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Conflicting Dermatome Maps: Educational and Clinical Implications

Evaluation of the perceptions of touch and pain on a patient's skin is a common, noninvasive test of neural function. It is an examination method that relies on knowledge of the distribution of both the cutaneous nerves and the branches of segmental spinal nerves (dermatomes). By comparing areas of altered sensation on the patient's skin with published dermatome and cutaneous nerve maps, a clinician can make a judgment on the location of a lesion.[24,35] Yet the textbooks commonly used in medical and allied health programs contain multiple, conflicting dermatome maps. These maps place clinically important dermatomes in varying locations. For example, the majority show the cutaneous distribution of the fourth lumbar spinal nerve (L4 dermatome) either running from the lateral aspect of the thigh to the medial side of the great toe, or confined to the medial portion of the leg distal to the knee. It is interesting and clinically relevant to examine the history of the dermatome maps in use today and to consider their significance in healthcare education and clinical practice.

SYNOPSIS: Sensory testing is a common noninvasive method of evaluating nerve function that relies on the knowledge of skin dermatomes and sensory fields of cutaneous nerves. Research to determine the extent of the dermatomes was conducted in Europe during the late nineteenth and early twentieth centuries. Experiments performed on cadavers, monkeys, and human patients prior to 1948 resulted in the creation of similar but somewhat different dermatome maps. A radically different map with long, swirling dermatomes was produced by Keegan and Garrett in 1948. This map was derived largely by examining compression of dorsal nerve roots by vertebral disc herniation. The maps appearing in textbooks are inconsistent. Some books show a version of the early maps, some show the Keegan and Garrett map, and others show maps that are not consistent with either. The purpose of this paper is to discuss the history of dermatome maps, including the experimental procedures by which each was obtained, and to relate the early maps to those found in textbooks commonly used in healthcare education programs. The paper discusses the significance of these maps as used for clinical diagnosis and the need for further research. *J Orthop Sports Phys Ther 2011;41(6):427-434. doi:10.2519/jospt.2011.3506*

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HISTORY OF DERMATOMES

The initial research to determine the extent of each dermatome was conducted in Europe during the late nineteenth and early twentieth centuries. Prior to 1948, researchers were in general agreement as to the shape and location of the dermatomes. Variations found by different scientists were most likely due to the use of different techniques (including the use of cadavers, monkeys, and human patients) in isolating the dermatomes. In 1948, Keegan and Garrett[17] published a radically different map which, though not clearly substantiated by more recent research, has been reproduced in many textbooks.

The earliest investigations of the distributions of the spinal nerves of humans consisted of careful dissection of their fibers. In 1886, Sir Wilmot Herringham[14] published the first account of the distribution of segmental nerve fibers through the brachial plexus into the upper limb, based on his dissections of neonatal and adult cadavers. He determined that the highest and lowest nerve roots of the brachial plexus innervated the skin of the proximal portion of the limb (on the lateral and medial sides of the limb, respectively), whereas the middle roots of the plexus innervated the skin of the distal portion of the limb. He explained this arrangement by likening the skin over the growing embryonic limb bud to India-rubber that stretches as the limb grows. Herringham also described a line on the ventral surface of the upper limb around which the dermatomes are aligned. This line runs along the axis of the limb, from the shoulder to the lower forearm, and

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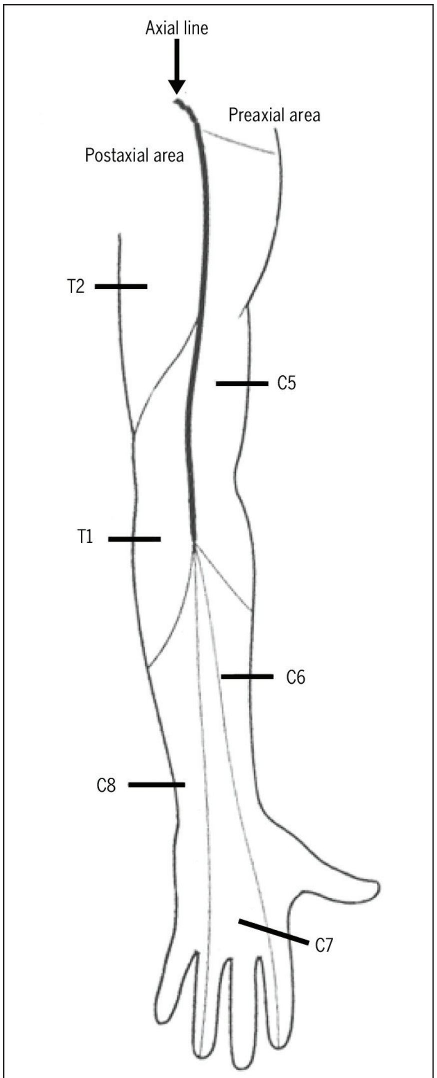

