Chapter 8

Summary, conclusions and future perspectives
Cerebral reorganization after flexor tendon repair

At the start of this PhD trajectory, little clinical evidence existed about the cerebral consequences of postoperative immobilization after flexor tendon injury. The pilot positron emission tomography (PET) study presented in chapter 2 demonstrated a clear change in cerebral activation patterns involved in finger flexion. After six weeks of relative immobilization following flexor tendon repair, there was increased parietal (and cingulate) activation. This disappeared after six weeks of active use of the hand. Furthermore, after regaining active control of finger flexion improved skill was associated with prominent putamen activation, which was remarkably low at the initial measurement immediately after the splinting period. In the larger PET study presented in chapter 3, these results were largely reproduced and sharpened. Immediately after the splinting period increased posterior parietal activation was found, although only in left sided injuries. Again, this disappeared after active use of the hand. Changes in activation in the cingulate cortex, however, could not be reproduced in the larger group. The increase in activation in the contralateral putamen which was particularly low in the first scanning session and in the insula increase after active use was confirmed in the larger patient group.

The initial parietal activation was explained to reflect an increased demand on a body scheme representation needed to instruct the appropriate movement\(^1\)^\(^2\). Putamen activity suggests that simple movements have been relearned and that an improved selection of specific muscles are used compared to the first study\(^3\)-\(^7\). Insular activity relates to enhanced efficiency of the related stimulus response associations\(^8\);\(^9\).

In skilled movement, suppression of unwanted muscle contractions is a characteristic feature, in which the basal ganglia play an important role\(^4\);\(^10\). This was supported by our EMG findings which showed insufficient flexor relaxation during serial contraction after six weeks of immobilization, which had resolved after active use of the hand.

Theoretically, one might argue that the absence of putamen activation as we found in the first PET session reflected the normal base-line, while the increased activation in the second session reflected excessive practice. However, in chapter 4 we showed in a functional magnetic resonance imaging (fMRI) study that in healthy subjects, performance of the same ‘double flexion’ task evoked activation of the contralateral putamen. These subjects showed significant bilateral activation in the insula and no significant activation in the parietal cortex, a distribution similar to our patients in the final scan session. Therefore we concluded that a six week period of relative hand immobilization induces a temporary loss of efficient cerebral control of hand movement (characterized by increased cortical demand and reduced striatal involvement).
theoretical drawback of the healthy subject study was that fMRI results were compared to PET results obtained in patients. After fMRI became available for research in our institution, the local ethical committee did not approve a repetition of our PET study with healthy subjects due to the radioactive isotopes administered. Although both PET and fMRI are capable of measuring regional cerebral activation, they are not identical.11

In the fMRI study on hand movement in healthy subjects we further addressed the question whether the control of particularly finger flexion would be more closely embedded in circuitry implicated in purposeful movements, such as grasping compared with finger extension. We found that left hand finger flexion contrasted to extension was related to significant activation in the ipsilateral (left) parietal cortex indicating that flexion demands higher-order motor control mechanisms more than extension.12-17 Moreover subtle differences were found in the activation of the contralateral sensorimotor cortex between finger flexion and extension. Finger flexion extended more lateral to the cerebral convexity where it meets the premotor cortex, while finger extension was found deep in the central sulcus. This gives an extra dimension to the current knowledge of functional segregation of the primary motor cortex. Up to now functional segregation of body parts and proximal-distal segregation was well known18-21, but this is the first time that segregation of antagonizing muscles of the same body part was suggested.

Central aspects of hand function

The main objective of the thesis was to determine whether motor imagery during the immobilization period after flexor tendon repair results in a faster recovery of hand function. While several hand assessment tools currently exist such as questionnaires, range of motion and other functional tests, they commonly do not focus on central (motor) control processes that lead to hand movements.22-25 Instead they focus on the results of a specific performance measure such as subjective satisfaction, force or success rate of a task.

The time that elapses between a stimulus and the start of a movement reflects time required to process and prepare the movement.26,27 Chapter 5 shows the use of a simple preparation time procedure (pressing buttons on a keyboard) to assess hand function. In healthy subjects a high test-retest reliability coefficient was found. Another important finding in healthy subjects was that no difference in preparation time was seen between the dominant and non-dominant hand. This justified the use of results of the uninjured hand as a ‘pre-injury’ state, which implied that worsening and improvement across time could be followed. While healthy subjects showed a learning effect six weeks after the initial measurement, patients after flexor tendon repair deteriorated significantly. This concerned mainly the injured side, but the uninjured side was
also affected. This demonstrated additional support for the fact that immobilization after tendon repair leads to changes in the central control of finger movements. Measuring preparation time gives some insight into these central control mechanisms of finger flexion.

In chapter 6 we introduced another hand outcome test, one that reflects underlying motor control processes\textsuperscript{28-30}. This test records kinematic parameters related to the drawing of triangles on a graphics tablet. In healthy subjects we demonstrated a linear trade-off between speed and accuracy of drawing. This enabled calculation of deviation in drawing for a standard drawing speed, allowing the comparison of different measurements. A high test-retest reliability coefficient was found. We also showed a better performance of the dominant hand over the non-dominant hand, suggesting sensitivity for hand skills. This was further supported by the fact that tendon injury patients performed worse with their operated hand, after six weeks of splinting, compared with their uninjured hand. This difference had disappeared another six weeks later. It was the first time that analysis of kinematic parameters was used for the study of functional recovery after tendon repair.

**Motor Imagery after flexor tendon Injury**

The above mentioned hand function tests and other modalities of hand function were used to determine the effects of motor imagery during rehabilitation after flexor tendon repair (chapter 7). The results indicated that motor imagery indeed improves hand function at the level of central motor control, as reflected by the change in preparation time, while other (more peripheral) modalities remained unaffected. However, subjects in the motor imagery group were more severely injured than subjects in the control group, which may have led to an underestimation of the effects of motor imagery. This factor may be eliminated by a larger study or case controlled study which may also provide more power.

Since motor imagery is primarily a central process it is no surprise that central effects were found while peripheral properties such as muscle strength or range of motion were not affected by it\textsuperscript{31,32}. This is consistent with the results of earlier studies with healthy subjects demonstrating similar effects of motor imagery on preparation time\textsuperscript{31}.

The effective use of motor imagery has already been described several times in rehabilitation after central nervous system disorders\textsuperscript{34-37}, but until now no studies appeared in the domain of tendon surgery.
Conclusions and future perspectives

To conclude, it seems plausible to argue that the obtained central effects of immobilization after tendon repair may be generalized towards all therapies which include immobilization. Therefore, from a neuroscientific viewpoint it is important to prevent immobilization or when this is not possible to minimize the duration of the immobilization period. If immobilization is inevitable due to the nature of the injury, motor imagery may be used as an additional tool to maintain the cerebral organization during the immobilization period to prevent some adverse effects of immobilization by updating the system with ‘offline’ sensory information.

Whether motor imagery may shorten the rehabilitation period needs further research. Due to the long rehabilitation period a shortening of rehabilitation after flexor tendon repair has also clear socio-economical advantages.

At a more basic level, future research might be directed towards unravelling the dynamics of interactions between the basal ganglia and various cortical regions during immobilization. One of the emerging questions is whether, and how, motor imagery may prevent functional deterioration in the basal ganglia. In addition it needs to be demonstrated whether the pattern of cerebral activations related to motor imagery of a distinct movement remains robust during the time this movement cannot be performed as a consequence of the immobilization. In this respect, one may consider serial imaging (fMRI) of healthy subjects and patients after flexor tendon repair comparing motor imagery and a control group.

References


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