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ORIGINAL COMMUNICATION

Mapping Sensory Nerve Communications Between Peripheral Nerve Territories

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The human cutaneous sensory map has been a work in progress over the past century, depicting sensory territories supplied by both the spinal and cranial nerves. Two critical discoveries, which shaped our understanding of cutaneous innervation, were sensory dermatome overlap between contiguous spinal levels and axial lines across areas where no sensory overlap exists. These concepts define current dermatome maps. We wondered whether the overlap between contiguous sensory territories was even tighter: if neural communications were present in the peripheral nerve territories consistently connecting contiguous spinal levels? A literature search using peer-reviewed articles and established anatomy texts was performed aimed at identifying the presence of communications between sensory nerves in peripheral nerve territories and their relationship to areas of adjacent and non-adjacent spinal or cranial nerves and axial lines (lines of discontinuity) in the upper and lower limbs, trunk and perineum, and head and neck regions. Our findings demonstrate the consistent presence of sensory nerve communications between peripheral nerve territories derived from spinal nerves within areas of axial lines in the upper and lower limbs, trunk and perineum, and head and neck. We did not find examples of communications crossing axial lines in the limbs or lines of discontinuity in the face, but did find examples crossing axial lines in the trunk and perineum. Sensory nerve communications are common. They unify concepts of cutaneous innervation territories and their boundaries, and refine our understanding of the sensory map of the human skin. Clin. Anat. 27:681–690, 2014.

Key words: dermatomes; nerve; communications; map; cutaneous; sensory

INTRODUCTION

The concept of segmental dermatome distribution has been the basis of cutaneous mapping of the human body since its description by Herringham (1886). This segmental pattern leads to areas of cutaneous sensory overlap in regions of adjacent sensory nerve supply (i.e., adjacent spinal nerve territories) which were described by Sherrington (1893) through selective posterior root sectioning in monkeys. However, the segmental pattern deviates in the upper and lower limbs, where discontinuous dermatomes meet forming discrete sensory boundaries (termed axial lines). These axial lines were elaborated by Sherrington (1893, 1898) and have explained why certain regions are devoid of cutaneous sensory overlap.

Dermatome maps are notoriously inconsistent, varying to some degree in their patterns of distribution and overlap (reviewed in Apok et al., 2011). The most commonly used maps in the upper and lower limbs and trunk/perineum are based on the work of Head and Campbell (1900), Foerster (1933), and Keegan and Garrett (1948), which were derived from clinical observations of traumatic

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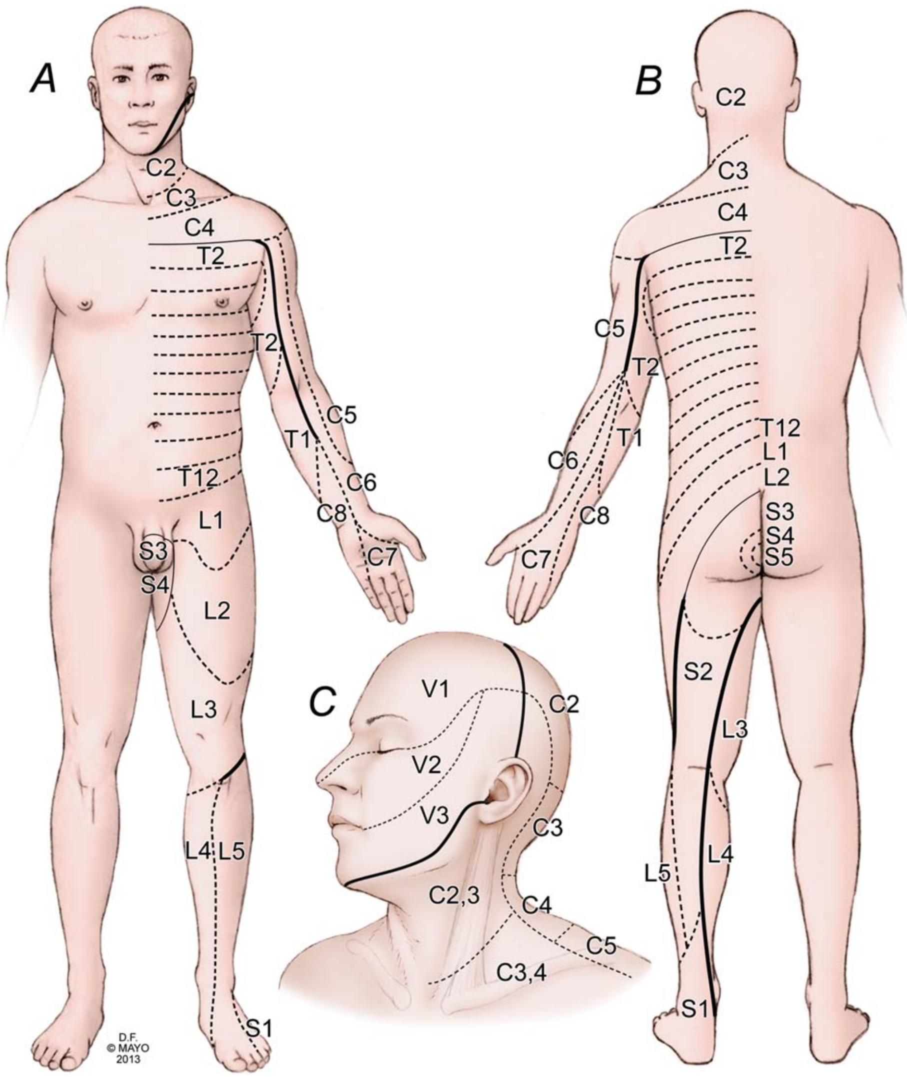