FIGURE 1. Schema of the dermatomes of the upper limb, illustrating Sir Wilmot Herringham's rules. The first rule states "of 2 spots on the skin that which is nearer the pre-axial border tends to be supplied by the higher nerve." Thus, the dermatomes in the preaxial area (C5 and C6) are higher nerves than those in the postaxial area (C8-T2). The second rule states "of 2 spots in the preaxial area the lower tends to be supplied by the lower nerve, and of two spots in the postaxial area the lower tends to be supplied by the higher nerve." Therefore, in the preaxial area, the forearm is supplied by a lower nerve (C6) than the arm (C5). In the postaxial area, the forearm is supplied by a higher nerve (C8) than the arm (T1 and T2). Note that along the axial line noncontiguous dermatomes are adjacent to each other.

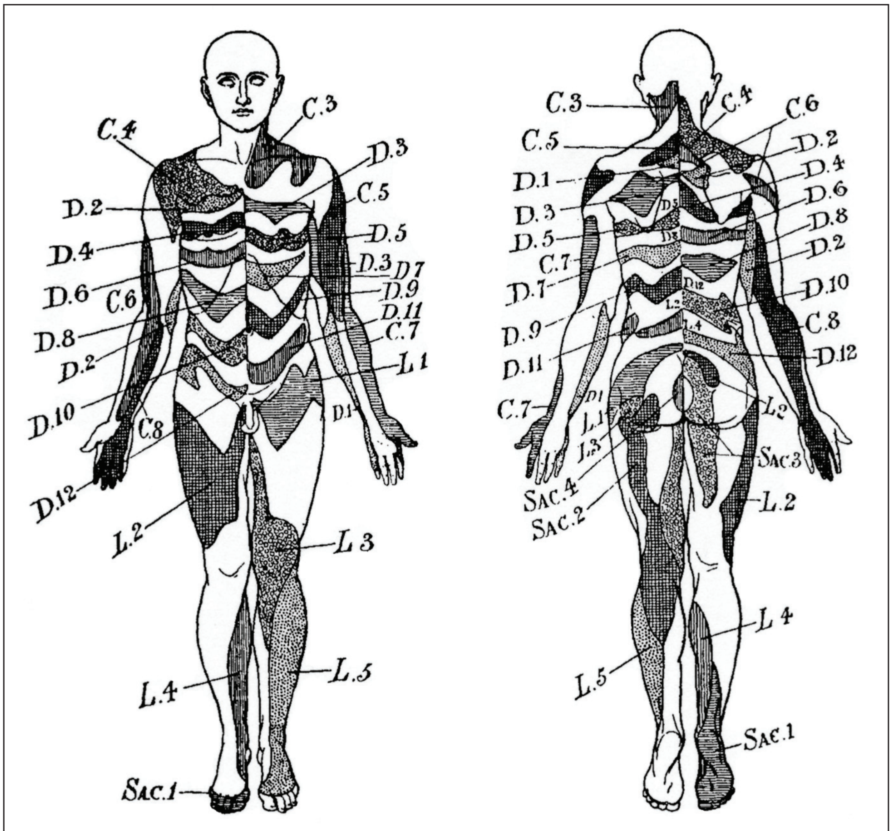

FIGURE 2. The dermatome map proposed by Sir Henry Head and A.W. Campbell based on clinical observations of herpes zoster eruptions. From *Brain*. 1900;23:353-523.

in current terminology is referred to as the ventral axial line. While the dermatomes of most spinal nerves lie adjacent to the dermatomes of the next higher and lower nerves, along this line dermatomes of noncontiguous spinal nerves abut each other. Herringham illustrated this pattern by describing the dermatomes as crossed by a line encircling the lower third of the forearm. Beginning at the middle of the ventral surface, this line ran to the radial border, across the dorsum, around the ulna, and back to the middle, crossing, in order, the dermatomes of the 6th, 7th, 8th, and 9th spinal nerves (C6 through T1) and ending back at the C6 dermatome.[14] Thus, in Herringham's view, the C6 dermatome abuts the T1 dermatome at the ventral axial line of the lower forearm. Based on his dissections, Herringham postulated 2 rules for the distribution of sensory nerves in the upper limb. A diagram that illustrates these rules is provided in **FIGURE 1**. Kosinski[20] describes the work of Bolk, who extended Herringham's dissection method to include the lower limb.

