016;35:7-13.
14. Akins JS, Vallely JJ, Karg PE, et al. Feasibility of freehand ultrasound to measure anatomical features associated with deep tissue injury risk. Med Eng Phys 2016;38:839-44.
15. Ohura T. External force and its clinical influence—the relationships between fundamental biomechanics and clinical findings. World Counc Enteros Ther J 2013;33(2):14-20.
16. Gefen A. The Compression Intensity Index: a practical anatomical estimate of the biomechanical risk for a deep tissue injury. Technol Heal Care 2008;16:141-9.
17. Sprigle SH, McNair D, Sonenblum S. Pressure ulcer risk factors in persons with mobility-related disabilities. Adv Skin Wound Care 2020;33:146-54.
18. Linder-Ganz E, Shabshin N, Itzchak Y, Yizhar Z, Siev-Ner I, Gefen A. Strains and stresses in sub-dermal tissues of the buttocks are greater in paraplegics than in healthy during sitting. J Biomech 2008;41:567-80.
19. Sonenblum SE, Measel M, Sprigle SH, Greenhalgh J, Cathcart JM. An exploratory analysis of the role of adipose characteristics in fulltime wheelchair users' pressure injury history. Front Bioeng Biotechnol 2021;9(November):1-10.
20. Hagisawa S, Shimada T, Arao H, Asada Y. Morphological architecture and distribution of blood capillaries and elastic fibres in the human skin. J Tissue Viability 2001;11(2):59-63.
21. Nanjo Y, Nakagami G, Kaitani T, et al. Relationship between morphological characteristics and etiology of pressure ulcers in intensive care unit patients. J Wound Ostomy Continence Nurs 2011; 38:404-12.
22. Santamaria N, Liu W, Gerdtz M, et al. The cost-benefit of using soft silicone multilayered foam dressings to prevent sacral and heel pressure ulcers in trauma and critically ill patients: a within-trial analysis of the Border Trial. Int Wound J 2015;12:344-50.
23. Wang W, Wu M, Liu Z, et al. Sacrum pubic incidence and sacrum pubic posterior angle: two morphologic radiological parameters in assessing pelvic sagittal alignment in human adults. Eur Spine J 2014;23:1427-32.
24. Abitbol MM. Evolution of the sacrum in hominoids. Am J Phys Anthropol 1987;74(1):65-81.
25. Miller AN, Routt MLC. Variations in sacral morphology and implications for iliosacral screw fixation. J Am Acad Orthop Surg 2012;20(1):8-16.

