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МОЗОЛИСТОЕ ТЕЛО И МЕЖПОЛУШАРНАЯ ДИСКОННЕКЦИЯ: НЕЙРОАНАТОМИЧЕСКИЙ АНАЛИЗ СИНДРОМА РАЗДЕЛЁННОГО МОЗГА

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THE CORPUS CALLOSUM AND HEMISPHERIC DISCONNECTION: A NEUROANATOMICAL PERSPECTIVE ON SPLIT-BRAIN SYNDROME

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Резюме. Мозолистое тело - ключевой комиссуральный тракт, обеспечивающий межполушарную интеграцию. В работе рассматриваются его анатомические и биофизические особенности с применением трактографии и кабельной теории. Случаи дисконнекции (врождённые и хирургические) иллюстрируют функциональные нарушения, подтверждая выводы Сперри и Газзанига о его критической роли в межполушарной координации.

Ключевые слова: мозолистое тело, синдром расщепленного мозга, межполушарная дисконнекция, кабельная теория, синдром чужой руки.

Resume. The corpus callosum is the principal commissural tract enabling interhemispheric integration, critical for unified cognition. This study analyzes its structural and biophysical role using tractographic data and cable theory. Disconnection cases (congenital and surgical) reveal significant functional consequences. These are echoed in the Nobel-winning split-brain research by Sperry and Gazzaniga, which underscores the callosum's essential role in hemispheric coordination.

Keywords: corpus callosum, split-brain syndrome, interhemispheric disconnection, cable theory, alien hand syndrome.

Relevance. Understanding the corpus callosum is key to how the brain maintains unified cognition. Disconnection syndromes, whether congenital or surgical, offer insight into the anatomical foundations of interhemispheric coordination, brain plasticity, and lateralization.

Aim: to examine the structural and biophysical properties of the corpus callosum and analyze how its disruption alters interhemispheric communication, using a neuroanatomical and clinical lens.

Objectives:

1. Analyze regional anatomy and fiber specialization of the corpus callosum.
2. Assess conduction dynamics through the application of cable theory and imaging data.
3. Examine clinical consequences of corpus callosum disconnection in both congenital and surgical contexts.

Materials and methods. The study is based on a literature review. Data were sourced from PubMed, Google Scholar, and Radiopaedia, with a focus on anatomical and imaging studies related to the corpus callosum.

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Results and their discussion. Beneath the unified appearance of the corpus callosum lies a precise anatomical hierarchy. Each segment; genu, trunk, splenium, connects functionally distinct cortical areas, and their fiber architecture reflects the demands of those connections. Posterior regions involved in visual processing demand high-speed conduction, while anterior regions governing executive function require slower, integrative signaling. These anatomical differences are not arbitrary. They correspond to distinct conduction requirements between cortical regions. To further explain how fiber structure influences conduction speed, a simplified application of cable theory may be considered. As introduced by Hodgkin and Rushton (1946), the length constant λ, which reflects how efficiently an electrical signal travels along an axon, is defined as:

$$\lambda = \sqrt{(r_m/r_i)}$$

Fig. 1 – length constant formula in cable theory

Here, r_m represents membrane resistance, which increases with myelin thickness, while r_i is axoplasmic (internal) resistance, which decreases with axon diameter. Splenial fibers, averaging 1.2 µm in diameter and having thicker myelin sheaths, exhibit a higher λ, favoring rapid transmission of visual information. In contrast, genu fibers (~0.7 µm) are optimized for slower, integrative processing: a structural basis for the functional hierarchy observed across callosal regions [6].

