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FLEXOR TENDON REPAIR.

REHABILITATION ADHERENCE, OUTCOME, AND COMPLICATIONS.

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Flexor tendon repair. Rehabilitation adherence, outcome and complications.
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“It is not difficult to suture tendons and prepare the ground for sound union. The real problem is to obtain a freely sliding tendon capable of good function”

- Guy Pulvertaft. 1948

POPULAR SCIENCE SUMMARY OF THE THESIS

Rehabilitation after flexor tendon repair in fingers is a balancing act for the patients. They need to move the fingers to recover good hand function but not with too much force as it can lead to rupture of the repaired tendon. To achieve this, patients are recommended to follow a rehabilitation protocol including exercises, restrictive hand use and wearing a protective splint on the injured hand. This balancing act can be hard for the patients while managing their everyday life. About one out of 10 patients need reoperation due to tendon rupture or poor hand function.

Despite the commonness of reoperation and the importance of adherence to the rehabilitation, there is little known about how adherence can be facilitated and what the risk factors for reoperations are. After a flexor tendon repair the outcome is often evaluated in terms of range of motion in the injured finger. The range of motion is then categorized as “poor”, “fair”, “good” or “excellent” based on a classification system. These classification systems have received criticism as they simplify the complexity of the injury. Despite this, there is little known about the relationship between patient-reported outcome and these classifications.

In this thesis we studied different aspects of adherence to rehabilitation, risk factors for complication, and the outcome of flexor tendon injuries with the aim of understanding them better.

In the first study we examined if a smartphone application could help patients follow the recommended home-based exercises during rehabilitation after flexor tendon repair. A total of 101 patients were randomly divided into two groups: one group that received a smartphone application and the other group who only received standard rehabilitation. The results were then compared in terms of adherence, self-efficacy and finger range of motion at two, six and 12 weeks after the tendon repair. We concluded that there was no difference between the groups and that the smartphone application could not improve adherence, range of motion or self-efficacy.

In the second study we interviewed seventeen patients after three months of flexor tendon rehabilitation in the finger. This was done to explore patients experience of rehabilitation in relation to following the recommendations of exercise and restrictive hand use. The result showed us that the patients’ perceptions of the injury, the cost and benefits of rehabilitation, the context and support in managing daily activities all affected how well patients could follow the recommended exercises and use the injured hand in a safe way.

In the third study we assessed factors that could increase the risk for reoperation. We assessed information from the Swedish national hand surgery register (HAKIR) on operation done between 2010 and 2019 on flexor tendons in the finger. We also assessed information from the register, Statistical Sweden (SCB) regarding income and education. We found that about 10% of repaired fingers had secondary surgery and that male sex, injury to the thumb and age above 25 increased the risk of tendon rupture. Injury to both tendons in one finger increased the risk for both finger stiffness and tendon rupture. We also found that patients with higher income had more reoperations due to finger stiffness compared with low-income patients.

In the fourth study we assessed how patients' perception of the outcome corresponded to the most used classification system in the literature. We used information from HAKIR, on patients assessed at three and 12 months after their flexor tendon repair. We found that the patients' perception of stiffness, hand function and satisfaction corresponded to the classifications system but only to some extent.

In conclusion, this thesis shows that patients' adherence is probably affected by their perception of the injury, and perception of the rehabilitation, the support and context during rehabilitation. The smartphone application evaluated could not increase the adherence to home-based exercise. We also showed that male sex, age above 25 and type of tendon injury increase the risk for reoperation. Patients' perception of the result did not correspond well with the most common outcome classification used. Understanding the risk factors, the constructs related to adherence, and patient-reported outcome may give important knowledge to surgeons and therapists when treating patients with flexor tendon injuries.

POPULAR SCIENCE SUMMARY IN SWEDISH. (SAMMANFATTNING PÅ SVENSKA)

Rehabilitering efter en böjsenskada i fingrarna är en balansakt för patienterna. De måste röra på fingrarna för att återfå en god handfunktion men detta kan de inte göra med för stor kraft för det gör så senan går av igen. För att uppnå denna balans rekommenderas patienterna att följa ett rehabiliteringsprogram som inkluderar träning, anpassad användning av den skadade hand samt att bära ett gips eller en ortos. Den här balansakten kan vara krävande för patienterna eftersom de behöver hantera sin vardag samtidigt. Omkring en av tio patienter behöver ytterligare kirurgi på grund av att senan går av igen eller pga dålig handfunktion.

Trots att reoperationer är vanliga och det är av vikt att följa rehabiliteringsprogrammet så vet vi lite kring hur följsamhet kan förbättras och vilka faktorer som ökar risken för reoperation. Resultatet efter en böjsenskada är ofta klassificerat baserad på fingrets rörlighet som ”dålig”, ”rimlig”, ”bra” eller ”utmärkt”. Dessa klassifikationer har dock utstått en del kritik eftersom de förenklar komplexiteten av skadan. Trots detta så finns det lite kunskap kring relationen mellan dessa klassifikationer och hur patienten upplever sin skada.