Although the dissections of Herringham and Bolk established the overall arrangement of the dermatomes, they could not distinguish the smallest branches of the spinal nerves. By the 1890s, other methods were being used to determine the extent of each dermatome. Sir Henry Head[12] first produced a dermatome map based on clinical observation of referred visceral pain and traumatic lesions of the spinal cord. He expanded this work by studying cases of herpes zoster. Herpes zoster, the virus that causes the common disease of chickenpox, can establish a latent infection in a single sensory ganglion. At a later date, the infection can become reactivated and travel down the affected nerve, resulting in a herpetic eruption over the dermatome of the nerve (shingles).[2,11] After studying nearly 500 cases of shingles, Head and A. W. Campbell[13] constructed a map showing the extent of cutaneous lesions caused

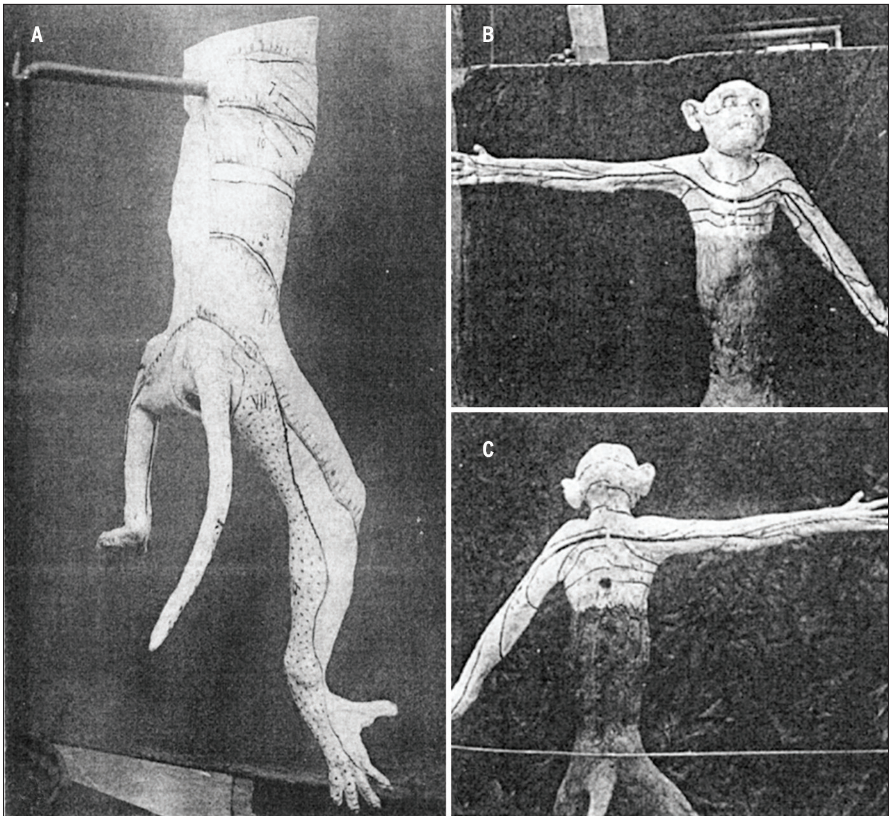

FIGURE 3. Sir Charles Sherrington's plaster models of monkeys, showing axial lines on the forelimbs and hind limbs. (A) From *Philosophical Transaction of the Royal Socitety of London, Series B.* 1893;184:641-763. (B and C) From *Philosophical Transaction of the Royal Society of London, Series B.* 1898;190:45-187.

by infection of different spinal ganglia (**FIGURE 2**). They noted that there was some minor overlap between adjacent nerve territories. They also emphasized that, in different individuals, body shape caused variation in the shape of the skin area affected. For instance, in a child, a thoracic dermatome would be a fairly even band running around the rather tubular trunk, but its shape would "differ considerably when extended on the narrow sloping chest of the phthisical or on the barrel-shaped, high-shouldered thorax of the emphysematous."[13] For this reason, Head and Campbell[13] observed that one could only be certain of the relationship of the nerves to each other and to constant features of the skin (ie, the nipples and umbilicus) when mapping the dermatomes of the trunk.

Also in the late 1800s, Sir Charles Sherrington[34] performed experiments on rhesus monkeys, in which he severed the dorsal nerve roots above and below the nerve being studied. This resulted in a dermatome with normal sensation, bound on either side by anesthetic areas. Comparing his data with numerous papers on human skin innervation, he observed that "the similarity between the two is almost minutely exact."