26. Okpala F. Measurement of lumbosacral angle in normal radiographs: a retrospective study in southeast Nigeria. Ann Med Health Sci Res 2014;4:757-62.
27. Maduforo C, West O, Nwankwo N, Onwuchekwa R, Stephen UE, Ogbulu D. Study of the lumbosacral angles of males in Port Harcourt, South-South, Nigeria. Niger J Health 2012;12(1):22-4.
28. Troyanovich SJ, Cailliet R, Janik TJ, Harrison DD, Harrison DE. Radiographic mensuration characteristics of the sagittal lumbar spine from a normal population with a method to synthesize prior studies of lordosis. J Spinal Disord 1997;10:380-6.
29. Abitbol MM. Sacral curvature and supine posture. Am J Phys Anthropol 1989;80(3):379-89.
30. Przybylski P, Pankowicz M, Boćkowska A, et al. Evaluation of coccygeal bone variability, intercoccygeal and lumbo-sacral angles in asymptomatic patients in multislice computed tomography. Anat Sci Int 2013;88(4):204-11.
31. Yoon MG, Moon M, Park BK, Lee H, Kim D. Analysis of sacrococcygeal morphology in Koreans using computed tomography. Clin Orthop Surg 2016;8:412-9.
32. Marwan YA, Al-Saeed OM, Esmaeel AA, Kombar ORA, Bendary AM, Azeem MEA. Computed tomography-based morphologic and morphometric features of the coccyx among Arab adults. Spine (Phila Pa 1976) 2014;39(20):E1210-9.
33. Lee JY, Gil YC, Shin KJ, et al. An anatomical and morphometric study of the coccyx using three-dimensional reconstruction. Anat Rec 2016;299:307-12.
34. Woon JTK, Stringer MD. Clinical anatomy of the coccyx: a systematic review. Clin Anat 2012;25(2):158-67.
35. Woon JTK, Perumal V, Maigne JY, Stringer MD. CT morphology and morphometry of the normal adult coccyx. Eur Spine J 2013;22:863-70.
36. Nathan ST, Fisher BE, Roberts CS. Coccydynia: a review of pathoanatomy, aetiology, treatment and outcome. J Bone Jt Surg 2010;92-B:1622-7.
37. Tetiker H, Kosar M, Cullu N, Canbek U, Otag I, Tastemur Y. MRI-based detailed evaluation of the anatomy of the human coccyx among Turkish adults. Niger J Clin Pract 2017;20(2):136-42.
38. Woon JTK, Maigne J-Y, Perumal V, Stringer MD. Magnetic resonance imaging morphology and morphometry of the coccyx in coccydynia. Spine (Phila Pa 1976) 2013;38(23):E1437-45.
39. Vrtovec T, Janssen MMA, Likar B, Castelein RM, Viergever MA, Pernuš F. Evaluation of pelvic morphology in the sagittal plane. Spine J 2013;13:1500-9.
40. Postacchini F, Massobrio M. Idiopathic coccygodynia. J Bone Jt Surg 1983;(1):1116-24.
41. Kerimoglu U, Dagoglu MG, Ergen FB. Intercoccygeal angle and type of coccyx in asymptomatic patients. Surg Radiol Anat 2007;29:683-7.
42. Hellems HK, Keates TE. Measurement of the normal lumbosacral angle. Am J Roentgenol 1971;113:642-5.
43. Bouten CVC, Breuls RGM, Peeters EAG, Oomens CWJ, Baaijens FPT. In vitro models to study compressive strain-induced muscle cell damage. Biorheology 2003;40(1-3):383-8.
44. Gawlitta D, Li W, Oomens CWJ, Baaijens FPT, Bader DL, Bouten CVC. The relative contributions of compression and hypoxia to development of muscle tissue damage: an in vitro study. Ann Biomed Eng 2007;35(2):273-84.
45. Sanada H, Nagakawa T, Yamamota M, Higashidani K, Tsuru H, Sugama J. The role of skin blood flow in pressure ulcer development during surgery. Adv Wound Care 1997;10:29-34.
46. Van Marum RJ, Meijer JH, Ribbe MW. The relationship between pressure ulcers and skin blood flow response after a local cold provocation. Arch Phys Med Rehabil 2002;83(1):40-3.
47. Mayrovitz HN, Sims N, Taylor MC. Sacral skin blood perfusion: a factor in pressure ulcers? Ostomy Wound Manage 2002;48(6):34-8, 40-2.
48. Chai CY, Bader DL. The physiological response of skin tissues to alternating support pressures in able-bodied subjects. J Mech Behav Biomed Mater 2013;28:427-35.
49. Stojadinovic O, Minkiewicz J, Sawaya A, et al. Deep tissue injury in development of pressure ulcers: a decrease of inflammasome activation and changes in human skin morphology in response to aging and mechanical load. PLoS One 2013;8(8):1-9.
50. European Pressure Ulcer Advisory Panel, National Pressure Injury Advisory Panel, Pan Pacific Pressure Injury Alliance. Prevention and Treatment of Pressure Ulcers/Injuries: Clinical Practice Guideline. The International Guideline. Haesler E, ed. EPUAP/NPIAP/PPPIA; 2019.
51. Hoogendoorn I, Reenalda J, Koopman BFJM, Rietman JS. The effect of pressure and shear on tissue viability of human skin in relation to the development of pressure ulcers: a systematic review. J Tissue Viability 2017;26(3):157-71.
52. Whitehead AL, Julious SA, Cooper CL, Campbell MJ. Estimating the sample size for a pilot randomised trial to minimise the overall trial sample size for the external pilot and main trial for a continuous outcome variable. Stat Methods Med Res 2016;25:1057-73.
53. PASS. Pilot study sample size rules of thumb. In: PASS Sample Size Software. Kaysville, UT: NCSS, LLC; 2021:684-1-684-4.
54. Julious SA. Sample size of 12 per group rule of thumb for a pilot study. Pharm Stat 2005;4:287-91.
55. Johanson GA, Brooks GP. Initial scale development: sample size for pilot studies. Educ Psychol Meas 2010;70:394-400.
56. Centers for Disease Control and Prevention. Defining Adult Overweight and Obesity. Division of Nutrition, Physical Activity, and Obesity, National Center for Chronic Disease Prevention and Health Promotion. 2020. www.cdc.gov/obesity/adult/defining.html. Last accessed August 2, 2022.
57. Gefen A, Brienza DM, Cuddigan J, Haesler E, Kottner J. Our contemporary understanding of the aetiology of pressure ulcers/pressure injuries. Int Wound J 2022;19:692-704.
58. Scott RG, Thurman KM. Visual feedback of continuous bedside pressure mapping to optimize effective patient repositioning. Adv Wound Care 2014;3:376-82.
59. Gunningberg L, Sedin IM, Andersson S, Pingel R. Pressure mapping to prevent pressure ulcers in a hospital setting: a pragmatic randomised controlled trial. Int J Nurs Stud 2017;72(APII):53-9.
60. Yap TL, Kennerly SM, Ly K. Pressure injury prevention: outcomes and challenges to use of resident monitoring technology in a nursing home. J Wound Ostomy Continence Nurs 2019;46:207-13.