Tbl. 1. Regional Microstructural and Functional Specialization of the Corpus Callosum

Region	Axon diameter (µm)	Myelination Thickness	Conduction speed	Functional domain
Genu	~0,7	Thin	Slower	Prefrontal
Trunk	~0,9	Moderate	Intermediate	Motor/ Somatosensory
Splenium	~1,2	Thick	Fastest	Visual/ Occipital Parietal

Agenesis of the corpus callosum (AgCC) results from disrupted axonal guidance during early embryogenesis, typically between weeks 12–20 of gestation. It may be partial or complete, often affecting the posterior segments such as the splenium. Imaging features include colpocephaly, parallel lateral ventricles, and elevation of the third ventricle. Clinically, AgCC may range from asymptomatic to subtle deficits in social cognition, problem-solving, or language, depending on the extent of associated malformations and compensatory plasticity [5].

While agenesis reflects a failure of development, corpus callosum disconnection can also occur intentionally through surgical intervention. Callosotomy was historically used to treat intractable epilepsy by severing interhemispheric pathways to prevent seizure spread. Its efficacy is well-established, with studies showing a 70–80% reduction in drop attacks after the procedure. However, cognitive trade-offs are common, with alien hand syndrome occurring in approximately 25% of patients, and tactile anomia - difficulty naming objects touched by the contralateral hand, affecting up to 60% [7].

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Depending on the extent of resection; partial or complete, different functional impairments may arise, providing further insight into the region-specific roles of callosal fibers.

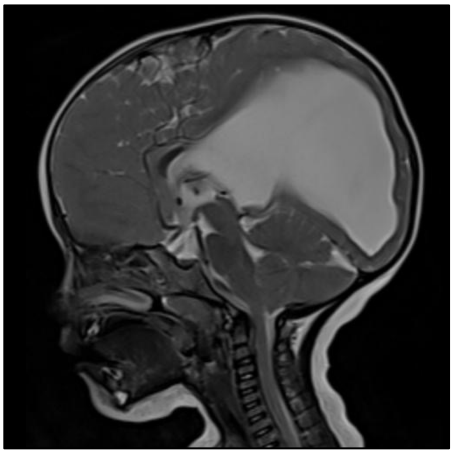

Fig. 2 – Pediatric CT: Partial agenesis with absent posterior segments [4]

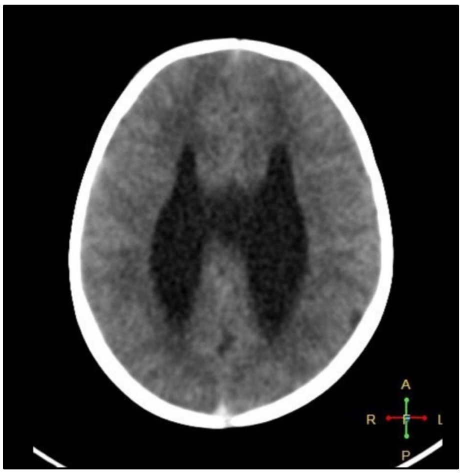

Fig. 3 – CT showing typical features of callosal agenesis [1]

In callosotomy, the corpus callosum is surgically sectioned to reduce interhemispheric seizure propagation. One technique - splenial aspiration, targets the posterior callosal segment, disrupting visual and parietal integration [7]. Although effective in seizure control, especially in drop attacks, splenial disconnection often leads to visual-verbal disconnection and alien hand syndrome. These outcomes highlight the splenium's role in rapid visuospatial transfer and intermanual coordination.

Callosotomy often results in characteristic disconnection syndromes, depending on the regions resected. Splenial damage may cause visual-verbal disconnection, where patients can see an object but fail to name it when presented to the left visual field. Alien hand syndrome, typically arising from anterior callosal or supplementary motor area involvement, manifests as involuntary, purposeless movements of one hand, often interfering with the other. These symptoms underscore the callosum's role in integrating bilateral motor, sensory, and cognitive processes into a unified behavioral response.