Sherrington found that adjacent dermatomes overlap extensively. He also found that, in the proximal portions of the dorsal and ventral surfaces of both the upper and lower limbs, there is a gap in which there are missing contiguous dermatomes and there is no overlap. He considered such gaps to be extensions of the median dorsal and ventral lines of the thorax and termed them middorsal and midventral lines of the limb.[33] In the upper limb, the gap forms an axial line that runs from the midline at the level of the sternal angle, down the ventral surface of the limb, into the forearm. This coincides with Herringham's original description of the arrangement of the dermatomes of the human forearm. These lines are shown on plaster casts of a monkey he created to show the dermatomes (**FIGURE 3**).

During the first decade of the twentieth century, resection of the dorsal roots of spinal nerves (rhizotomy) was used to treat intractable pain referred from the viscera and to reduce spasticity in cases of cerebral palsy, central nervous system trauma, and tabes.[8] Otfrid Foerster,[9] a German neurologist, used this intervention to delineate the dermatomes of the lower limb in humans in the same manner that Sherrington had used in monkeys. He also determined the C6 dermatome by this process. To complete the study of the upper limb, he used data from multiple patients in what he called the "constructive method": "It is obvious that when a series of contiguous roots is divided, the superior border of the resulting anesthesia represents the inferior border of the dermatome which corresponds to the next higher intact root, while the inferior border of the anesthetic area represents the superior border of the next lower dermatome. By such observations I have been able to map out nearly all dermatomes in man."[9] To augment these data, he electrically stimulated the cut ends of the posterior nerve roots, resulting in vasodilation over the dermatome.

Foerster compared his data to that published by Head and Sherrington. He found that cutting a single nerve root in man did not cause any loss of sensation, which is the same effect that Sherrington had observed in monkeys. In his experiments with electrical stimulation, the areas of vasodilation corresponded to the dermatomes determined by anesthesia, although the areas were smaller, having little overlap with adjacent dermatomes. He noted that it compared favorably with the dermatome map based on herpetic outbreak published by Head and Campbell.[13] Foerster's 1933 map is shown in **FIGURE 4**. Dr Frederick Fender[7] at Stanford

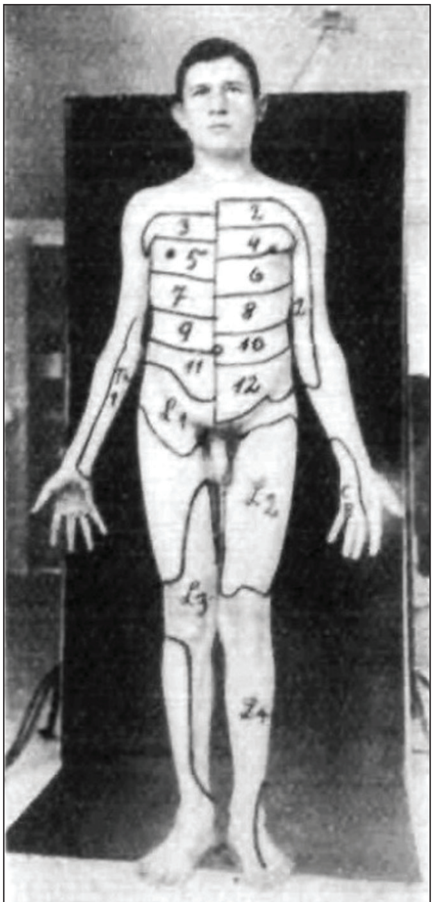

FIGURE 4. Otfrid Foerster's map of thoracic dermatomes, based on clinical observations of anesthesia after rhizotomy. From *Brain.* 1933;56:1-39. Used by permission.