For more than 198 additional continuing professional development articles related to Skin and Wound Care topics, go to NursingCenter.com/CE.

Lippincott® NursingCenter®

CME | NCPD Nursing Continuing Professional Development

CONTINUING MEDICAL EDUCATION INFORMATION FOR PHYSICIANS

Lippincott Continuing Medical Education Institute, Inc., is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians.

Lippincott Continuing Medical Education Institute, Inc., designates this journal-based CME activity for a maximum of 1 *AMA PRA Category 1 Credit*™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

PROVIDER ACCREDITATION INFORMATION FOR NURSES

Lippincott Professional Development will award 2.5 contact hours for this nursing continuing professional development activity.

LPD is accredited as a provider of nursing continuing professional development by the American Nurses Credentialing Center's Commission on Accreditation.

This activity is also provider approved by the California Board of Registered Nursing, Provider Number CEP 11749 for 2.5 contact hours. LPD is also an approved provider of continuing nursing education by the District of Columbia, Georgia, and Florida CE Broker #50-1223. Your certificate is valid in all states.

OTHER HEALTH PROFESSIONALS

This activity provides ANCC credit for nurses and *AMA PRA Category 1 Credit*™ for MDs and DOs only. All other healthcare professionals participating in this activity will receive a certificate of participation that may be useful to your individual profession's CE requirements.

CONTINUING EDUCATION INSTRUCTIONS

- Read the article beginning on page 586. For nurses who wish to take the test for NCPD contact hours, visit www.NursingCenter.com/ce/ASWC. For physicians who wish to take the test for CME credit, visit http://cme.lww.com. Under the Journal option, select Advances in Skin and Wound Care and click on the title of the CE activity.
- You will need to register your personal CE Planner account before taking online tests. Your planner will keep track of all your Lippincott Professional Development online NCPD activities for you.
- There is only one correct answer for each question. A passing score for this test is 7 correct answers. If you pass, you can print your certificate of earned contact hours or credit and access the answer key. Nurses who fail have the option of taking the test again at no additional cost. Only the first entry sent by physicians will be accepted for credit.

Registration Deadline: October 31, 2024 (physicians); September 5, 2025 (nurses).

PAYMENT

The registration fee for this CE activity is $24.95 for nurses; $22.00 for physicians.