Fig. 1. Standard cutaneous dermatome map of the (**a**) anterior and (**b**) posterior surfaces of the body modified from figures 42.3, 54.3, 45.14, and 79.19 in Gray's Anatomy (Standring, 2008). Axial lines are represented by solid lines while sensory nerve territories are depicted by dashed lines. The solid axial lines are thinned in the trunk and perineal regions where communications were found to cross. In the upper extremity, axial lines are present on the anterior and posterior surfaces of the arm separating the and T1-2 dermatomes. In the trunk, there is an axial line anteriorly separating the C4 and T2 dermatome levels and posteriorly separating the C4 and T2 dermatomes levels. In the perineal region and lower extremity, axial lines are present, both anteriorly and posteriorly, separating non-contiguous dermatomes. Anteriorly, two small axial lines are found—one just distal to the knee separating the L3 and L5 dermatomes; and a second axial line is seen in the perineal region, separating the S2-4 and L2-4 dermatomes. Posteriorly, two axial lines are present separating the S2-4 dermatomes from the L2-4 dermatomes. In the face (**c**), an axial line is found in Cunningham's Textbook of Anatomy separating the trigeminal nerve from the cervical sensory nerves.

spinal cord lesions, herpes zoster infection distribution, and sensory rhizotomy and herniated discs. Map was constructed by Lee et al. (2008) based on clinical reports in the literature, including nerve block and peripheral nerve stimulation studies (Inouye and Buchthal, 1977; Poletti, 1991; Nitta et al., 1993; Wolff et al., 2001). More recently, the work of Denny-Brown and colleagues significantly altered the traditional view of a static dermatome map, where the size of dermatomes change depending on the characteristics of adjacent spinal cord segments, suggesting that the dermatome map is in fact dynamic and dependent on central communications between spinal levels (Denny-Brown and Kirk, 1968; Kirk and Denny-Brown, 1970; Denny-Brown et al., 1973). This provides a possible explanation to the large degree of variability in sensory mapping.

TABLE 1. Nerve Communications in the Upper Extremity

Nerve communication		Reference
Supraclavicular (C3,4)	Axillary (C5)	(Lewis, 1918)
Intercostobrachial cutaneous (T2)	Posterior brachial (C5-8, T1)	(Loukas et al., 2006)
Intercostobrachial cutaneous (T2)	Medial brachial cutaneous (C8,T1)	(Race and Saldana, 1991; O'Rourke et al., 1999; Loukas et al., 2006)
Intercostobrachial (T2)	Medial antebrachial cutaneous (C8, T1)	(Race and Saldana, 1991)
Medial brachial cutaneous (C8, T1)	Medial antebrachial cutaneous (C8, T1)	(Lewis, 1918)
Medial antebrachial cutaneous (C8,T1)	Posterior antebrachial cutaneous (C7)	(Marathe et al., 2010)
Superior lateral cutaneous (C5)	Inferior lateral cutaneous (C5-8, T1)	(Koizumi et al., 1999)
Inferior lateral cutaneous (C5-8,T1)	Lateral antebrachial cutaneous (C6,7)	(Lewis, 1918)
Lateral antebrachial cutaneous (C6, 7)	Superficial branch radial (C7)	(Linell, 1921; Ikiz and Ucerler, 2004)
Posterior antebrachial cutaneous (C7)	Lateral antebrachial cutaneous (C6,7)	(Lewis, 1918)
Medial antebrachial cutaneous (C8,T1)	Dorsal branch ulnar (C8, T1)	(Lewis, 1918)
Medial antebrachial cutaneous (C8,T1)	Posterior antebrachial cutaneous (C7)	(Lewis, 1918)
Lateral antebrachial cutaneous (C6, 7)	Palmar cutaneous branch median (C6-8)	(Lewis, 1918)
Superficial branch. radial (C7)	Dorsal branch ulnar (C8, T1)	(Loukas et al., 2011)
Superficial branch radial (C7)	Palmar cutaneous branch median (C6-8)	(Loukas et al., 2011)
Medial antebrachial cutaneous (C8,T1)	Palmar cutaneous branch ulnar (C8,T1)	(Lewis, 1918)
Ulnar digital nerve (C8) (ring digit)	Median digital (C7) (ring digit)	(Loukas et al., 2011)
Palmar cutaneous branch ulnar (C8,T1)	Palmar cutaneous branch median (C6-8)	(Stancic et al., 1999; Loukas et al., 2011)

Nerve root derivations taken from Gray's Anatomy (Standring, 2008)

In the head and neck region, sensory overlap between adjacent sensory territories was described by Sherrington (1893, 1898) in his studies on monkeys, even between the 5th cranial and 2nd cervical spinal nerve territories where he stated "the skin-fields of the 5th cranial and 2nd cervical mutually behave as if the two nerves were immediately juxtaposed members in a spinal series, without intercalation of any intermediate segment." In contrast, later studies by Harvey Cushing (1904) on the sensory dermatome of the 5th cranial nerve defined a boundary between the trigeminal and cervical spinal nerves in patients where the trigeminal sensory root was divided. This boundary or line of discontinuity is consistent with the facial map presented in Cunningham's Textbook of Anatomy (Cunningham and Romanes, 1981).

The fact that a nerve root can be transected without losing sensation has been presumed to be due to adjacent nerve overlap. Common to all maps are areas of sensory overlap along borders of adjacent spinal nerves, demarcated most dermatome maps by dashed lines. Where non-contiguous spinal nerves meet, so called axial lines are formed across which minimal to no sensory overlap occurs. The term axial line has been utilized to demarcate the line extending proximally from the trunk to the distal aspects of the limbs (Cunningham and Romanes, 1981). For semantics, we utilize the "line of discontinuity" when discussing sensory discontinuity in the face. Axial lines are depicted by solid black lines on dermatome maps. Sensory overlap has been thought to occur overlapping areas of sensory innervation where more than one nerve a cutaneous subunit. Inter-neural communications are defined as physical connections between two nerves and provide an alternative mechanism by which sensory overlap occurs in cutaneous innervation.

Neural communications between peripheral nerves were once thought to be rare. However, recent reports are expanding the prevalence of these connections and our understanding of the peripheral nervous system. This study aimed to determine whether there is a pattern to these communications and whether in fact, these intercommunications consistently exist between adjacent sensory peripheral nerves.