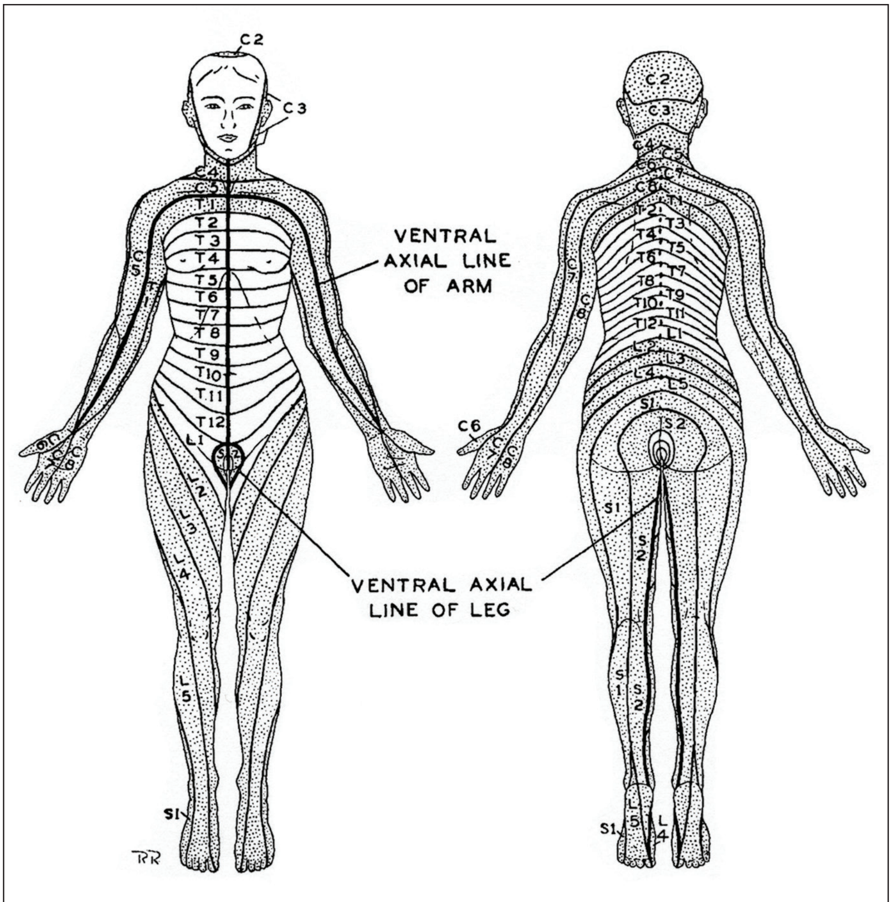

FIGURE 5. Keegan and Garrett's dermatome map, based on hypoalgesia produced by compression of a single nerve root by herniated disc or by anesthesia of a single nerve root. From *Anatomical Record*. 1948;102(4):409. Used by permission.

University received permission to summarize and republish Foerster's results in the United States.

In 1948, Jay Keegan and Frederick Garrett[17] published a radically different dermatome map of the extremities, with linear dermatomes extending down each limb (**FIGURE 5**). The map was based on hypoalgesia produced by compression of a single nerve root by a herniated disc. One hundred sixty-five cases involved the upper limb, of which 47 were verified by surgery as affecting a single nerve root. One thousand two hundred sixty-four cases involved the lower limb, 707 of which were verified by surgery. Keegan and Garrett also recruited 10 medical student volunteers for anesthesia of a single lower cervical nerve root by Novocain injection.

Their results clearly violated the rules of Herringham that had been accepted for a half century. Keegan and Garret argued against the established dermatome maps. They asserted that Foerster was wrong in his belief that severing a single nerve root causes no sensory loss.[17] In addition, they postulated that "dorsal axial lines of dermatomic junction have no reality; that the dermatomes continue unbroken from dorsal midline to their termination in the limb." They believed that their "conclusion justified that Sherrington erred through a relatively minor, though systematic, misinterpretation of his data, and that 'dermatomic loops' and 'dorsal axial lines' do not exist."[17]

In discussing the then-recent publication by Keegan and Garrett, R. J. Last[21] made the following statement: "If their findings are confirmed, a fundamental alteration of the accepted dermatome maps will be required. On the whole, the dermatomes of Keegan and Garrett are more extensive than those of Sherrington, Head and Foerster. Nevertheless, their findings are open to certain criticisms. (1) The subjective method of mapping a dermatome by hypoalgesia, must be open to wide error. (2) The lack of overlap of adjacent dermatomes is difficult to accept in face of the almost unanimous opinions of countless observers. (3) No mention is made of variability, yet pre-fixation and post-fixation of the plexuses are known to be common. (4) Their claim that an isolated nerve root is affected in their cases of disc protrusions or injected medical students is not convincing; there may well have been some