I denna avhandling studerar vi olika aspekter av följsamhet till rehabiliteringen, risk faktorer för komplikationer och resultatet av böjsenskador med syftet att förstå dem bättre.

I den första studien undersökte vi om en applikation i en mobiltelefon kunde hjälpa patienter att förbättra följsamheten till träningen under rehabiliteringen efter en böjsenskada. Patienterna delades upp i två grupper, en som fick använda en mobiltelefonapplikation och en som fick utföra rehabilitering som vanligt. Sedan jämförde vi de båda gruppernas följsamhet, tilltro till sin egen förmåga samt rörlighet vid två, sex och tolv veckor efter operation. Resultatet visade att det inte var någon skillnad mellan grupperna och slutsatsen blev att applikationen inte kunde förbättra följsamheten.

I den andra studien intervjuade vi 17 patienter efter tre månaders rehabilitering av en böjsenskada. Detta gjorde vi för att bättre förstå patienters erfarenhet av rehabiliteringen i relation till att följa råden som de får. Resultatet visade att patienternas uppfattning av skadan, kostnaden och fördelarna med rehabiliteringen, kontexten och stödet att hantera dagliga aktiviteter påverkar hur de följer råden kring träning och användning av handen.

I den tredje studien studerade vi faktorer som kan påverka risken för reoperation efter böjsenskada. Vi studerade information från det svenska nationella handkirurgiska registret HAKIR och SCB på patienter opererade för böjsenskada mellan 2010 och 2019. Vi såg att 10% av patienterna reopereras och att män, med ålder över 25år och skada på tummen hade ökad risk för reoperation pga att senan gick av under rehabiliteringen. Har man en skada på båda senorna i ett finger ökar det risk för reoperation både pga stelhet och ruptur. Patienter med högre inkomst hade även högre andel reoperationer pga stelhet jämfört med patienter med låg inkomst.

I den fjärde studien undersökte vi hur patienternas upplevelse av fingret förhåller sig till den vanligaste klassifikationen av resultatet efter böjsenskada. Vi använde information från HAKIR på patienter uppföljda vid tre och tolv månader efter operation. Vi såg att patienters upplevelse av stelhet, handfunktion och nöjdhet av operationen hängde ihop med klassifikationen, dock bara till en viss del. När en patient upplever sig mindre stel, eller med bättre handfunktion eller mer nöjd ökar det chansen att de klassificerades högre. Men däremot så stämde detta samband dåligt mellan enskilda steg av klassificeringen.

Sammanfattningsvis så kunde inte mobiltelefonapplikationen förbättra patienternas följsamhet till hemträningsprogrammet. Patienternas följsamhet påverkas troligen av deras uppfattning av sin skada, uppfattningen av rehabiliteringen, samt deras sociala sammanhang och kontexten under rehabiliteringen. Vi identifierade att manligt kön, ålder samt typ av skadad sena påverkar risken för reoperation. Vidare så visade det sig att patienternas upplevelse av sin skada stämmer dåligt överens med den vanligaste klassifikationen av skadan. Att förstå riskfaktorer, den underliggande konstruktionen av följsamhet och patientrapporterade utfall kan ge viktig kunskap till kirurger och terapeuter som behandlar patienter med böjsenskada.

ABSTRACT

Flexor tendon injuries in the finger (zones 1 and 2) are problematic due to high rates of both rupture of the repair and of soft tissue adhesions resulting in poor range of motion. Both complications often result in reoperations and worse outcome of the injury. Rehabilitation after flexor tendon repair is a balancing act for the patient. The exercise and daily activities of the hand need to be at enough force to avoid soft tissue adhesion forming which restrict finger motion but still with low enough force to avoid rupture of the repaired tendon. This creates high demands on patient's adherence while coping with the injury in everyday life. The literature describes the importance of adherence but, there is little evidence in terms of how to improve and understand patient adherence to flexor tendon rehabilitation. Risk factors for the two most common reasons for reoperations have been studied but there is a lack of studies including detailed variables about the repair, the injury and the patient. The outcome after flexor tendon repair is often reported as a classification into a category; poor, fair, good or excellent based on the finger range of motion. This classification could be criticized as being too simplistic for a complex injury, but still there is little known about how the patients´ perceptions of their outcome corresponds to these classifications. The overall aim of this thesis was to improve and explore rehabilitation adherence and outcome, including a smartphone intervention and patients´ perspectives, and to explore complications after flexor tendon repair and rehabilitation.

In paper 1, a total of 101 patients were included at the start of early active motion rehabilitation after their flexor tendon repair. Patient were randomised to rehabilitation with the aid of a smartphone application or according to standard rehabilitation. Patients adherence, self-efficacy and range of motion were then assessed at baseline, and two, six and 12 weeks after repair. There were no overall differences between the groups in range of motion, adherence, or self-efficacy.