METHODS

We designed a study to see if we could logically identify sensory nerve communications in peripheral and cranial nerve territories between: (1) adjacent

TABLE 2. Nerve Communications in the Lower Extremity

Nerve communications		Reference
Medial femoral cutaneous (L2,3)	Lateral femoral cutaneous (L2,3)	(Lewis, 1918; Cunningham and Romanes, 1981)
Medial femoral cutaneous (L2,3)	Obturator (L2-4)	(Lewis, 1918; Cunningham and Romanes, 1981)
Medial femoral cutaneous (L2,3)	Saphenous (L3,4)	(Lewis, 1918; Cunningham and Romanes, 1981)
Lateral femoral cutaneous (L2,3)	Saphenous (L3,4)	(Lewis, 1918; Cunningham and Romanes, 1981)
Saphenous (L3,4)	Superficial fibular (L5, S1)	(Lewis, 1918)
Saphenous (L3,4)	Obturator (L2-4)	(Lewis, 1918)
Superficial fibular (L5, S1)	Sural (L5, S1,2)	(Lewis, 1918; Cunningham and Romanes, 1981; Drizenko et al., 2004)
Sural (L5, S1,2)	Posterior femoral cutaneous (S1-3)	(Lewis, 1918)
Sural (L5, S1,2)	Lateral plantar (S1,2)	(Lewis, 1918)
Lateral plantar (S1,2)	Medial plantar (L4,5)	(Cunningham and Romanes, 1981; Frank et al., 1996; Govsa et al., 2005)
Superficial fibular (L5,S1)	Deep fibular (L4,5)	(Cunningham and Romanes, 1981)
Superficial fibular (L5, S1)	Medial plantar (L4, 5)	(Cunningham and Romanes, 1981)

Nerve root derivations taken from Gray's Anatomy (Standring, 2008)

spinal nerves (i.e., between axial lines); and (2) non-adjacent spinal nerves (i.e., crossing axial lines).

The dermatome maps of the anterior and posterior trunk as well as upper and lower limbs presented in the 40th edition of Gray's Anatomy (Standring, 2008) were used as a template for the spinal nerve sensory distributions, peripheral nerve territories, and axial lines of the trunk and limbs (Figs. 1a and 1b). Of note, there is considerable variability in dermatome maps, especially in the posterior trunk, and this is noted in the figure captions presented in Gray's Anatomy. Of the maps presenting the dermatomal distribution of the posterior trunk, the dermatome map in chapter 42 in Gray's Anatomy was used as a template for study. An additional line of sensory discontinuity depicted in Cunningham's Textbook of Anatomy separating the third division of the trigeminal nerve and cervical sensory dermatomes was also utilized (Cunningham and Romanes, 1981) (Fig. 1c). This book was used as a template for cranial nerve sensory distributions. To address major discrepancies in the depiction of dermatome maps, peripheral nerve

TABLE 3. Nerve Communications in the Trunk and Perineum/Gluteal Regions

Nerve communications		Reference
Supraclavicular nerves (C3,4)	T2 cutaneous	(Lewis, 1918; Mancall and Brock, 2011)
T2	T12 cutaneous	(Shields, 2009; Mancall and Brock, 2011)
T12 (anterior division)	Iliohypogastric (T12, L1)	(Lewis, 1918)
Iliohypogastric (T12, L1)	Ilioinguinal (L1)	(Lewis, 1918)
Iliohypogastric (T12, L1)	Genitofemoral (L1, 2)	(Fitzgibbons and Greenburg, 2002)
Genitofemoral (L1, 2)	Ilioinguinal (L1)	(Rab et al., 2001; Fitzgibbons and Greenburg, 2002)
Ilioinguinal (L1)	Medial femoral cutaneous (L2, 3)	(Klaassen et al., 2011)
Genitofemoral (L1, 2)	Lateral femoral cutaneous (L2, 3)	(Fitzgibbons and Greenburg, 2002)
Ilioinguinal (L1)	Posterior femoral cutaneous (S1-3)	(Cunningham and Romanes, 1981)
Pudendal nerve (S2-4)	Posterior femoral cutaneous (S1-3)	(Lewis, 1918)
Superior cluneal (L1-3)	Medial cluneal (S1-3)	(Tubbs et al., 2010)
Genitofemoral (L1,2)	Medial femoral cutaneous (L2,3)	(Lewis, 1918; Cunningham and Romanes, 1981)

Nerve root derivations taken from Gray's Anatomy (Standring, 2008)

TABLE 4. Nerve Communications in the Head and Neck

Nerve communication		Reference
Greater occipital (C2)	Lesser occipital (C2,3)	(Lewis, 1918; Tubbs et al., 2007)
Greater occipital (C2)	Third occipital (C3)	(Lewis, 1918; Tubbs et al., 2007)
Lesser occipital (C2,3)	Third occipital (C3)	(Tubbs et al., 2007)
Great auricular (C2,3)	Lesser occipital (C2,3)	(Lewis, 1918; Cunningham and Romanes, 1981)
Zygomaticotemporal (V2)	Lacrimal (V1)	(Lewis, 1918)
Zygomaticotemporal (V2)	Auriculotemporal (V3)	(Lewis, 1918)

Nerve root derivations taken from Gray's Anatomy (Standring, 2008)

territories or axial line positions, we utilized a secondary source, the Atlas of Anatomy (Tank and Gest, 2009).

A systematic review of the scientific literature using PubMed and Ovid Medline as well as the internet source Google Scholar was performed for all known reported neural communications between sensory nerves in the upper limb, trunk, perineum, lower limb, and head and neck. Key words used in the search included nerve communications, sensory overlap, axial lines, interauricular line, dermatome, and map. Searches included the names of all the individual peripheral nerves between which communications were sought. Searches were restricted to English language papers and all relevant secondary references were captured. The search was limited to finding documentation of the existence of an interneural communication. This article was not intended to be a comprehensive search of all reports of the specific communication.

RESULTS

Within Regions of Axial Lines (Lines of Discontinuity)

Upper and lower limbs. Sensory neural intercommunications between all adjacent territories within the upper and lower limbs were identified and these findings are summarized in Tables 1 and 2.

