Cerebral reorganization and motor imagery after flexor tendon Repair
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Chapter 1
General introduction
General introduction

The human hand, as a result of an evolutionary process of millions of years, represents one of nature’s most precisely balanced structures, a wonderful physical device with multiple sensorimotor functions. Tendons are largely responsible for the dynamics of the hand. Grasping movements provide the ability to manipulate objects around us. Initially, immediately before actually grasping an object, the finger extensors are deployed for opening the hand to fit the size of the object. This is followed by flexion of the finger joints providing precision grip with an exact adjustment of individual fingers to the shape of the target. Proprioceptive reflexes contribute to the regulation of force necessary to lift or move the object without destroying it, unless destruction is the grasp’s aim. Furthermore a precise interaction between visual and proprioceptive information is needed to tune the movement to the intended goal in the environment.

Since hand function is controlled by the brain, tendon injuries are not peripheral disorders per se but they also have central consequences. This means that the disordered flow of afferent information will lead to an impaired sensorimotor representation of the hand in the brain and by this to a compromised efferent flow of motor commands. In spite of this neuroscientific evidence, clinical studies of these peripheral-central interactions are still rare. An interesting exception may be found in studies on the recovery process following leg amputation. These studies indicate central reorganization of postural control after amputation and rehabilitation. Although studies are scarce, the implications are important since the hand as a prominent effector organ is frequently injured. Tendon injuries and in particular flexor tendon injuries belong to the most common injuries encountered by hand surgeons in the emergency room. The past decades showed substantial improvements of flexor tendon repair so that it became possible to regain normal function after an injury that formerly would have led to a lifelong disability. In spite of the surgical and technical improvements, surgery is still followed by a several-week-period of rehabilitation by intensive occupational therapy and physiotherapy. Now that surgical treatment of flexor (and extensor) tendon injury has virtually reached its technical limits, the question can be raised how to further improve this treatment so that the rehabilitation period can be shortened.

It is an interesting question whether the use of novel motor learning procedures can shorten this rehabilitation period. Such a novel motor learning procedure is termed motor imagery. Motor imagery can be described as the cognitive activity of imagining the performance of a movement without actually performing the movement or even without tensing the muscles. It has not only been shown that motor imagery activates more or less the same brain areas as actual
movement but that it results in learning too. Additionally, there is growing evidence that it may play a relevant role in (neurological) rehabilitation.

The main objective of the present thesis is to determine whether motor imagery during the immobilization period after flexor tendon injury results in a faster recovery of hand function. However, before this objective can be reached, a few questions have to be answered.

**Does peripheral immobilization of the hand after flexor tendon injury result in central changes?**

In other words, what are the effects of the relative immobilization, which patients have to undergo for weeks after tendon surgery, on brain areas responsible for the control of hand function? Due to the impaired afferent flow of information central systems have to adapt. What are the characteristics of this neural adaptation? Chapters 2 and 3 attempt to answer these questions. These chapters describe the cerebral effects of immobilization in a pilot and a larger sample of patients by measuring task-related brain activation with Positron Emission Tomography (PET). Differences between cerebral control of finger flexion immediately after the relative immobilization period after flexor tendon repair (six weeks postoperatively) and again after six weeks of active training are discussed. Our conclusions were substantiated by an additional single patient EMG study. The unique circumstances of dynamic splinting after flexor tendon repair surgery provided a condition with selective deprivation of active flexion movements while voluntary extension movements kept joint stiffness due to tendon adhesions to a minimum. The fact that patients reported clumsiness during performance of purposeful motor tasks, even with fully restored dynamics of passive hand function, further motivated research for a central cause of functional deficit.

However, before drawing any conclusions regarding central functional changes as a result of peripheral immobilization in patients, more should be known about the control of hand function in healthy subjects. Chapter 4 describes a functional magnetic resonance imaging (fMRI) study on the cerebral control of finger flexion and extension in healthy subjects. Unlike extension, flexion requires precision grip, characterized by the exact adjustment of individual fingers to the shape of the target and the coordination of fingertip forces. We therefore hypothesized that higher order motor control principles are more involved in the control of flexion than in the control of extension. At the level of the primary motor cortex, we also studied the distribution of finger movement. Since the 1950s, a somatotopic representation of body parts is well known as Penfield’s homunculus. However, the functional segregation of two opposing movements of the same body part (fingers) does not fit into this somatotopic scheme.

Although PET and fMRI can be used to reveal cerebral control of hand function, these diagnostic measures are expensive, rather invasive and time consuming. Many useful non-
invasive and cheap tools to assess hand function have been described in the past. However, the vast majority measures joint ranges of motion, force and other output-characteristics that reflect the state of the involved effector organ (hand) rather than its cerebral control\textsuperscript{12,22–27}. In general the relationship between the brain and the injured effector organ is neglected. In chapter 5 we consider the duration of the preparation time of finger flexion as a reflection of central control processes. Furthermore we argue that changes in the duration are related to functional recovery.

Chapter 6 describes a newly developed hand function test that is more sensitive to \textit{how} movements are performed rather than the existing result-oriented hand assessment scores. The test measures kinematic parameters related to the drawing of a triangle (as the reflection of a complex multi-joint finger movement) on a graphics tablet.

Chapter 7 is focused on the question whether motor imagery (as a treatment procedure) may play a role in the rehabilitation of hand function after tendon surgery. It is known, that the central control of movements is influenced by the state of sensory feedback\textsuperscript{28}. Proprioceptive inflow may represent the dominant sensory input to the online representation of the body in space\textsuperscript{29}. As was shown, relative immobilization after surgery influences the integrity of the functional control architecture in the brain. It is therefore an intriguing question whether imaginary training (motor imagery) may keep the cerebral representation of the hand intact in spite of the immobilization. In other words, can motor imagery function as a substitute for sensory movement-related information that is disturbed during the relative immobilization-period? The adult somato-sensory cortex is known to alter its maps subsequent to injury\textsuperscript{30}, temporarily as in repaired tendon injuries, or irreversibly as in amputees and paraplegics. It is also known, that cortical plasticity related to chronic pain can be modified by behavioral interventions that provide (novel) feedback to brain areas that were altered by somato-sensory pain memories\textsuperscript{31}.

In the present thesis some evidence is given for the clinical value of motor imagery. Furthermore, the thesis stresses the importance of the notion that peripheral disorders should not be seen as “stand-alone” events, but that they influence central processes. In \textit{functional} terms no strict separation exists between peripheral and central mechanisms.

Chapter 8 summarizes the results of this thesis and provides future perspectives of cerebral reorganization and motor imagery after flexor tendon injury.
Chapter 1

References