In paper 2, Seventeen patients with flexor tendon repairs were interviewed after three months of early active motion rehabilitation. The interviews were then transcribed and analysed according to deductive content analysis based on the health belief theory. The results are described in six categories: perceived susceptibility to loss of hand function; perceived severity of the injury; perceived relationship between cost, benefits and efficacy of rehabilitation; perceived self-efficacy; relationship between patient and practitioner; and external factors.

In paper 3 data was collected from the Swedish national hand surgery registry (HAKIR) and Statistics Sweden (SCB) on a cohort of patients with flexor tendon repair between 2010 and 2019. A total of 1375 patients were identified and followed for at least one year to assess reoperation due to rupture or tenolysis. The result showed that 5% of patients had been reoperated due to rupture and 4.8% due to tenolysis. There was an increased risk of rupture in

male patient, age above 25 and in patients where the FPL tendon had been repaired. If both the FDP and FDS tendons were repaired, it increased the risk for both tenolysis and rupture. With increasing income, the frequency of tenolysis increased.

In paper 4 we collected data from HAKIR on patient with flexor tendon repair between 2010 and 2020. We then used data on patients with a complete set of data from the patient questionnaires and functional assessments of range of motion at three and 12 months after repair. The patient questionnaire included the HQ-8, Quick-DASH and perceived satisfaction with results. We assessed 215 patients at three months after repair, and 150 patients at 12 months. We calculated the association between patient reported outcome and the Original Strickland classification. As perceived stiffness increased the OR of being in a higher Strickland level decreased, although perceived stiffness could only discriminate between the independent levels of fair and good. An increased Quick-DASH score decreased the OR of being in a higher Strickland level, although only between fair and poor results at three months. As perceived satisfaction with result increased, the OR of being in a higher Strickland level also increased. But perceived satisfaction could only discriminate between the levels of fair and good at twelve months.

In conclusion, the smartphone application did not increase the adherence, self-efficacy or range of motion during the first three months of rehabilitation. Patients' perceptions of the injury, the rehabilitation, and the context and support during rehabilitation affects adherence. Several risk factors were associated with reoperation due to rupture or tenolysis, namely male sex, age above 25, injury to FPL or both FDP and FDS. Patient-reported outcome only corresponded with some independent levels of Strickland and the classification of range of motion into poor, fair, good and excellent may thus add little value to the patients. Understanding the risk factors, the constructs related to adherence and patient-reported outcome may give important knowledge to surgeons and therapists when treating patients with flexor tendon injuries.

LIST OF SCIENTIFIC PAPERS

I. **Svingen J**, Rosengren J, Turesson C, Arner M. A smartphone application to facilitate adherence to home-based exercise after flexor tendon repair: A randomised controlled trial. Clinical rehabilitation. 2021;35(2):266–75.

II. **Svingen J**, Arner M, Turesson C. Patients' experiences of flexor tendon rehabilitation in relation to adherence: a qualitative study. Disability and rehabilitation. 2022;1–9.

III. **Svingen J**, Wiig M, Turesson C, Farnebo S, Arner M. Risk factors for reoperation after flexor tendon repair: a registry study. J Hand Surg Eur Vol. 2022 May 17:17531934221101563. doi: 10.1177/17531934221101563. Epub ahead of print. PMID: 35579214.

IV. Renberg M, **Svingen J**, Arner, M, Farnebo S. Patient reported outcome and their association to the Original Strickland classification after flexor tendon repair. *Submitted manuscript*

CONTENTS

LIST OF ABBREVIATIONS

A1-A5	Annular pulleys
AISEQ	Athletic Injury Self-Efficacy Questionnaire
ADL	Activities of daily living
DASH	Disability of the Arm, Shoulder, and Hand questionnaire
DIP	Distal interphalangeal
FDP	Flexor digitorum profundus
FDS	Flexor digitorum superficialis
FPL	Flexor pollicis longus
HBM	The Health Belief Model
HAKIR	The Swedish National Health Care Registry for Hand Surgery
HQ8	HAKIR questionnaire 8
ICF	International Classification of Functioning
MCP	Metacarpo phalangeal
MCID	Minimal clinically important difference
MHQ	Michigan Hand Outcomes Questionnaire
OR	Odds ratio
PIP	Proximal interphalangeal
PROM	Patient-Reported Outcome Measure
ROM	Range Of Motion
SIRAS	Sport injury rehabilitation adherence scale
TAM	Total active motion
Quick-DASH	Short version of Disability of the Arm, Shoulder, and Hand questionnaire.