Trunk/perineum. In the trunk, communications between neighboring thoracic and thoracoabdominal segmental territories were identified (Table 3). A communication between the T12 anterior cutaneous nerve and the iliohypogastric nerve was also identified unifying the trunk and perineal regions. In the perineum, all adjacent sensory territories were found to have communications with one exception (Table 3). We could not identify documented communications between the ilioinguinal nerve and the obturator nerve whose territories were depicted as adjacent contiguous regions on the Gray's Anatomy map.

Head and neck. In the head and neck, we found nerve communications between the three divisions of the trigeminal nerve and between adjacent cervical levels including the greater, lesser and third occipital nerves, and the great auricular nerve (Table 4).

Across Regions of Axial Lines (Lines of Discontinuity)

Upper and lower limbs. Our literature search did not identify any examples of physical neural communications crossing axial lines in the upper and lower (Table 5).

TABLE 5. No Neural Communications Across Axial Lines

Absent neural communications	
Intercostobrachial (T2)	Inferior lateral cutaneous (C5-8, T1)
Medial brachial cutaneous (C8,T1)	Superior lateral cutaneous (C5)
Intercostobrachial (T2)	Superior lateral cutaneous (C5)
Intercostobrachial (T2)	Posterior antebrachial cutaneous (C5-8, T1)
Posterior brachial cutaneous (C5-8,T1)	Superior lateral cutaneous (C5)
Medial antebrachial cutaneous (C8,T1)	Lateral antebrachial cutaneous (C6,7)
Inferior lateral cutaneous (C5-8, T1)	Medial antebrachial cutaneous (C8,T1)
Pudendal (S2-4)	Femoral nerve (L2-4)
Pudendal (S2-4)	Ilioinguinal (L1)
Pudendal (S2-4)	Iliohypogastric (T12,L1)
Medial femoral cutaneous (L2,3)	Superficial fibular (L5,S1)
Medial femoral cutaneous (L2,3)	Sural (S1,2)
Posterior femoral cutaneous (S1-3)	Obturator (L2-4)
Posterior femoral cutaneous (S1-3)	Lateral femoral cutaneous (L2, 3)
Lateral femoral cutaneous (L2, 3)	Sural (L5, S1, 2)
Posterior femoral cutaneous (S1-3)	Saphenous (L3,4)
Sural (L5, S1, 2)	Saphenous (L3,4)

Nerve root derivations taken from Gray's Anatomy (Standring, 2008)

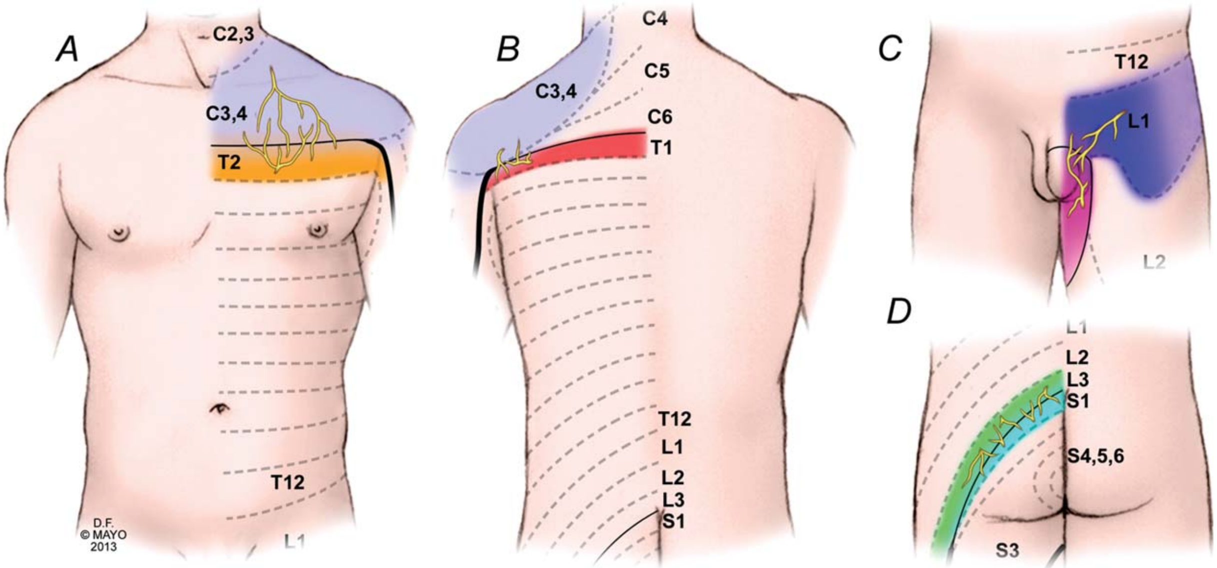

Fig. 2. Communications crossing axial lines. (**a**) Communication between the supraclavicular nerves (C3, 4) and the T2 spinal nerve crossing the anterior axial line; (**b**) Communication between the C3, 4 contributions to the spinal accessory nerve and the T2 posterior primary rami, crossing the posterior axial line; (**c**) Communication between the ilioinguinal nerve (L1) and the perineal branch of the posterior femoral cutaneous nerve (S1-3), crossing the anterior axial line in the perineum; (**d**) Communication between the superior (L1-3) and inferior (S1-3) cluneal nerves, crossing the posterior axial line in the perineum.

Trunk/perineum. In the trunk and perineum, neural communications were identified crossing axial lines. Anteriorly, communications between the supraclavicular nerves (C3, 4) and the cutaneous branch of the T2 spinal nerve were found, crossing the upper anterior axial line in the thorax (Fig. 2a) (Lewis, 1918; Standring et al., 2005; Mancall and Brock, 2011). Posteriorly, communications between the cervical plexus contributions to the spinal accessory nerve and the T2 posterior spinal rami were found, crossing the upper posterior axial line in the thorax (Maigne et al., 1991) (Fig. 2b). In the perineum, communications were documented between the ilioinguinal (L1) and posterior femoral cutaneous nerves (S1-3), crossing the anterior axial line in the perineum (Cunningham and Romanes, 1981) (Fig. 2c) and the superior cluneal (L1-3) and middle cluneal (S1-3) nerves, crossing the posterior axial line (Fig. 2d) (Tubbs et al., 2010).

