Fasciculus? A Microsurgical Anatomic Study

ABSTRACT: OBJECTIVE: Using a fiber-dissection technique, our aim was to expose and study the myelinated fiber bundles of the brain to achieve a clearer conception of their configurations and locations. During the course of our study, the superior occipitofrontal fasciculus became the focus of our interest. Many publications have defined this as a bundle of association fibers, located between the corpus callosum and the caudate nucleus, that connects the frontal and occipital lobes. By examining this area using fiber dissection, we realized that the descriptions of the anatomy are inadequate; thus, we focused on the elucidation of the anatomic structures of this region and, in particular, that known as the superior occipitofrontal fasciculus.

METHODS: Twenty previously frozen, formalin-fixed human brains were dissected under the operating microscope using the fiber-dissection technique.

RESULTS: On coronal sections of the brain, a structure 2 to 3 mm in width and situated on the superolateral aspect of the cerebral hemispheres. These fiber tracts include the corpus callosum, the anterior commissure, and the hippocampal commissure. Projection fibers connect the cerebral cortex with subcortical regions. These radiating projection fibers form the corona radiata, and, near the rostral part of the brain stem, they form a compact band of fibers known as the internal capsule.

CONCLUSION: The structures of the brain are better understood when the fiber-dissection technique is used to explore their configurations and locations. The resulting information is especially beneficial for planning strategies and tactics of neurosurgical procedures.

KEY WORDS: Fiber-dissection technique; Inferior occipitofrontal fasciculus; Microsurgical anatomy; Superior occipitofrontal fasciculus; Superior thalamic peduncle

The white matter of the cerebral hemispheres consists of myelinated fiber bundles, called fasciculi, which are divided into three groups: 1) association, 2) commissural, and 3) projection. Association fibers interconnect cortical regions within the same hemisphere. The main association fasciculi are the arcuate fibers, the cingulum, the uncinate fasciculus, the superior and inferior longitudinal fasciculi, and the superior and inferior occipitofrontal fasciculi. The commissural fibers cross the midline and interconnect the two hemispheres. These fiber tracts include the corpus callosum, the anterior commissure, and the hippocampal commissure. Projection fibers connect the cerebral cortex with subcortical regions. These radiating projection fibers form the corona radiata, and, near the rostral part of the brain stem, they form a compact band of fibers known as the internal capsule.

We used the fiber-dissection technique to reveal the association, commissural, and projection fibers of the brain. This technique, which involves peeling away the white matter tracts of the brain to display its internal anatomic organization, was the first to allow a true three-dimensional appreciation of the brain. As early as the 17th century, this technique was used to demonstrate many tracts and fasciculi of the brain. Since the development of the microtome and histological techniques, fiber dissection has not been extensively used. Klingler cultivated an interest in the fiber-dissection technique and developed an improved method of brain fixation and fiber dissection that now bears his name, Klingler’s technique. He maintained that dissecting fiber tracts of the white matter was the best method for acquiring an accurate knowledge and understanding of the internal structures of the brain.

During our anatomic study, we were unable to identify the superior occipitofrontal fasciculus. Our analysis of numerous publications revealed inconsistencies in the definitions, locations, and patterns of this fasciculus. Our study, which is the first to allow a true three-dimensional appreciation of the brain, was the first to allow a true three-dimensional appreciation of the brain. As early as the 17th century, this technique was used to demonstrate many tracts and fasciculi of the brain. Since the development of the microtome and histological techniques, fiber dissection has not been extensively used. Klingler cultivated an interest in the fiber-dissection technique and developed an improved method of brain fixation and fiber dissection that now bears his name, Klingler’s technique. He maintained that dissecting fiber tracts of the white matter was the best method for acquiring an accurate knowledge and understanding of the internal structures of the brain.

MATERIALS AND METHODS

We dissected 20 previously frozen, formalin-fixed human brains under the operating microscope using the fiber-dissection technique of Klingler. The brains were removed from the craniums no later than 10 to 12 hours postmortem and were fixed in a 10% formalin solution for at least 2 months. To maintain the normal contours of the brain, the basilar artery was ligated and used to suspend the brain in the formalin solution. The specimens were then washed under running water for several hours to remove the formalin and were refrigerated at temperatures ranging from -10 to -15°C for 1 week. Afterwards, they were immersed in water and allowed to thaw. The specimens were then dissected using the operating microscope with 6x to 40x magnification. The primary dissection tools were handmade, thin, wooden spatulas with various tip sizes.