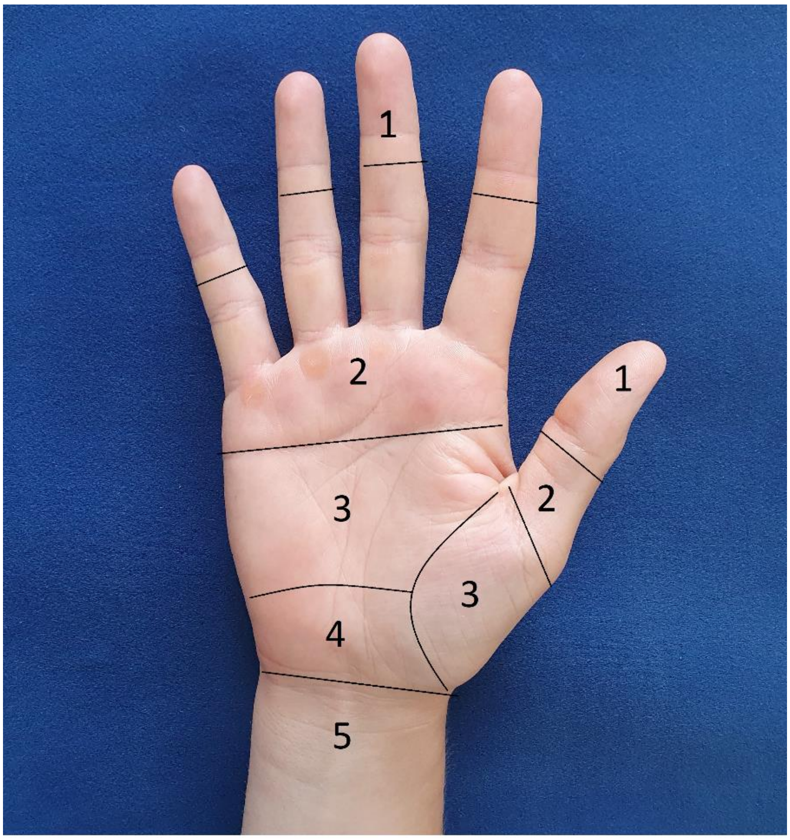
FLEXOR TENDON INJURIES

1 BACKGROUND

The first reported tendon repair was performed in the tenth century by the surgeon Avicenna (1). However, until the 17th century tendon surgery was rarely performed because nerves and tendons were regarded as the same structures. In the early 20th century flexor tendon surgery is more frequently described in the hand, mainly using tendon grafts (2). At this time poor results were common, and adhesions were a big problem. In 1948, Sterling Bunnell in the US first published the term “no mans´ land” for describing injuries of flexor tendons in the tendon sheath region. In a study by Haugen 1955, 94 of 98 repaired flexor tendons in zone 2 had regained no function at all (3). In the second half of the 20th century primary repair of flexor tendons using an early start of post-operative mobilisation began to revolutionise outcomes. Around the same time objective measurements of outcome were suggested (4). Using stronger suture techniques for tendon repairs, post-operative rehabilitation regimes became more and more aggressive. Early mobilization of a tendon repair however imposes higher demands on patients´ adherence to instruction, including necessary restrictions on hand use and exercises. There are few previous studies on adherence although its importance in order to reach good results and minimise the rate of complications.

The human hand has a complex anatomy that creates fine motor and sensory skills that are essential for everyday life. The muscles in the hand can be divided into intrinsic and extrinsic muscles depending on their origin. The hand has three extrinsic flexor tendons that control flexion in the interphalangeal joints of the fingers. The flexor digitorum profundus muscle (FDP) has its origin on the proximal part of the ulna, the deep facia and the interosseous membrane and insert on the distal phalanges of dig II-V. The FDP muscle flexes both the distal interphalangeal (DIP) joint and the proximal interphalangeal (PIP) joint. The flexor digitorum superficialis (FDS) has four separate muscle bellies that originate from the distal ulna, the radius and the medial epicondyle of the humerus. The FDS tendons insert on the middle phalanges and the main action is flexion of the PIP joints. The flexor pollicis longus (FPL) muscle has its origin on the volar side of the radius and inserts on the distal phalanx in the thumb. Its main action is flexion of the interphalangeal (IP) joint of the thumb. The FPL muscle has also been reported to be a primary mover of the MCP joint (5). At the level of the metacarpo phalangeal (MCP) joints the tendons enter an intrasynovial sheath that lubricates the gliding surface of the tendon and provides nutrition. In the same area the tendon is held close to the bone by a pulley system constituted of five annular pulleys (A1-A5) and three cruciate (C1-C3). During normal range of motion (ROM) the tendons glid 32-24mm (6), which creates 260 degrees of motion in the three finger joints (7).

The mechanism of injury is most commonly a sharp cut on metal or glass (8). The injury can be divided into five zones depending on location of the injury and the surrounding anatomy (Picture 1). Zone one is between the insertion of FDS and insertion of FDP, zone two between the MCP joint and the insertion of FDS, zone three between the MCP and the carpal ligament, zone four between the carpal ligament and the radiocarpal joint and, zone five proximal to the radiocarpal joint. Injuries in zone 2 are the most common (9) and this is also the area receiving most attention in the literature. There is also a more recent injury classification that divides zones one and two into seven subzones based on the location of the pulley system (10). This thesis will concentrate on flexor tendon injuries in the finger level (zones one and two).



Picture 1. Flexor tendon zones.