Head and neck. In the head and neck, we did not identify any reported sensory communications between the trigeminal nerve and the nerves derived from the cervical spinal cord supplying the neck and parieto-occipital regions (Table 5).

DISCUSSION

Neural communications have been thought to be obscure and insignificant. Documentation of these communications can be found in dermatome maps, even in the drawings of early editions of Gray's Anatomy. We demonstrate that these communications not only are common but also have patterns that potentially have an embryological basis. This article extends the term sensory dermatome overlap to the presence or absence of physical neural intercommunications. Sensory dermatome overlap has been long thought to be limited by axial lines, and we aimed to extend this concept to neural communications. Our findings indicate that within axial line territories, in areas of sensory dermatome overlap, there often also exist physical communications between nerves derived from contiguous spinal nerves. The finding of peripheral nerve communications in contiguous territories in the limbs is consistent not only with the axial line theory but also with embryological development where longitudinal growth of limb buds displaces contiguous spinal levels resulting in segmental gaps in sensory innervation (Last, 1949; Pearson et al., 1966). However, when testing the axial line theory against neural communications, we found exceptions to the rule in the trunk.

Within Regions of Axial Lines (Lines of Discontinuity)

Upper and lower limbs. In the limbs, neural intercommunications were found within all peripheral nerve territories contained within axial line boundaries (Figs. 3b–3e). The finding of peripheral nerve communications in contiguous territories in the limbs is consistent not only with the axial line theory but also with embryological development. Motor and sensory nerves arise from the spinal cord in a segmental fashion and form superimposed innervation of muscles

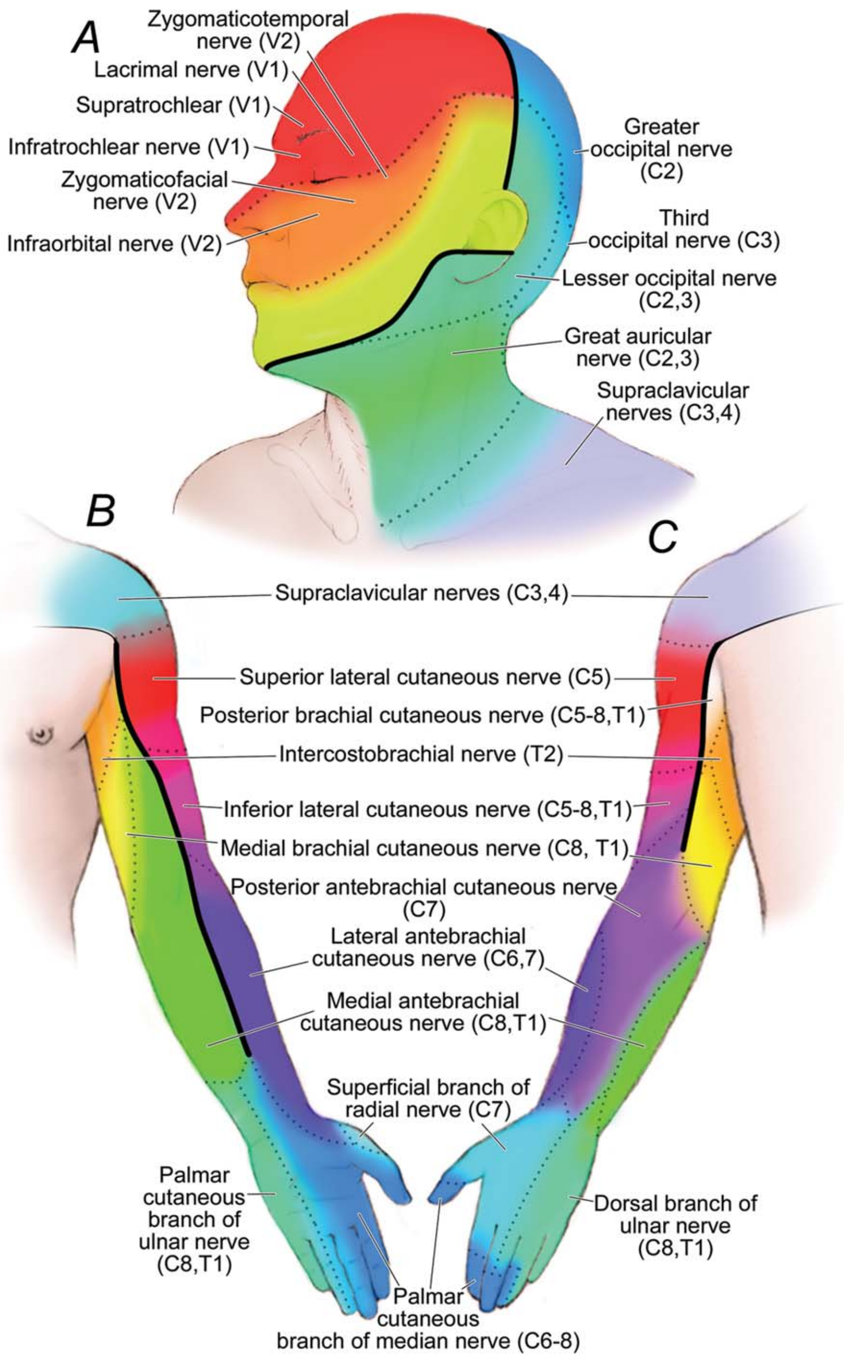

Fig. 3. The refined sensory map of the (**a**) head and neck, (**b**, **c**) upper and (**d**, **e**) lower limbs, incorporating physical neural communications across dashed lines and absence of communications across the solid axial lines. Color transitions depict the presence of physical neural intercommunications and sensory overlap whereas solid black lines represent axial lines across which communications do not occur. The axial lines proximally in the trunk and perineal regions are thinned to denote the presence of communications crossing these boundaries. The root derivations of each peripheral nerve were referenced from Gray's Anatomy 40th edition (Standring, 2008).

and overlying skin on the body wall. This segmental pattern, however, is not as concise in the limbs, where myotomes do not strictly correspond to overlying dermatomes from a specific spinal nerve. Myotomal cells invade the limbs in a cranial to caudal progression, so that more cranial myotomes are represented