RESULTS

In 16 of the 20 specimens, we dissected the medial aspect of the cerebral hemispheres. After removing...
the cortex, the hippocampus, the medial portion of the corpus callosum, and the fornix, we demonstrated the entire anatomy of the lateral ventricle (Fig. 2A). The removal of the ependyma (which is a single layer of specialized epithelium lining the ventricles) of the frontal horn and the body of the lateral ventricle allowed the exposure of the subcallosal stratum. The subcallosal stratum is a subependymal structure located between the caudate nucleus and the radiation of the corpus callosum. The head and body of the caudate nucleus were removed to demonstrate the fibers of the anterior and superior thalamic peduncles (Fig. 2B). After total removal of the ependyma of the lateral wall and the roof of the lateral ventricle, we demonstrated the posterior portion of the subcallosal stratum and the tapetum of the corpus callosum, both of which were found to be subependymal structures. The tapetum, a subgroup of callosal fibers in the splenial region, forms the roof and lateral wall of the atrial portion of the lateral ventricle and sweeps around the temporal horn, thereby separating the fibers of the optic radiation from the temporal horn. During our fiber dissection, we could not identify the precise location of the border separating the tapetum and the subcallosal stratum. However, we noted a distinct difference between these two structures, and we suspect that the border lies between the body and atrial portions of the lateral ventricle. In the subcallosal stratum, we could not identify a definite fiber system. For this reason, we prefer to use the nomenclature "stratum" (a layered, sheetlike mass of substance of nearly uniform thickness), to describe this structure rather than "fasciculus," as some authors do (1,3,23,28,32). There was, however, a fiber system clearly present in the tapetum. Also, we observed that the subcallosal stratum had microscopic connections with the superior margin of the caudate nucleus. We next dissected away the anterior portions of the subcallosal stratum and the radiation of the corpus callosum to allow identification of the extensions of the anterior and superior thalamic peduncles to the cortex (Fig. 2C). After removing the remaining portions of the subcallosal stratum and the caudate nucleus, we dissected away the tapetum, the stria terminalis, and the amygdala, exposing the entire anatomy of the anterior, superior, posterior, and inferior thalamic peduncles as well as the optic radiation on the roof of the temporal horn (Figs. 2D and 3).

In the four remaining specimens, we performed coronal sections through the center of the third ventricle. We identified a structure 2 to 3 mm in width, on the superolateral aspect of the caudate nucleus and lateral to the subcallosal stratum. This structure was previously thought to be the superior occipitofrontal fasciculus. Continuing further the dissection of the ependyma of the lateral ventricle, the caudate nucleus, the stria terminalis, and the thalamus, we observed that the fibers constituting this structure formed an angle inferiorly, extending to the thalamus and, therefore, belonging to the superior thalamic peduncle (Fig. 4, A and B).

Studies of histological coronal cross sections led to the identification of a structure on the superolateral aspect of the caudate nucleus, which was speculated to be formed by association fibers connecting the occipital and frontal lobes. It was referred to as the "superior occipitofrontal fasciculus" (7,8,18,23,24,30,32). Our serial dissections of 20 brain specimens clearly demonstrated, however, that these fibers are projection fibers (rather than association fibers) belonging to the superior thalamic peduncle, which radiates from the posterior limb of the internal capsule, and also that its fibers form a connection between the ventral thalamic nuclei and posterior frontal and parietal lobes.

**DISCUSSION**

Little is known concerning the relations, courses, and connections of the fibers of the white matter. These fibers are difficult to follow by histological techniques, and descriptions are largely based on experimental studies, which provide a fairly complete account of these connections in subhuman primates (23,33). In comparison to histological sections, dissection following the fiber tracts of the white matter of the brain is an older method. The fiber-dissection technique was one of the earliest methods used to demonstrate the internal structures of the brain. In 1685, Vieussens (31) completed the first successful study using the fiber-dissection technique. He demonstrated the corona radiata, the internal capsule, the cerebral peduncle, and the pyramidal tracts of the pons and medulla oblongata. In 1810, Gall and Spurzheim (9) dissected the corona radiata, the internal capsule, and the medullary decussation of the pyramids. Mayo (22), in 1827, published pictures of several dissected brains, which are considered to be the best to date. Other early anatomists also demonstrated many tracts and fasciculi of the brain using this technique (4,6,17,21,29).