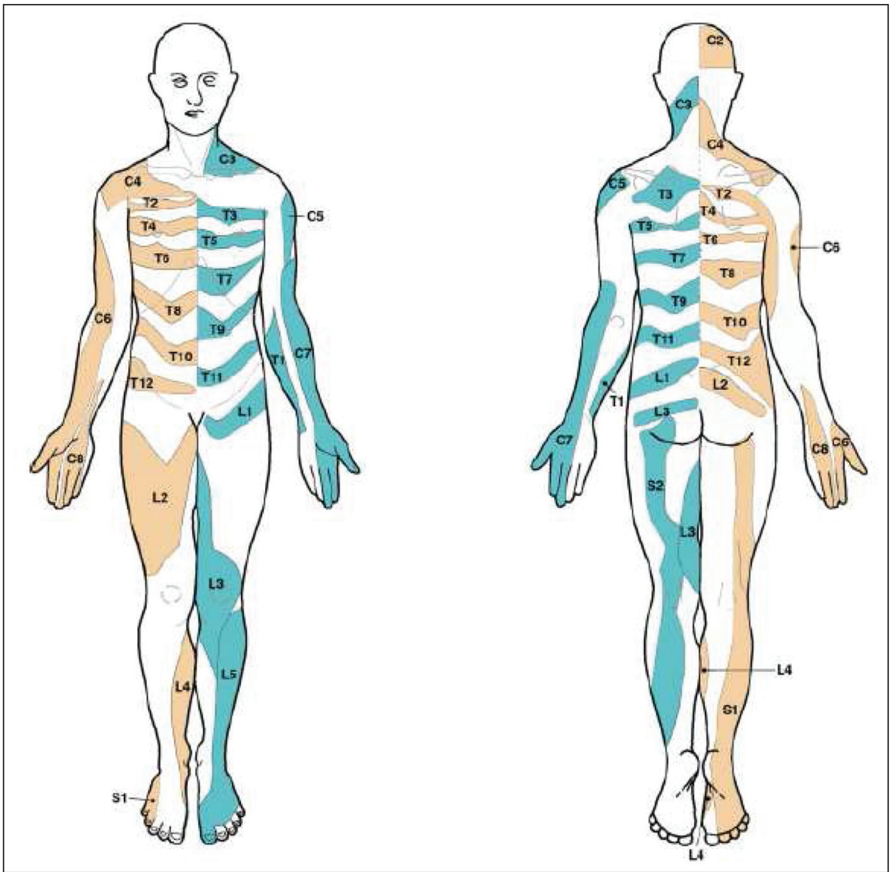

FIGURE 6. Composite dermatome map created by Lee et al using data from Foerster, Head, and Campbell, Inouye and Buchthal, Nitta et al, and Cole et al. From *Clinical Anatomy;* 2008; 21:363-373. Used by permission.

involvement of adjacent nerve roots."

Although we have searched the literature of the past 60 years, we have found no experimental confirmation of Keegan and Garrett's work. On the contrary, we have found evidence contradicting both their results and the validity of their techniques. A recent Brazilian study retrospectively examined the charts of patients with compressive radiculopathy at lumbar and sacral levels.[5] The investigators evaluated nerve conduction studies, electromyographic (EMG) data, neurosurgical findings, and imaging data from computerized tomography or magnetic resonance imaging. The researchers concluded that "the L4 dermatome is probably located in the medial aspect of the leg," distal to the knee. This finding is consistent with the work of Head and Foerster but contradicts Keegan and Garrett's long, swirling L4 dermatome. Davis et al[4] examined 500 consecutive cases of surgically verified herniated nucleus pulposus. Sensory changes were only found in 327 of the cases and no typical sensory pattern emerged. "The extreme variability in the sensory pattern makes the method of devising a dermatome chart on the basis of the sensory changes associated with herniated nucleus pulposus an unreliable one."[4] In studying lumbar nerve root compression due to disc herniation, Nygaard and Mellgren[28] found that sensory thresholds were significantly increased in adjacent dermatomes in both the symptomatic and asymptomatic limb. They noted that chemical substances can travel in the cerebrospinal fluid and affect neighboring nerve roots.

After evaluating the literature, Lee et al[22] created a composite dermatome map (**FIGURE 6**), based on published data from 5 papers they considered to be the most experimentally reliable. A list of the methods and areas studied in these papers are presented in **TABLE 1**. The composite map was produced by redrawing the Foerster and the Head and Campbell maps on figure outlines, then superimposing them to find consensus areas. The areas not common to both diagrams were eliminated. The upper limb dermatomes thus derived were modified using the data from Inouye and Buchthal,[16] while the lower limb dermatomes were modified using data from Cole et al[3] and Nitta et al.[27] Lee et al[22] did not use the Keegan and Garrett data in their map, because, "despite the widespread uncritical reproduction of the Keegan and Garrett map, it is the most flawed of the three core maps." Yet the Keegan and Garrett dermatome map permeates textbooks and atlases commonly used in physical therapy education programs (**TABLE 2**).

DERMATOME MAPS CURRENTLY USED IN TEXTBOOKS

To determine which dermatome maps are included in healthcare textbooks, we examined the most commonly used physical therapy texts, as listed in a 2006 survey conducted by the Federation of State Boards of Physical Therapy.[36] Some of these books are also used in other disciplines, namely occupational therapy, nursing, dentistry, and medicine. Therefore, this issue is not unique to physical therapy.

