Somatotopic Arrangement and Location of the Corticospinal Tract in the Brainstem of the Human Brain

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INTRODUCTION

The corticospinal tract (CST) is the most important motor pathway in the human brain. Detailed knowledge of CST somatotopy is important in terms of rehabilitative management and invasive procedures for patients with brain injuries. In this study, I conducted a review of nine previous studies of the somatotopical location and arrangement at the brainstem in the human brain. The results of this review indicated that the hand and leg somatotopies of the CST are arranged medio-laterally in the mid to lateral portion of the cerebral peduncle, ventromedial-dorsolaterally in the pontine basis, and medio-laterally in the medullary pyramid. However, few diffusion tensor imaging (DTI) studies have been conducted on this topic, and only nine have been reported: midbrain (2 studies), pons (4 studies), and medulla (1 study). Therefore, further DTI studies should be conducted in order to expand the literature on this topic. In particular, research on midbrain and medulla should be encouraged.

Key Words: Corticospinal tract, somatotopy, brainstem, cerebral peduncle, midbrain, pons, medulla
(DTI), have contributed to research on somatotopy at the supratentorial level. However, only a few DTI studies have reported on somatotopy in the human brain.11,18

In the current study, I reviewed the literature on somatotopic location and arrangement at the brainstem of the human brain. Relevant studies were identified using the following electronic databases (Pubmed and MEDLINE) from 1966 to 2011. The following key words were used: CST, somatotopy, brainstem, cerebral peduncle (CP), midbrain, pons, and medulla. I limited this review to human studies of the CST and excluded studies of the corticocentral or the corticobulbar tract. Ultimately, nine studies were selected for this review.8,11,16-19,21,34,35

**MIDBRAIN**

Many studies using the Wallerian degeneration phenomenon on brain CT or MRI, direct brain stimulation study during surgery,27 pedunculotomy for control of involuntary movements,27,38 or DTI18,39,40 have demonstrated the location of the CST at the CP of the human brain. Studies reporting that the CST was located in the middle portion of the CP have been a general trend; on the other hand, some textbooks or studies have suggested more specific data: the middle three-fifths,1 middle half,31 or middle two-thirds.22 However, three recent DTI studies provided visual data suggesting that the CST was located in the mid to lateral portion of the CP.18,39,40

As for the somatotopic location and arrangement of the CST, many neuroanatomy textbooks have shown mediolateral arrangement of somatotopies for the arm and leg.1,22 However, there has been a shortage of studies that elucidated somatotopic anatomy in detail.18,34 In 1967, Martinez, et al.34 investigated somatotopic anatomy using a direct brain stimulation study during stereotactic surgery in more than 700 patients. They found face predominance from 7 to 12 mm behind the anterior commissure, and maximal response for the upper limb at 14 mm and at 19 mm for the lower limb. They reported an antero-posterior somatotopic arrangement from the face to the upper and lower limbs, rather than a mediolateral arrangement at the upper CP. Since the introduction of DTI, one DTI study has reported on the somatotopic arrangement of the CST at the CP.18 In 2008, Park, et al.18 attempted to demonstrate the somatotopic arrangement at the CP of nine normal human brains. They found antero-posterior somatotopic arrangement from the face to the upper and lower limbs, rather than a mediolateral arrangement at the upper CP. Since the introduction of DTI, one DTI study has reported on the somatotopic arrangement of the CST at the CP.18 In 2008, Park, et al.18 attempted to demonstrate the somatotopic arrangement at the CP of nine normal human brains. They found antero-posterior somatotopic arrangement from the face to the upper and lower limbs, rather than a mediolateral arrangement at the upper CP. Since the introduction of DTI, one DTI study has reported on the somatotopic arrangement of the CST at the CP.18 In 2008, Park, et al.18 attempted to demonstrate the somatotopic arrangement at the CP of nine normal human brains. They found antero-posterior somatotopic arrangement from the face to the upper and lower limbs, rather than a mediolateral arrangement at the upper CP. Since the introduction of DTI, one DTI study has reported on the somatotopic arrangement of the CST at the CP.18 In 2008, Park, et al.18 attempted to demonstrate the somatotopic arrangement at the CP of nine normal human brains. They found antero-posterior somatotopic arrangement from the face to the upper and lower limbs, rather than a mediolateral arrangement at the upper CP. Since the introduction of DTI, one DTI study has reported on the somatotopic arrangement of the CST at the CP.18