Because performing the fiber-dissection technique is relatively difficult and time-consuming, its neglect became almost inevitable after the development of the microtome and histological techniques. During the early part of the 20th century, a few anatomists, such as Johnston (15), Jamieson (14), Hoeve (12), and Curran (4), still preferred the fiber-dissection technique for studying brain anatomy. In 1909, Curran (4) described the inferior occipitofrontal fasciculus using this technique. He stated that one of the limitations of cross-section studies is the inability of these sections to clearly demonstrate acute vertical changes in the direction of the fibers. In 1929, Hultkrantz (13) published an atlas with illustrations of fiber-dissected brains. In 1935, Klingler (16) developed an improved method of brain fixation and fiber dissection that now bears his name. His atlas on fiber dissection, published with Ludwig in 1956, contains detailed anatomic studies of the brain (21). Although his studies were impressive, this technique never became widely used. Illustrations of the internal structure of the brain in current textbooks are usually pictures of sections or schematic drawings. Only a few fiber dissections from earlier textbooks are still reproduced (2,8,11,26,27,33).

The superior occipitofrontal fasciculus was described at the end of the 19th century, but its...
location and pattern have never been clearly defined (1,8,11,13,18,23,24,26,27,30,32). The prevailing consensus is that this fasciculus interconnects the frontal and occipital lobes and passes over the superolateral aspect of the caudate nucleus as association fibers. On coronal sections of the brain, it is identified on the superolateral aspect of the caudate nucleus and lateral to the subcallosal stratum as a structure 2 to 3 mm in width (7,8,11,23,24,30,32). However, Platzner (27) and De Armond et al. (5), in separate atlases, identified this structure on the coronal sections of the brain as the "superior occipitofrontal fasciculus." They identified and named the "superior occipitofrontal fasciculus" that interconnects the frontal and occipital lobes in the inferior part of the extreme capsule. Ludwig and Klingler (21), and then Gluhbegovic and Williams (19), demonstrated and referred to the "inferior occipitofrontal fasciculus" but did not mention the "superior occipitofrontal fasciculus." They exposed the superior thalamic peduncle; however, they did not discuss that these fibers appear to compose what others refer to as the "superior occipitofrontal fasciculus" on coronal sections. Ludwig and Klingler (21) also identified what we call the "subcallosal stratum" as the "subcallosal fasciculus." Hultkrantz (23) identified the "subcallosal stratum" as the "subcallosal fasciculus" or the "occipitofrontal fasciculus of Forel." In *Dorland's Medical Dictionary* (1), the "superior occipitofrontal fasciculus" and the "subcallosal fasciculus" are both defined as "a collection of association fibers lying just internal to the intersection of the internal capsule and corpus callosum, interconnecting the cortex of the occipital and temporal lobes with that of the insula and frontal lobe, and probably comprising a significant part of the tapetum." Hoeve (12) also mentioned a relationship between the "occipitofrontal fasciculus of Forel" and the tapetum. Most likely, he was describing what we call the "subcallosal stratum." Crosby et al. (5) identified what we call the "subcallosal stratum" as the superior occipitofrontal fasciculus or subcallosal fasciculus. Both Parent (26) and Carpenter (2) identified the "inferior occipitofrontal fasciculus" but made no mention of the "superior occipitofrontal fasciculus" in their books. The superior occipitofrontal fasciculus was not mentioned in the current *Nomina Anatomica* (25), perhaps because of the brevity of the list (the inferior occipitofrontal fasciculus, clearly demonstrated by Curran [4], also did not appear there). Williams et al. (33) did not specifically mention either the superior or inferior occipitofrontal fasciculus. They referred to only the "occipitofrontal fasciculus," but its anatomic description corresponds to that of the "superior occipitofrontal fasciculus." These confusing nomenclatures and descriptions are an indication that this structure is not clearly understood.

Riley (28), in his atlas based on myelin-stained material, used the terms "superior occipitofrontal fasciculus" and "stratum reticulatum coroneae radiatae" interchangeably. He stated that this structure is thought by Marburg to represent a thalamocortical radiation. He also mentioned the subcallosal stratum in the same definition with the subcallosal fasciculus, adding that its constituents are not clear. Krieg (18), in 1942, described the superior and inferior occipitofrontal fasciculi as association fibers; however, in 1966, he preferred the term "medio-frontal bundle" instead of "superior occipitofrontal fasciculus." His definitions regarding the mediofrontal bundle and the subcallosal fasciculus (subcallosal stratum) are revealing.

In the angle between capsule and callosum are two bundles not generally understood. The lateral blends with the internal capsule, but its fibers are more nearly horizontal than adjacent capsular ones. This proves to be the projection from the medial thalamic nucleus to the frontal areas. The other tract, subcallosal fasciculus, is not understood at all. It is coextensive with the lateral ventricle, but seems to arise from nowhere and to end nowhere, and is composed of little more than a feltwork of poorly myelinated fibers. Some of them seem to end in the caudate (19).