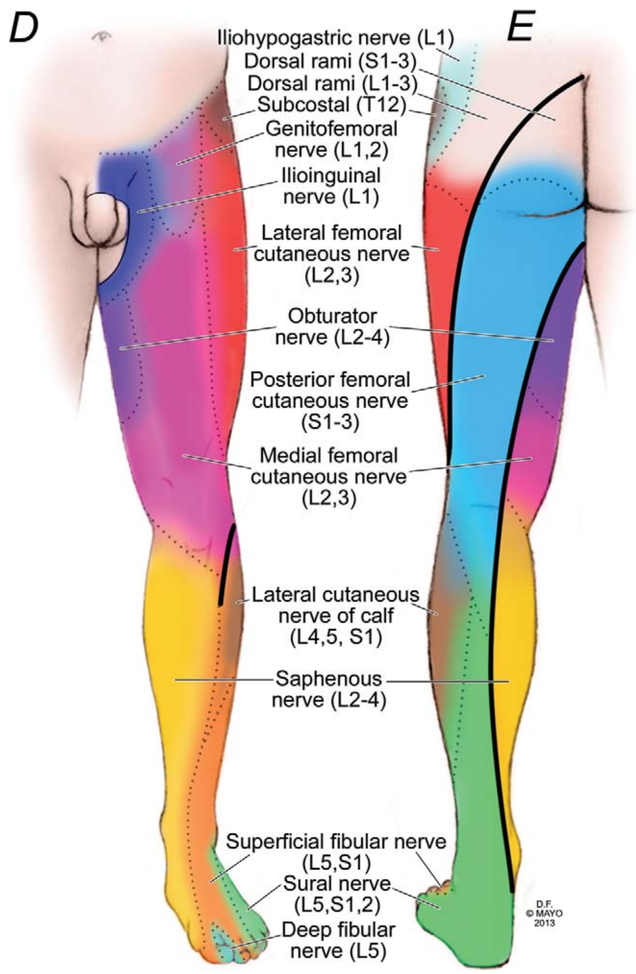

Fig. 3. (Continued)

proximally and more caudal myotomes are found distally. Conversely, the dermatome distribution is affected by longitudinal growth of the limbs as the cutaneous sensory nerves elongate toward their targets. Due to this longitudinal development, segmental gaps form between spinal nerves resulting in axial lines (Last, 1949). Owing to the incongruity of these segments, no communications would be expected between these territories due to the developmental gap between them [e.g., no communications between the superior lateral cutaneous nerve (C5) and the intercostobrachial nerve (T2)].

Trunk/perineum. In the trunk, cutaneous innervation is simple and spinal segmental congruity is maintained throughout. Accordingly, we found documented communications between each of the consecutive thoracic spinal nerves (T2 through to T12) (Lewis, 1918; Mancall and Brock, 2011). Additionally, there were documented communications between the T12 spinal nerve and the iliohypogastric nerve, connecting the trunk and perineal regions. In the perineum, we were unable to find a direct communication between the ilioinguinal and obturator. The anatomy in this region is diverse in the literature with many different variants described. The ilioinguinal nerve has been described to arise from a loop between the first and second lumbar nerves, sometimes even the second and third lumbar nerves, which would connect the ilioinguinal, obturator, and anterior femoral cutaneous nerves (Klaassen et al., 2011). Additionally, we found sources where the ilioinguinal nerve can be replaced by or merged with the genitofemoral nerve, accounting for our inability to find a direct distal communication between the ilioinguinal and the obturator nerve; we did, however, find communications between the genitofemoral and obturator (Rab et al., 2001). A peripheral nerve map was found corroborating this finding where the ilioinguinal nerve sensory territory was not adjacent to the obturator nerve sensory territory (Tank and Gest, 2009). In this situation, all territories would then have communications—genitofemoral and obturator as well as the anterior femoral cutaneous and ilioinguinal nerves.

Head and neck. We found communications between branches of the trigeminal nerve and between branches of the cervical plexus (C2-5), which are derived from anterior rami (Fig. 3a). There is negligible sensory function from the C1, and thus it is not present on standard dermatome maps. Interestingly, sensory motor intercommunications exist between trigeminal nerve sensory branches and branches of the facial nerve, consistent with pharyngeal arch development (i.e. connections between nerves serving the first and second pharyngeal arches, respectively). However, communications have not been described between branches derived from posterior rami of the spinal nerves (e.g., greater and lesser occipital nerves) and trigeminal nerve sensory branches. Although gross peripheral connections are not seen between these latter mentioned nerves, a central communication may exist have speculated that stimulation of the greater occipital nerve resulting in forehead pain may be related to convergence of these fibers in the trigeminal nucleus caudalis (Piovesan et al., 2003); others have found that a block of the branches of the cervical plexus (e.g., great auricular nerve) may provide relief to patients with trigeminal neuralgia (Crue et al., 1956). This is not surprising as the most caudal aspect of the trigeminal sensory nucleus is the cephalic continuation of the substantia gelatinosa of the first and second cervical segments (Stookey and Ransohoff, 1959). Central intercommunications are also seen in spinal nerves, such as between adjacent posterior rootlets (Tubbs et al., 2008).

Across Regions of Axial Lines (Lines of Discontinuity)

When testing neural intercommunications against axial line boundaries, we found communications crossing these boundaries proximally in the trunk and perineum. In the trunk, for example, communications exist between the supraclavicular nerves (C3, 4) and the cutaneous branches of the T2 spinal nerve, crossing the anterior axial line of the upper trunk and communications between the C3, 4 contributions to the spinal accessory nerve and the T2 posterior rami, crossing the posterior axial line. Posteriorly in the trunk, there has been debate as to the presence of cutaneous contributions, variably from C4-T2 (Pearson et al., 1966). Suffice it to say, different depictions of posterior trunk dermatomes exist. We used the map published in chapter 42 of the 40th edition of Gray's Anatomy (Standring, 2008) and this was one of many variations. For example, in the maps by Head and Campbell (1900) the posterior axial line was depicted between C6 and T2. However, the map of Keegan and Garrett (1948) maintains segmental congruity, with no segmental gap and no axial line. Furthermore, some maps depict an axial line separating C4 or C6 from T1. Of note, motor sensory intercommunications have been described between pectoral and intercostal nerves (Koizumi and Horiguchi, 1992).