| Location | Authors             | Publication year | Subject No. | Method                          | Results                                                   |
|----------|---------------------|------------------|-------------|---------------------------------|-----------------------------------------------------------|
| Midbrain | Martinez et al.34   | 1967             | 700         | Direct stimulation study        | Antero-posterior somatotopic arrangement (face-upper limb-lower limb) |
|          | Park et al.18       | 2008             | 9 (normal)  | Diffusion tensor tractography   | Medio-lateral somatotopic arrangement (hand-foot)         |
| Pons     | Schneider and Gautier35 | 1994            | 17 (stroke) | Clinico-radiological study      | Arm somatotopy : antero-medial                            |
|          | Bassetti et al.8    | 1996             | 21 (infarct)| Clinico-radiological study      | Leg somatotopy : postero-lateral                          |
|          | Tohgi et al.21      | 1996             | 36 (infarct)| Clinico-radiological study      | Hand somatotopy : ventro-medial                           |
|          | Schmahmann et al.19 | 2004             | 25 (infarct)| Clinico-radiological study      | Leg somatotopy : ventro-medial                            |
|          | Marx et al.17       | 2005             | 41 (infarct)| Clinico-radiological study      | No somatotopical difference of arm and leg                |
|          | Hong et al.11       | 2010             | 25 (normal)| Diffusion tensor tractography   | Hand somatotopy : ventro-medial                           |
|          | Kwon et al.16       | 2011             | 30 (normal)| Diffusion tensor tractography   | Hand somatotopy : medial                                 |

Table 1. Previous Studies on Somatotopical Location and Arrangement in the Brainstem of the Human Brain
Somatotopy of the Corticospinal Tract at the Brainstem

The CST is located in the center of the pontine basis, which is surrounded by transpontine fibers. Several clinico-radiological correlation studies have reported on the somatotopic arrangement and location of the CST at the pons. In 1994, Schneider and Gautier discovered that fibers for arm motor function were located antero-medially, while those for leg motor function were located more posterolaterally at the pons in 17 stroke patients with brainstem lesions. During the same year, Bassetti, et al. reported that 10 patients among 12 patients with ventro-medial pontine infarcts showed moderate to severe weakness of the distal hand; in contrast, nine patients with ventrolateral pontine infarct showed no weakness or mild weakness. However, Tohgi, et al. reported different results, showing hand dominant weakness in patients with infarct in the dorso-medial region of the pontine basis, and leg dominant weakness in patients with infarct in the ventro-medial region of the pontine basis in 36 patients with pontine basis infarct. In 2004, Schmahmann, et al. demonstrated that hand representation was located ventromedially at the upper and mid-pons, and that leg representation was located dorso-laterally at the lower pons in 25 patients with focal infarcts on the pontine basis. Soon after, using a three-dimensional brain mapping technique from brain MRI and motor-evoked potential, Marx, et al. revealed that lesion location was more dorsal in patients with hemiparesis affecting the proximal muscles and more ventral in patients with distal limb weakness, among 41 patients with pontine infarct. However, they concluded that the arms and legs did not show significant somatotopic differences. Recently, using DTT, Hong, et al. investigated the anatomical location of CST somatotopies for the hand and leg at the pons in 25 normal human brains. In the group analysis, they found that hand somatotopy descended through the ventro-medial portion of the pontine basis and that leg somatotopy was located dorso-laterally to the hand somatotopy of the CST. Individual DTI data showed that the relative average location of the CST for the hand was 47.70% with the standard from the midline to the most lateral point of the upper pons, and 35.87% in the lower pons. For the leg, the average location of the CST was 56.82% in the upper pons and 40.63% in the lower pons. For the anteroposterior direction from the most anterior point of the pons to the most anterior point of the fourth ventricle, the location of the CST for the hand was 42.30% in the upper pons and 36.18% in the lower pons. For the leg, the location of the CST was 45.68% in the upper pons and 39.01% in the lower pons.

The CST descends through the medullary pyramid (MP) in the medulla. The MP is the narrowest area through which the CST descends in the human brain. The location of the whole CST in the MP can be easily identified on a conventional MRI or a color map of DTI. However, little is known about somatotopy in the MP. To the best of our knowledge, only one study has been reported on this topic. Using normalized DTT, Kwon, et al. investigated the somatotopic arrangement of the CST at the MP in 30 normal human brains. They found that the hand somatotopy of the CST was located in the medial portion of the MP; in contrast, the leg somatotopy occupied the lateral portion of the MP.

In the current review, I reviewed previous studies of somatotopy of the CST in the brainstem of the human brain. Detailed knowledge of CST somatotopy is important in terms of rehabilitative management and invasive procedures for patients with brain injury; however, few DTI studies have been conducted on this topic. To the best of my knowledge, only nine studies on this topic have been reported: midbrain (2 studies), pons (6 studies), and medulla (1 study). Therefore, further DTI studies should be conducted in order to expand the literature on this topic. In particular, research on midbrain and medulla should be encouraged, because only three studies have been reported. Recent developments in DTI allow depiction of various cranial nerves in the human brain; therefore, studies of the corticonuclear tract should also be encouraged.42,43

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