The healing flexor tendon undergoes three stages, inflammation: proliferation and remodeling which overlap each other. The Inflammation stage occurs during the first week. Macrophages and fibroblasts infiltrate the injury site with subsequent phagocytosis of the tissue. The proliferative stage occurs after a few days to one month after injury. Tenocytes mostly creates collagen 3, which is mechanically inferior to other collagen types. The remodelling stage normally starts between one and two months after repair. Collagen 1 then starts to become dominant, and the extracellular matrix begins to align (11, 12).

Tendon healing can be described by two mechanisms, intrinsic and extrinsic. Intrinsic healing occurs through cell growth within the tendon. Extrinsic healing comes from outside the tendon through an inflow of cells and nutrients from the sheath and the surrounding area. Research has suggested that the extrinsic process starts earlier and is more reactive (12). A dominance of extrinsic healing has been described to lead to more adhesions (13). Adhesions represent a more common problem after intra synovial flexor tendon repairs (zone 2) and mechanical load is important in reducing them (14). These biological factors create the rationale for early mobilisations regime after flexor tendon repair.

The incidence of traumatic tendon injuries in the hand is 33 in 100 000 per year in the United states (9). For complete flexor tendon injuries without fractures the incidence was seven in 100 000 every year in a population in northern Finland (15). The injury is five times more common in men and can happen at every stage in life. The mean injury age is 35-39 years (15, 16). A flexor tendon injury entails a substantial cost for both the health care service and society (144000SEK in 2003), and it increases by 57% in the case of reoperation (17).

1.1 FLEXOR TENDON REPAIR

During the last few decades there has been a substantial amount of research on different aspects of flexor tendon repair. This has led to considerable improvements of the suture strength. Despite the increased knowledge, there is an ongoing debate regarding the ideal method to suture a flexor tendon (18). According to Strickland, the ideal suture should be easy to perform, have secure knots with smooth junctions, create minimal gapping between the tendon ends, and minimal interference with the vasculature, as well as have sufficient strength to allow early exercise without rupture (19). To achieve the ideal suture, several factors could be considered; repair or resection of the FDS and annular pulleys, the number of strands, the core suture technique, suture diameter and number of knots, the configuration of the peripheral repair, the suture purchase, the tension of suture (20). At least four strands for the core suture is generally recommended in the literature (20), although a review concluded there was no difference in rupture rate between a two- strand or multi-strand techniques due to the heterogeneity in the research (21). A release of the second annular pulley (A2) is safe in terms of tendon bowstringing (22) and reduces the tendon gliding resistance (23), it is recommended if needed (10). A tendon purchase of at least one centimetre has been shown to increase strength compared to shorter ones (24, 25). A great variety in suture techniques is described in the literature (26), which makes comparisons between studies difficult.

1.2 FLEXOR TENDON REHABILITATION

Just as for the tendon repair techniques, rehabilitation after flexor tendon injuries has developed during the last few decades. Rehabilitation often starts within the first few days after repair with regular finger exercises. This has been shown to improve range of motion (27) and improve tendon strength (28). The incentive for an early start is to produce enough tendon excursion to minimise the adhesion formation created during healing. There are many different rehabilitation protocols in use (29) but no real consensus regarding which is the optimal (30). The large number of different protocols in the literature makes it practically impossible to list them all in this thesis, but they can be divided into three groups. Passive flexion exercise by a rubber band (Kleinert method) connected to the injured finger or by the patient using the uninjured hand (Duran method) (31) (32). This makes the flexion passive and extension passive or active. ´Place and hold´ includes passive flexion done by the patient with the uninjured hand and an active hold of the finger in the flexed position (33). Early active motion includes active flexion of the injured finger (34). Local culture at the hand units probably influences the choice of rehabilitation protocol.

The protocols in the literature have developed over the years from passive exercises to more active regimes with active flexion that sometimes also includes wrist motion during the first weeks. An active component in the exercise has been shown to be beneficial for range of motion but may increase the rupture rate (30, 35-37).

Active flexion exercise has convincing incentives in theory as it creates more tendon excursion compared to passive (38, 39). This is suggested to decrease adhesion and may be the reason for improved ROM. However, the association between tendon excursion during rehabilitation and final ROM has been debated. An animal model comparing 1.7mm tendon excursion with 3.6mm did not result in any significant difference in ROM, adhesions or gapping of the repair (40). However, there is still a lack of studies of high quality from which to draw reliable conclusions. A recent Cochrane review of rehabilitation interventions after flexor tendon repair concluded there was a lack of evidence to suggest any rehabilitation approach to be superior (41).

Common to all protocols is some degree of restricted hand motion during the first four to six weeks with a cast or a splint. The hand is positioned with flexion in MCP and straight IP joints. The wrist historically was placed in a flexed position, but there are reports of protocols that use a more extended immobilisation position (42) or no mobilisation at all (43).

Picture 2. A patient with cast immobilisation typically used at our department during the first four weeks of rehabilitation.