In the gluteal region, communications exist posteriorly between the superior (L1-3) and middle (S1-3) cluneal nerves. Anteriorly, we found a communication documented between the ilioinguinal (L1) and posterior femoral cutaneous (S1-3) nerves. The exact location of the communication was not described, but from inference, it appears to occur over the scrotum in males and over the labia and clitoral area in females. The junction between the perineal and lower limbs is an area of developmental rotation, which could explain the communication between the posterior femoral cutaneous nerve and the anteriorly situated ilioinguinal nerve. Innervation of the scrotum is one area in particular that is incompletely understood. There are anterior and posterior scrotal nerves derived from the ilioinguinal and pudendal nerves, respectively. Although many sources describe these branches ramifying along the scrotum, we were unable to find a documented communication between these nerves. Additionally, the genitofemoral nerve also innervates the scrotum and labium majus.

All of the communications crossing axial lines occurred at proximal sites of upper and lower limb development. As the pectoral and pelvic girdles are transitional areas during development with rotational movements, it is not surprising that axial lines are crossed as significant differential growth occurs here. As the limb buds develop, longitudinal growth creates distal axial borders across which communications do not seem to cross in the limbs. A possible mechanism for this difference could be that communications between nerves are formed after developmental rotation of the pectoral and pelvic girdles, but prior to longitudinal growth of the limbs.

Limitations of This Study

There are several limitations of this study. Anatomic variation is well recognized such that individual dermatomal maps predictably differ. Axial lines are based on dermatome distributions and thus when superimposing these maps with multi-segmental peripheral nerves, secondary sources were sought to reconcile differences in spinal contributions. Even the same reference may display different maps, spinal nerve distributions and, therefore, axial lines in different sections of the reference. The cutaneous sensory contribution of the back was an area of great variation with different maps depicting different levels between which the posterior axial line crossed. Anatomic variation was also found for the axial line distribution in the upper extremity, with variation in maps presented in different editions of Gray's Anatomy. For this study, we tried to be exhaustive using numerous sources to best compile all known neural intercommunications and how they fit into the axial line boundaries. Even when communications are described, their prevalence or exact location is not always apparent, making exact mapping difficult. Of note, many communications appear to occur distally between terminal branches. In addition, the absence of a described communication does not preclude its existence and new communications are continually being described. For example, Loukas et al. (personal communication, 2006) reported findings of communicating branches between the sural (L5, S1, 2) and saphenous nerve (L3, 4) below the medial malleolus (exact location not available). At face value, this finding seems to be a minor point. However, this anatomic observation is noteworthy in that this location is below the boundary of the posterior axial line of the leg, and crosses a non-contiguous junction. In contrast, we are unaware of a more occurring example, one which would cross an axial line in the limb. Based on our findings, we feel that all cutaneous neural intercommunications within the body will follow the axial line paradigm.

Clinical Implications

The presence of consistent neural communications in contiguous territories has clinical implications in potentially understanding: (1) unexpected sensory examination following nerve injury; (2) involvement of adjacent contiguous dermatomes in herpes zoster; (3) distribution of perineural spread in cancer; (4) propagation of intraneural ganglion cysts; and (5) treatment of painful neuromas. The absence of communications across axial lines may provide a barrier to perineural propagation along sensory nerve pathways.

CONCLUSIONS

We present our preliminary findings, which can be used as a foundation on which further data can be added. This study takes the first step in refining the dermatome map to include distal physical communications between cutaneous sensory nerves Nerve communications appear to be constant between sensory regions derived from contiguous spinal nerves. The exceptions to the axial line boundaries appear to be consistent with embryological development. Still there remains much ambiguity in cutaneous innervation and further work is necessary to clarify these small but important neural communications. The dermatome map is changing.

REFERENCES

Apok V, Gurusinghe NT, Mitchell JD, Emsley HC. 2011. Dermatomes and dogma. Pract Neurol 11:100-105.

Crue BL, Shelden CH, Pudenz RH, Freshwater DB. 1956. Observations on the pain and trigger mechanism in trigeminal neuralgia. Neurology 6:196-207.

Cunningham DJ, Romanes GJ. 1981. Cunningham's Textbook of Anatomy. 12th ed. London: Oxford University Press.

Cushing H. 1904. The sensory distribution of the fifth cranial nerve. Bull Johns Hopkins Hosp 15.

Denny-Brown D, Kirk E. 1968. Hyperesthesia from spinal and root lesions. Trans Am Neurol Assoc 93:116-120.

Denny-Brown D, Kirk EJ, Yanagisawa N. 1973. The tract of Lissauer in relation to sensory transmission in the dorsal horn of spinal cord in the macaque monkey. J Comp Neurol 151:175-200.

Drizenko A, Demondion X, Luyckx F, Mestdagh H, Cassagnaud X. 2004. The communicating branches between the sural and superficial peroneal nerves in the foot: A review of 55 cases. Surg Radiol Anat 26:447-452.

Fitzgibbons RJ, Greenburg AG. 2002. Nyhus and Condon's Hernia. 5 ed. Philadelphia: Lippincott Williams and Wilkins.

Foerster O. 1933. The dermatomes in man. Brain 56:1-39.

Frank PW, Bakkum BW, Darby SA. 1996. The communicating branch of the lateral plantar nerve: A descriptive anatomic study. Clin Anat 9:237-243.

Govsa F, Bilge O, Ozer MA. 2005. Anatomical study of the communicating branches between the medial and lateral plantar nerves. Surg Radiol Anat 27:377-381.

Head H, Campbell AW. 1900. The pathology of herpes zoster and its bearing on sensory localisation. Brain 23:353-523.

Herringham WP. 1886. The minute anatomy of the brachial plexus. Proc R Soc Lond 41:423.