In 1973, he published his studies on the cerebral fiber systems based on chimpanzee brains (with degeneration-stained preparations) and human newborn, infant, and adult brains (with myelin-stained sections) (20). He conciles the difficulty of interpreting histological techniques, because the axonal pathways "appear to be an inextricable feltwork in myelin stained sections." He recommended experimental studies with monkeys using a degeneration-stained technique to better understand the human brain; however, he also added that the human brain does not follow the same pattern as the monkey's brain. In this study, he renamed the mediofrontal bundle the "juxtacaudate system" because it is complex and difficult to unravel and added that this system must belong to the thalamic radiations.

Our study using the fiber-dissection technique clearly shows that when referring to the coronal section of the brain, the structure on the superolateral aspect of the caudate nucleus and lateral to the subcallosal stratum is not the "superior occipitofrontal fasciculus"; rather, it is the "superior thalamic peduncle" and is, therefore, composed of projection fibers. In our opinion, it has been incorrectly identified and described as the "superior occipitofrontal fasciculus" because of the limitations of cross-section studies, which fail to elucidate the angle taken by these fibers. The superior thalamic peduncle diverges from the posterior limb of the internal capsule, and its fibers form a two-way connection between the ventral thalamic nuclei and rolandic area and adjacent portions of the frontal and parietal lobes (2,3,23). Fibers, carrying general somatic sensory signals from the body and head, form part of this radiation and terminate in the postcentral gyrus.

Also, according to some authors, what we call the "subcallosal stratum" is the superior occipitofrontal
fasciculus occipitofrontal fasciculus of Forel [4,12, 13]. We do not agree with those authors. The subcallosal stratum is a subependymal structure that is located in the superolateral wall of the frontal horn and body of the lateral ventricle, and, during our dissection, we could not identify a definite fiber system. The subcallosal stratum disappears near the atrial portion of the lateral ventricle and the tapetum, which is the subgroup of callosal fibers that belong to the commissural system, and appears in the superolateral wall of the lateral ventricle (Fig. 2C). Therefore, what we call the "subcallosal stratum" does not connect the frontal and occipital lobes.

CONCLUSION

Previous anatomic studies relied on histological cross sections and incorrectly indicated that the structure located on the superolateral aspect of the caudate nucleus is composed of association fibers, forming the "superior occipitofrontal fasciculus." Our fiber dissections revealed this structure to be the "superior thalamic peduncle," which is composed of projection fibers. The fiber-dissection technique confirmed that the "inferior occipitofrontal fasciculus," which Curran (4) described in detail, connects the occipital lobes to the frontal lobes and is, therefore, composed of association fibers. Considering the results of our study that a "superior occipitofrontal fasciculus," as such, does not exist, a more apt nomenclature for the "inferior occipitofrontal fasciculus" would be the "occipitofrontal fasciculus."

Because other anatomic techniques do not consistently provide an accurate perspective of the brain's complex structures, a revival of the fiber-dissection technique of the white matter is strongly advocated. This technique is time-consuming and intricate to perform, but it is beneficial to increasing our knowledge of brain anatomy, which is essential for neurosurgical procedures.

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Türe et al. present an important contribution to neuroanatomy by demonstrating, via a time-consuming technique of fiber dissection along with a series of beautiful pictures and an extensive review of the literature, that the superior occipitofrontal fasciculus does not exist. Because the anatomic descriptions of white matter fasciculi are usually dated from long ago, it would be very interesting and very important for other anatomic centers to use the Klingler (1) fiber dissection technique, resulting in more and more discoveries in this field.

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REFERENCES: (1)