Protecting the hand with the wrist in an extended position has been shown to lower the force needed for flexion (44, 45). A review regarding unrestricted wrist motion during rehabilitation concluded there was insufficient evidence to draw any conclusions (46). Patients are recommended not to use their injured hand during the period of cast or splint protection to avoid overloading the repaired tendon and causing rupture. From around six weeks after the repair the patients is recommended to gradually increase the load on the injured hand. Patients are not recommended to fully load their hand until 12 weeks after the repair. A consequence is often that the patients are unable to manage their household task without difficulties, manage their own hygiene, drive a car, participate in leisure activities or take care of others (47). Because of the consequences, patients may experience a change in their life roles after a traumatic hand injury (48). Patients can cope with a traumatic hand injury differently (49), but the process of coping with flexor tendon rehabilitation while managing their own life is demanding for them. In a qualitative study by Fitzpatrick the patients reported struggling to cope with the pain and restrictive hand use (50). Patients meet an occupational therapist or physiotherapist who guides the rehabilitation and coping process during regular visits. The level of experience of the therapist is important as it has been shown to influence the ROM and satisfaction after flexor tendon repair (51).

Exercise is recommended to start four to seven days after the repair to avoid the initial increase in oedema within the first days which creates resistance to movement (52). The ratio between suture strength and the force needed for motion suggests that five days after surgery is the best time to start (53). The force needed for finger flexion reduces with each repetition, and because of this, the first flexion exercises are recommended to be done passively (54). The main body of research on rehabilitation has been done on the protocols used during the first weeks, few studies exist on the components of the duration and frequency of exercise within the protocols. A wide range of recommendations regarding the components of exercise is in use, from 20-30 repetitions four times a day (55) to fewer exercises every hour (56). There is little evidence to suggest which frequency and duration is optimal. Gelberman compared 12000 repetitions of passive exercise 75 hours a week with 1000 repetition four hours a week and showed a significantly better range of motion in the high repetition group (57). Takai compared passive exercise for 60min/day with 5min/day with the same number of repetitions, and showed a higher tendon strength with higher frequency (58). Most departments of hand surgery in Sweden use early active motion protocols during the first four weeks of rehabilitation. This includes a number of passive repetitions of flexion followed by active flexion and extension in the fingers.

1.3 COMPLICATIONS AFTER FLEXOR TENDON REPAIR AND REHABILITATION

Complications after flexor tendon repair is a recognised topic in the field of hand surgery. A reason is that tendon repair in the intra synovial sheath is technically difficult due to the delicate balance between tendon healing and gliding. Different complications have been described (59) but adhesions and tendon ruptures are the most common and the main reasons for reoperation (60).

Ruptures are often reported in the literature along with the end results of the repair but there are few well-designed studies reporting reasons or risk factors for ruptures. One reason for this may be the large volume of data needed to draw conclusions as the incidence is reported to be around 4% (61, 62). Research on causes of rupture has been linked to poor adherence regarding restrictive hand use (63). Dy reported that core suture techniques or the presence of an epitendinous suture did not influence the rupture rate (61). Shepard reviewed the influence of time between repair and start of rehabilitation in a cohort of 3501 patients and concluded that an early start (within the first seven days) did not influence the rate of reoperations caused by rupture or tenolysis (64). The influence of the time between injury and tendon repair on outcome has been debated (65). In a study by Reito, a delay of more than three days and the mechanism of injury (cutting vs high energy) were associated with complications (66). The injury mechanism involving a saw has similarly been shown to increase the risk of reoperation but not the rupture rate (67).

Adhesions between the tendon and the surrounding tissue can be diagnosed as a substantial discrepancy between active and passive ROM (68). However, there is no clear definition of the level of discrepancy. Adhesions may require secondary surgery with tenolysis but not in all patients. A decision on whether to perform a tenolysis or not is made during a consultation between the surgeon and patient, and not all patients with poor results want to have a tenolysis (69). Tenolysis rates between 3.5 (60) and 14.4 (70) percent have been reported. In a study by Rigo (62) several factors negatively affected ROM, namely; age, smoking, injury localisation, extent of soft tissue or skeletal injury, delay to surgery, and surgical management of the pulley system and the FDS. Edsfeldt (16) reported that higher age influenced ROM one year after repair of flexor tendons.

1.4 ADHERENCE

Adherence and compliance are two common concepts used to describe the degree to which patients' behaviour corresponds to medical advice. These two phrases have been used interchangeably in the past, with similar definitions (71, 72). However, there has been a shift from compliance to adherence, where the definition of adherence has also shifted to more focus on the active participation by the patient, as a resource in a partnership with the health care worker (73). To highlight this, The World Health Organization in 2003 (74) changed their definition of adherence from *"the extent to which the patient follows the medical instructions"* to *"the extent which a person´s behaviour corresponds with agreed recommendations from a health care provider"* . If this general concept of adherence should be explained in terms of rehabilitation after flexor tendon repair, it should be the extent to which a person´s behaviour – wearing a protective splint/cast, adapting hand use, following exercise instructions, corresponds with agreed recommendations from the health care provider, often a physiotherapist or/and an occupational therapist. Exercise adherence can be viewed from the different dimensions of exercise (75). These dimensions is linked to the recommendation of exercise which is given with a certain level of sets, repetitions, force, and joint motion. This corresponds to the quantity and quality of exercise. Similar dimension could be applied on protective splint wear and adapting hand use. For instance, how often is the splint removed and for how long, and what are the level of force on the injured hand during activities.