The texts examined are inconsistent in their description of dermatome distribution. This is true regarding both intertextbook and intratextbook consistency. There is no standardization of the map(s) in the texts. Some books even have different maps on different pages, with no explanation. This is particularly evident in texts with multiple chapters written by different authors. Many textbooks appear to use the maps of Foerster or Keegan and Garrett, yet most are either poorly referenced or not referenced at all. Of the 14 books examined, 6 con-

TABLE 1 Information Used by Lee et al[22] to Generate a Composite Dermatome Map

Authors	Methodology Used to Localize Dermatome	Body Area Investigated	Quality of Evidence (as Evaluated by Lee et al)
Foerster	Method of measuring loss of sensation after rhizotomy not specified	Lower limb, trunk, upper limb by the "constructive method"	Good
Head and Campbell	Area covered in herpes zoster lesion	Lower limb, trunk, upper limb	Good
Inouye and Buchthal	Nerve conduction studies	Upper limb	Good
Nitta, Tajima, Sugiyama, and Moriyama	Measured touch sensation with writing brush after nerve block	Lower limb	Good
Cole, Lesswing, and Cole	Measured pain sensation after neurectomy	Lower limb	Intermediate

TABLE 2 Use of Dermatome Maps in Commonly Used Physical Therapy Textbooks

Title	Author	Year	Number of Physical Therapy Programs Using Book*	Dermatome Map Consistent With Original Data From	Reference Given
Orthopedic Physical Assessment	Magee	2007	65	Could not be determined	None
Therapeutic Exercise: Foundations and Techniques	Kisner and Colby	2007	64	Keegan and Garrett	None
Pathology: Implications for the Physical Therapist	Goodman, Boissonnault, and Fuller	2009	61	Keegan and Garrett; could not be determined	Gilman and Newman, Gatz's Essentials of Clinical Neuroanatomy, 10th ed, FA Davis, 2003; American Spinal Injury Association
Physical Rehabilitation: Assessment and Treatment	O'Sullivan and Schmitz	2001	56	Keegan and Garrett	Auerbach, Wilderness Medicine, 4th ed, Mosby, 2001
Clinically Oriented Anatomy	Moore, Dalley and Agur	2010	48	Foerster; Keegan and Garrett	Foerster; Keegan and Garrett
Atlas of Human Anatomy	Netter	2006	47	Keegan and Garrett	Keegan and Garrett (also mentions Foerster in caption)
Neurological Rehabilitation	Umphred	2001	46	Could not be determined	American Spinal Injury Association
Muscle and Sensory Testing	Reese	2005	34	Could not be determined	None
Physical Examination of the Spine & Extremities	Hoppenfeld	1976	29	Could not be determined	None
Orthopaedic Examination, Evaluation, and Intervention	Dutton	2004	29	Foerster	Wilkins and Rengachary (eds), Neurosurgery, McGraw-Hill, 1996
Acute Care Handbook for Physical Therapists	Paz and West	2002	27	Keegan and Garrett	Maitland (ed), Vertebral Manipulation, 5th ed, Butterworth-Heinemann, 1986
Neuroscience: Fundamentals for Rehabilitation	Lundy-Ekman	2002	26	Keegan and Garrett	None
Muscles: Testing and Function with Posture and Pain	Kendall, McCreary, and Provance	2005	24	Keegan and Garrett	Keegan and Garrett
The Rehabilitation Specialist's Handbook	Rothstein, Roy, and Wolf	2005	20	Could not be determined	None

**From https://www.fsbpt.org/download/TextbookSurveyPTBooks.pdf. The most recent editions of the textbooks listed by the Federation of State Boards of Physical Therapy are given.*

tain no reference for their maps, while 5 use secondary sources (**TABLE 2**). Only 3 books—Moore and Dalley's *Clinically Oriented Anatomy*,[25] Netter's *Atlas of Human Anatomy*,[26] and Kendall's *Muscles: Testing and Function*[18]—cite the original research papers. Five texts illustrated dermatomes that were inconsistent with any map for which we could find original research data. Four of the 5 (Magee,[24] Hoppenfeld,[15] Reese,[31] and Rothstein et al[32]) gave no references for their maps.

Umphred's *Neurological Rehabilitation*[37] and 1 chapter in *Pathology: Implications for the Physical Therapist* by Goodman et al[10] cite a map from the American Spinal Injury Association (ASIA). The map on the ASIA webpage[1] does not indicate how the dermatomes were derived. Reese's *Muscle and Sensory Testing*[31] used an unreferenced map similar to the ASIA map. Furthermore, the majority of authors give no explanation for the choice of the map(s) used. Only Moore and Dalley's *Clinically Oriented Anatomy*[25] includes a rationale for using both the Foerster and the Keegan and Garrett maps, explaining that the Foerster map correlates better with clinical findings, while the Keegan and Garrett map correlates with embryonic development.