Ikiz ZA, Ucerler H. 2004. Anatomic characteristics and clinical importance of the superficial branch of the radial nerve. Surg Radiol Anat 26:453-458.

Inouye Y, Buchthal F. 1977. Segmental sensory innervation determined by potentials recorded from cervical spinal nerves. Brain 100:731-748.

Keegan JJ, Garrett FD. 1948. The segmental distribution of the cutaneous nerves in the limbs of man. Anat Rec 102:409-437.

Kirk EJ, Denny-Brown D. 1970. Functional variation in dermatomes in the macaque monkey following dorsal root lesions. J Comp Neurol 139:307-320.

Klaassen Z, Marshall E, Tubbs RS, Louis RG Jr, Wartmann CT, Loukas M. 2011. Anatomy of the ilioinguinal and iliohypogastric nerves with observations of their spinal nerve contributions. Clin Anat 24:454-461.

Koizumi M, Horiguchi M. 1992. A study on the communication between the pectoral nerve and the extramural nerve branches of the intercostal nerves. J Anat 67:606-615.

Koizumi M, Kawai K, Maeda S, Okamoto K, Kodama K. 1999. Communication between the axillary and radial nerves in the human upper arm. Ann Anat 181:213-221.

Last RJ. 1949. Innervation of the limbs. J Bone Joint Surg Br 31B: 452-464.

Lee MW, McPhee RW, Stringer MD. 2008. An evidence-based approach to human dermatomes. Clin Anat 21:363-373.

Lewis WH. 1918. Anatomy of the Human Body. 20th ed. Philadelphia: Lea & Febiger.

Linell EA. 1921. The distribution of nerves in the upper limb, with reference to variabilities and their clinical significance. J Anat 55:79-112.

Loukas M, Hullett J, Louis RG Jr, Holdman S, Holdman D. 2006. The gross anatomy of the extrathoracic course of the intercostobrachial nerve. Clin Anat 19:106-111.

Loukas M, Abel N, Tubbs RS, Matusz P, Zurada A, Cohen-Gadol AA. 2011. Neural interconnections between the nerves of the upper limb and surgical implications. J Neurosurg 114:225-235.

Maigne JY, Maigne R, Guerin-Surville H. 1991. Upper thoracic dorsal rami: Anatomic study of their medial cutaneous branches. Surg Radiol Anat 13:109-112.

Mancall EL, Brock DG. 2011. Gray's Clinical Neuroanatomy: The Anatomic Basis for Clinical Neuroscience. Philadelphia, Pa.: Elsevier Saunders.

Marathe R, Mankar S, Joshi M, Sontakke Y. 2010. Communication between radial nerve and medial cutaneous nerve of forearm. J Neurosci Rural Pract 1:49-50.

Nitta H, Tajima T, Sugiyama H, Moriyama A. 1993. Study on dermatomes by means of selective lumbar spinal nerve block. Spine (Phila Pa 1976) 18:1782-1786.

O'Rourke MG, Tang TS, Allison SI, Wood W. 1999. The anatomy of the extrathoracic intercostobrachial nerve. Aust N Z J Surg 69: 860-864.

Pearson AA, Sauter RW, Buckley TF. 1966. Further observations on the cutaneous branches of the dorsal primary rami of the spinal nerves. Am J Anat 118:891-903.

Piovesan EJ, Kowacs PA, Oshinsky ML. 2003. Convergence of cervical and trigeminal sensory afferents. Curr Pain Headache Rep 7: 377-383.

Poletti CE. 1991. C2 and C3 pain dermatomes in man. Cephalalgia 11:155-159.

Rab M, Ebmer , Dellon AL. 2001. Anatomic variability of the ilioinguinal and genitofemoral nerve: Implications for the treatment of groin pain. Plast Reconstr Surg 108:1618-1623.

Race CM, Saldana MJ. 1991. Anatomic course of the medial cutaneous nerves of the arm. J Hand Surg Am 16:48-52.

Sherrington CS. 1893. Experiments in examination of the peripheral distribution of the fibres of the posterior roots of some spinal nerves. I. Philos Trans R Soc Lond Biol Sci 184:641-763.

Sherrington CS. 1898. Experiments in examination of the peripheral distribution of the fibres of the posterior roots of some spinal nerves. II. Philos Trans R Soc Lond Biol Sci 190:45-186.

Shields TW. 2009. General Thoracic Surgery. 7th ed. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins.

Stancic MF, Micovic V, Potocnjak M. 1999. The anatomy of the Berrettini branch: Implications for carpal tunnel release. J Neurosurg 91:1027-1030.

Standring S. 2008. Gray's Anatomy: The Anatomical Basis of Clinical Practice. 40th ed. New York: Elsevier Churchill Livingstone.

Standring S, Ellis H, Berkovitz BKB. 2005. Gray's Anatomy: The Anatomical Basis of Clinical Practice. 39th ed. New York: Elsevier Churchill Livingstone.

Stookey B, Ransohoff J. (eds.). 1959. Trigeminal Neuralgia: Its History and Treatment. Springfield, IL.

Tank PW, Gest TR. 2009. Atlas of Anatomy. 1 ed. Philadelphia: Lippincott Williams & Wilkins.

Tubbs RS, Salter EG, Wellons JC, Blount JP, Oakes WJ. 2007. Landmarks for the identification of the cutaneous nerves of the occiput and nuchal regions. Clin Anat 20:235-238.

Tubbs RS, Loukas M, Shoja MM, Ardalan MR, Apaydin N, Myers C, Shokouhi G, Oakes WJ. 2008. Contributions of the fourth spinal nerve to the brachial plexus without prefixation. J Neurosurg Spine 8:548-551.

Tubbs RS, Levin MR, Loukas M, Potts EA, Cohen-Gadol AA. 2010. Anatomy and landmarks for the superior and middle cluneal nerves: Application to posterior iliac crest harvest and entrapment syndromes. J Neurosurg Spine 13:356-359.

Wolff AP, Groen GJ, Crul BJ. 2001. Diagnostic lumbosacral segmental nerve blocks with local anesthetics: A prospective double-blind study on the variability and interpretation of segmental effects. Reg Anesth Pain Med 26:147-155.