Despite the shift to adherence, this concept has also been under debate and criticism, which has contributed to the establishment of the term 'concordance'. The concept of concordance builds on respect for the patient's agenda and highlights the interaction with the patient as a negotiation between equals in an alliance that may result in a mutual agreement (76). But the concept of concordance is not like adherence and compliance as it focuses on the consultation process and not the behaviour after treatment. Concordance has been suggested to be synonymous with patient-centred care, and to be a way to improve and understand adherence (77). Concordance has implications during the rehabilitation of flexor tendon injuries but the time limits during appointments and the lack of research in the field, together with the fact that some restrictions during rehabilitation has an adherence nature makes the implication more difficult (78). The term 'adherence' will be used hereafter in this thesis.

When a behaviour does not correspond to the agreed recommended behaviour, it is defined as non-adherence. Non-adherence can be divided into two dimensions; purposeful and unintentional (79). The difference between the two depends on the patient´s awareness of the behaviour, if the patient is aware that his or her behaviour does not correspond to the agreed behaviour, then it is purposeful, if not then it is unintentional. This is of importance because it tells us something about the underlying reason for non-adherence and to understand the reason is the first step in trying to help patients become more adherent. It has been shown that therapists and patients' views of the underlying reasons for non-adherence can differ. The therapist often describe that the patient forgot the instructions, was unsure of what to do or had difficulties reading the programme, while patients describe time management and high pain levels as larger problems (80). Although adherence has received much attention in research the field is not unproblematic. There is no uniform definition of adherence, although the definition used by WHO has been used frequently in recent years and there is no uniform way of measuring adherence.

1.4.1 Understanding adherence

As describe above, adherence is a very complex behaviour phenomenon, with countless potential reasons and explanations for its occurrence. In trying to understand and explain a behaviour, a theory can be useful. In the field of health behaviour, the role of a theory is to explain the components of when, how and why a behavior does and does not occur, and, which potential ingredients should be targeted to influence the behaviour (81). In terms of rehabilitation after flexor tendon repair this could be translated to explain for example when, how, and why a patient protects their repaired tendon with a splint/cast or adapts hand use and does regular exercises. Basically, trying to explain a patient´s behaviour during the rehabilitation. The effectiveness of a theory in explaining a behaviour is dependent on the type of theory and behaviour. There are many theories regarding health behaviour and the literature regarding whether interventions based on theory are better or not is conflicting (82).

The Health Belief Model (HBM) has a long history and has been influenced by the work of psychologist Kurt Lewin (83). Briefly, the theory explains a person's health behaviour as influenced by the perception of the domains in the model. These are the seriousness of the health risk, susceptibility to the health risk, and the benefits and the cost of the behaviour (83). The domain of self-efficacy was later added to the model and explains that persons with higher self-efficacy will be more likely to carry out the risk reducing action compared to those with low self-efficacy (84). Self-efficacy can be defined as the patients´ perception of their own capability to attain and succeed at a certain level of performance (85). The HBM was later adapted for rehabilitation of hand injuries by Groth (86) including the following factors; perceived susceptibility for loss of hand function, perceived severity of the hand injury, perceived efficacy of rehabilitation, perceived relationship between cost and benefits of rehabilitation, self-efficacy, and the patient -practitioner relationship.

1.4.2 Measuring adherence

There is a lack of adherence measurements (87, 88) for home-based exercise that have been tested for validity and reliability, which makes it hard to compare research. In a few diagnoses there are validated measures, such as for low back pain (89) and dizziness (90). The sport injury rehabilitation adherence scale (SIRAS) is valid and reliable to test adherence during a clinical physiotherapy session after knee surgery (91, 92), and musculoskeletal rehabilitation (93). In the hand rehabilitation context of measuring adherence, different measures have been used. Self-reported duration and frequency of exercise which is then compared to prescribed exercise to gain an adherence frequency (94). Attendance at therapy sessions as number of missed appointments (95). Exercise diaries where patient fill in there duration and frequency of exercises done during a day or week (96). Self- developed questionnaire regarding the therapist assessment of the patients exercise performance (97). The relevance of measuring adherence during flexor tendon rehabilitation is not only related to exercise, but also to restrictive hand use and orthosis use. There is no validated method to measure adherence to orthosis use and there is great inconsistency in the literature (98). One example of method used is self-reported questionnaires (99, 100). After a rupture, researchers have explained the behaviour that might have led to the rupture as non-adherent based on excessive hand use compared to the recommended restriction (43, 63). Although there are ways to assess adherence to rehabilitation after hand injuries the lack of standardisation is problematic, and the different ways in which adherence has been measured should be considered when interpreting results.