CLINICAL SIGNIFICANCE OF DERMATOME MAPS

Sensory testing of the skin is a common noninvasive method of evaluating the function of both the peripheral and central components of the nervous system. While diagnoses are not made with sensory testing alone, sensory testing is an important tool for identifying the location of a neurological injury. All skin sensations are carried by cutaneous branches of the peripheral nerves. In the trunk, each spinal nerve innervates a strip of skin, so the cutaneous area supplied by each nerve is identical to its dermatome. However, in the limbs spinal nerve fibers are mixed in the brachial (upper limb) or lumbosacral (lower limb) plexus, so that each peripheral nerve contains fibers from multiple spinal cord levels.[25] Therefore, the dermatome map of the limbs, which illustrates the areas of skin supplied by fibers from each of the spinal nerves, is different from the cutaneous nerve map, which shows the areas of skin supplied by each of the cutaneous branches of the peripheral nerves. If an area of paresthesia coincides with the territory of a cutaneous nerve, the patient's problem is very likely associated with the peripheral nerve supplying the area. If the paresthesia coincides with the dermatome of a spinal nerve, then the patient's problem is most likely in the central nervous system or in the spinal nerve between the spinal cord and the plexus, where the nerve fibers are mixed. The approximate level is determined based on the dermatome affected.

One clinically relevant dermatome is that of the fourth lumbar spinal nerve, which may be compressed by herniation of a lumbar intervertebral disc or by lumbar spinal stenosis. The cutaneous distribution of L4 is a good example of how different dermatome maps may lead to incorrect diagnosis or miscommunication. Its sensory distribution over the thigh, leg, ankle, and foot differs in several commonly used texts. Books using the Foerster map, as well as the texts by Reese, Dutton and Umphred, show no L4 dermatome on the thigh. Other books place the L4 dermatome in the anteromedial,[23] posterolateral,[23] or both the medial and lateral aspects of the thigh,[30] or on the distal anterior surface of the thigh proximal to the knee.[15] If a clinician finds altered sensation on the lower anterolateral surface of the thigh, he/she could localize the injury to the level of the second, third, fourth, or fifth lumbar spinal nerve, depending on the map used. Likewise, altered sensation over the anteromedial aspect of the leg could be attributed to an injury at the third, fourth, or fifth lumbar spinal level.

The problem of inconsistency in the use of dermatome maps can affect students, therapists in the clinic, and clinicians communicating with other healthcare professionals. Healthcare providers who are actively treating patients may provide conflicting information when communicating with other professions based on the dermatome map utilized. Patients are frequently treated by a healthcare team consisting of physicians, occupational therapists, physical therapists, and others. Inconsistent dermatome information may influence the different team members who are treating the signs and/or symptoms of pathology associated with different spinal nerve levels. Also, students trying to learn the segmental distribution of spinal nerves may be confused by the varying information found in texts that might lead to incorrect answers on their licensing board exams.

In striving for evidence-based practice, we should expect our textbooks to be consistent, to cite original research data, and to present data that has been subjected to the rigors of external review. We routinely use dermatomes to diagnose the location of neurological injury, but do we truly know the location of the dermatomes? Historically, at least 2 contradictory dermatome maps have been proposed. These maps are quite dissimilar in the placement of the clinically important dermatomes of the lower limb. While the maps of both Foerster and Head and Campbell generally place the dermatomes of the higher spinal nerves proximal to the dermatomes of the lower nerves, Keegan and Garrett's map shows all the dermatomes extending unbroken from their origin in the lumbar area or gluteal region until their termination at the axial line. This places Foerster's and Head and Campbell's L4 dermatome entirely distal to the knee, while Keegan and Garrett have it swirling from the lower lumbar region around the thigh to end at the great toe. Lee et al[22] have attempted to clarify the dermatome map confusion by creating a new, composite map derived from consensus data from early maps, omitting the Keegan and Garrett data. One concern regarding this map is that the data used for its creation came from experiments that used different methods to identify dermatomes. One of the 2 core papers (Foerster) did not specify the method used to determine presence or loss of sensation after rhizotomy, while the other (Head and Campbell) examined skin lesions seen in shingles. Each of the other 3 papers used a different method: Nitta et al[27] tested the sensation of discriminative touch, Cole et al[3] tested pain sensation, and Inouye and Buchthal[16] measured nerve conduction after electrical stimulation. One would expect to see variation in the areas defined by these different procedures. So it is unclear if a consensus map derived from these studies truly represents the boundaries of the dermatomes.

Because the dermatome maps currently in use were developed in the late nineteenth and early twentieth centuries using a variety of techniques, we believe that the cutaneous distribution of spinal nerves to the limbs should be re-evaluated. Current technology provides the opportunity to more precisely define the cutaneous distribution of the spinal nerves. The extensive use of the Keegan and Garrett map should also be examined.

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