Figure 1. **A**, coronal section through the center of the third ventricle, the mamillary body, and the hippocampus. In this panel, number 22 is identified as the superior occipitofrontal fasciculus (*arrow*) (our dissection identified the structure marked 22 as the superior thalamic peduncle). 23, stria terminalis; 32, optic tract; 33, cerebral peduncle; 35, hippocampus (*from*, Nieuwenhuys R, Voogd J, van Huijzen C: *The Human Central Nervous System*. Berlin, Springer-Verlag, 1988, p 101, with permission [23]). **B**, long association bundles of the right hemisphere in a lateral view. In this schematic figure, number 1 is identified as the superior occipitofrontal fasciculus (*arrow*) (in our dissection, we observed no fasciculus composed of association fibers following the pattern as shown in **A**). 2, site of corona radiata; 3, superior longitudinal fasciculus; 6, outline of insula; 7, inferior occipitofrontal fasciculus; 8, inferior longitudinal fasciculus; 9, site of anterior commissure; 10, uncinate fasciculus (*from*, Nieuwenhuys R, Voogd J, van Huijzen C: *The Human Central Nervous System*. Berlin, Springer-Verlag, 1988, p 367, with permission [23]).
Figure 2. Serial dissections of the medial aspect of the left cerebral hemisphere. A, dissecting the cortex and the corpus callosum and partially removing the fornix (f) and amygdala (a) further reveals the caudate nucleus (cn) in the lateral wall of the lateral ventricle, as well as the stria terminalis (st), the thalamus (t), and the hypothalamus (h), which are covered by the transparent ependyma (e). The radiation of the corpus callosum (rcc), the anterior commissure (ac), the midbrain (m), the mamillary body (mb), the optic chiasm (oc), and the pineal body (pb) are also labeled. B, after partial removal of the ependyma (e) and the caudate nucleus (cn) in the frontal horn and body of the lateral ventricle, we demonstrated the subcallosal stratum (ss), the anterior thalamic peduncle (atp), and the superior thalamic peduncle (stp). rcc, radiation of the corpus callosum; st, stria terminalis; f, fornix; t, thalamus. C, after totally removing the ependyma of the lateral wall and roof of the lateral ventricle, dissecting away the anterior portions of the subcallosal stratum (ss) and the radiation of the corpus callosum (rcc), we demonstrated cortical extensions of the anterior thalamic peduncle (atp) and superior thalamic peduncle (stp), as well as the corona radiata (cr), the intersection of the corpus callosum with the corona radiata (icc), the tapetum of the corpus callosum (ta), and the inferior thalamic peduncle (itp). cn, caudate nucleus; st, stria terminalis; f, fornix; t, thalamus; a, amygdala. D, tapetum, subcallosal stratum, caudate nucleus, stria terminalis, and amygdala have been dissected away. The thalamus (t) and fibers of the anterior thalamic peduncle (atp), superior thalamic peduncle (stp), posterior thalamic peduncle (ptp), and inferior thalamic peduncle (itp), as well as the optic radiation (or) on the roof of the temporal horn, are demonstrated. The fibers of the superior thalamic peduncle form an angle (arrow) inferiorly and continue to the thalamus. The change in direction of the superior thalamic peduncle inferiorly is not demonstrated on histological coronal sections. It is clearly shown that there is no fasciculus on the superolateral aspect of the caudate nucleus and lateral to the subcallosal stratum connecting the frontal lobe to the occipital lobe, which has been described in previous publications as being the superior occipitofrontal fasciculus. According to our observations, this structure is the superior thalamic peduncle. cr, corona radiata; iicc, intersection of the corpus callosum with the corona radiata; rcc, radiation of the corpus callosum; f, fornix.
Figure 3. The medial aspect of the left hemisphere. The anterior and middle portions of the corpus callosum, the ependyma of the lateral ventricle, the subcallosal stratum, the caudate nucleus, the stria terminalis, the fornix (f), and the thalamus (t) have been dissected away. The angle (arrow) of the fibers belonging to the superior thalamic peduncle (stp) are shown. ac, anterior commissure; atp, anterior thalamic peduncle; cr, corona radiata; icc, intersection of corpus callosum with corona radiata; on, optic nerve; pg, parahippocampal gyrus; rcc, radiation of corpus callosum; s, splenium of corpus callosum; sn, substantia nigra.
Figure 4. **A**, anterior view coronal section of the left hemisphere through the center of the thalamus (**t**). The superolateral aspect of the caudate nucleus (**cn**) and, lateral to the subcallosal stratum (**ss**), the superior thalamic peduncle (**stp**), described in previous publications as the superior occipitofrontal fasciculus, are clearly shown. The ependyma (**e**) is a single layer of specialized epithelium lining the ventricle. **cg**, cingulate gyrus; **cc**, corpus callosum; **cp**, choroid plexus; **st**, stria terminalis; **f**, fornix; **ic**, internal capsule; **p**, putamen. **B**, slightly anteromedial view. The ependyma, the caudate nucleus, and the stria terminalis have been dissected away. The arrows indicate the course taken inferiorly by the superior thalamic peduncle. **cc**, corpus callosum; **cg**, cingulate gyrus; **f**, fornix; **gp**, globus pallidus; **i**, insula; **ic**, internal capsule; **p**, putamen; **t**, thalamus.