The Poffenberger paradigm investigates interhemispheric transfer by measuring reaction times to unilateral visual stimuli responded to with either hand. In healthy brains,

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responses are 2 to 4 milliseconds slower when the stimulus and responding hand are contralateral, reflecting the time required for neural signals to cross the corpus callosum. This crossed-uncrossed difference (CUD) highlights the corpus callosum's essential role in facilitating rapid communication between hemispheres, enabling coordinated sensorimotor function. Disruptions in callosal connectivity, as seen in agenesis or surgical disconnection, alter this transfer, underscoring its importance in normal brain anatomy and function [8].

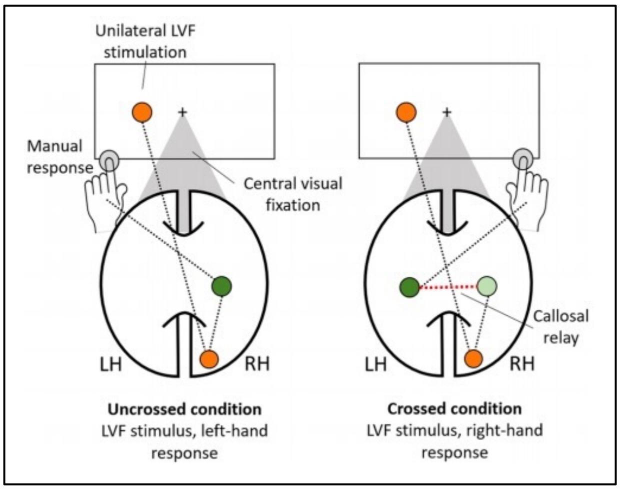

Fig. 4 – Crossed vs. uncrossed conditions in the Poffenberger paradigm

A notable consequence of corpus callosum disconnection, particularly following callosotomy, is the emergence of alien hand syndrome, characterized by involuntary, yet purposeful, movements of one hand independent of conscious control. This phenomenon arises due to the loss of interhemispheric inhibition, leading to disinhibition of the supplementary motor area and resulting in unilateral motor discordance [3]. A classic manifestation involves one hand performing goal-directed actions that directly oppose or interfere with the other, such as the left hand unbuttoning a shirt while the right hand buttons it. Clinically, this was exemplified in a 56-year-old male patient with a left hemispheric stroke involving the fronto-mesial cortex and corpus callosum. His right hand autonomously grasped objects and opposed the left hand's movements, interfering with routine tasks like eating. Neuroanatomically, alien hand syndrome reflects both callosal disconnection disrupting interhemispheric control and frontomesial damage causing disinhibited motor planning in the contralateral limb.

Despite the structural loss of interhemispheric connectivity in agenesis of the corpus callosum (AgCC), the brain exhibits remarkable neuroplasticity, its intrinsic ability to reorganize and adapt structurally and functionally. Compensatory mechanisms often involve alternative intrahemispheric pathways and recruitment of associative cortices to maintain cognitive and sensorimotor function. Structural imaging studies in AgCC patients have demonstrated increased cortical thickness in regions such as the prefrontal and parietal cortices, suggesting compensatory hypertrophy in areas involved in higher-order processing. In contrast, decreased cortical thickness is often observed in primary sensory areas, possibly reflecting underutilization due to disrupted interhemispheric transfer. These adaptive changes illustrate how the developing brain can remodel itself in response to early callosal absence, enabling relatively preserved function despite a major anatomical deficit

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[2]. A rare and extreme example of such adaptation is observed in Kim Peek, a megasavant with complete agenesis of the corpus callosum and absent commissural tracts, whose exceptional memory and cognitive abilities suggest extensive intrahemispheric reorganization. While not representative of typical AgCC outcomes, such cases highlight the potential scope of neuroplastic compensation in atypical brain development.

Conclusions:

1. Regional fiber architecture of the corpus callosum aligns precisely with functional demands, shaping conduction speed and integration.
2. Disconnection (congenital or surgical), produces measurable deficits from reaction time delays to syndromes like alien hand.
3. Adaptive mechanisms such as cortical thickening and compensatory rerouting reveal the brain's remarkable neuroplastic potential.

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