1.4.3 Impact of adherence

The effect of adherence should not be underestimated in health care in general as it is an important aspect of the effectiveness of almost all interventions. The impact of adherence has been described extensively in different health-related domains. A meta-analysis showed that the probability for a good health outcome was three times higher in adherent patients compered to non- adherent (101). Adherence decreased the risk of cuff tears after arthroscopic shoulder repairs (102). Kolt found that adherence were associated with outcome after low back pain rehabilitation (103). Research regarding the impact of adherence on rehabilitation after hand surgery is scarce. A study of 44 mallet finger injuries found that patients in the compliant group had 50% more cases with excellent outcome compared to patients in the noncompliant group. Lyngcoln et al assessed three different adherence scores (attendance, home-exercise and the SIRAS) and their association with outcome after distal radius fractures. They concluded that adherence explained 57% of hand function scores and 52% of wrist extension (96).

The causality between adherence to flexor tendon rehabilitation and outcome has not been established although the topic has been much discussed in research and by health care workers, often explaining tendon rupture and poor outcome as due to non-adherence. Toker showed that the number of therapy sessions after flexor tendon injuries correlated to range of motion, and that increasing the number of sessions improved outcome (104). Harris et al explored the cause of rupture in 440 patients with flexor tendon injuries in zone two and found that about half of the ruptures had happened after non-adherent behaviour regarding restrictive hand use (63). Su reported similar causes for ruptures (105). Gelberman compared two groups, (low and high duration of exercise) after flexor tendon injury in zone two and concluded that higher duration of exercises improved range of motion (57). Takai showed that a greater frequency of exercise after tendon repair improved healing properties of the tendon (58). This indicates that adherence to recommendations regarding sufficient duration and frequency of exercise, and adaptive hand use, and attending therapy sessions is beneficial for the outcome after flexor tendon repair.

1.4.4 Improving adherence.

Research with the aim of improving adherence has used a complete health behaviour theory, ingredients of health behaviour theory or interventions unrelated to theory, such as different ways to give information. Regardless of approach, research in this field is not unproblematic since there has been a lack of a uniform definition of the interventions used in behaviour change interventions (106). With the aim of improving this and providing a standardised way to describe interventions for behaviour change, Susan Michie et al, developed a taxonomy in 2013 describing 93 components of behaviour change techniques (107).

A systematic review of interventions to improve adherence in upper limb conditions found evidence that self-efficacy improves adherence in chronic conditions (108). A systematic review of splint wear in acute upper limb conditions found a positive correlation to adherence in patients with perception of a positive effect of the splint (109). A total of 67% of patients have been reported to remove their protective splint during tendon rehabilitation which correspond to a non-adherent behaviour regarding protective splint use (100). Savas (99) reported the same, 67% of patients were non-adherent or partially adherent to splint use after extensor or flexor tendon injury. In most cases, the reasons why a patient removes the splint is to manage hygiene and activities of daily living (ADL) (100). Patients are also more likely to remove the splint if they feel that it is too complex compared to their perception of the injury (110) or if they have depressive symptoms (99). Suggestions on how to improve adherence to splint wear are to make the patients more informed about their injury and treatment (110), include information about how to handle ADL (111), and identify depression symptoms early (99).

The role of smartphone application in hand therapy interventions have been discussed (112, 113). The technical possibilities in smartphone applications have several potential advantages in terms of increasing rehabilitation adherence. Smartphone applications can provide exercise feedback based on performance and data collected from till patient. There is some promising research regarding the ability to increase adherence in rehabilitation after acute hand injuries (114), but there is no smartphone application for flexor tendon rehabilitation known for the author.

In general, research regarding adherence in upper limb conditions is scarce and more research is needed regarding how to improve adherence after flexor tendon repair. In physiotherapy, strong evidence has been found that intention to engage, self-efficacy, self-motivation, social support and previous adherence can predict adherence to home-based physiotherapy (115). Barriers for adherence in patients with musculoskeletal disorders include low levels of physical activity, low self-efficacy, psychological conditions such as depression and anxiety, and, low social support (116). Potential ways to improve adherence for prescribed self-management strategies in physiotherapy are written exercise instructions, a behaviour exercise programme with a booster session and goal setting, as well as activity monitoring and feedback (117).

1.5 OUTCOME OF FLEXOR TENDON REPAIR AND REHABILITATION

There is no consensus on the core outcome set after flexor tendon repair, although suggestions have been made (118). In the past, there has been an emphasis on clinical assessment of ROM and strength. The ROM is often classified into a categorical scoring systems when reporting of results. For the patient, their perceived disability after a flexor tendon repair may be of more importance than clinical assessments. Patient reported outcome measures (PROMs) are often collected via questionnaires where the patients can answer without involvement of the health care. Although PROMs are an important part of the outcome, the use of them is low in comparison to the classification of ROM (119, 120).

1.5.1 Clinical outcome.

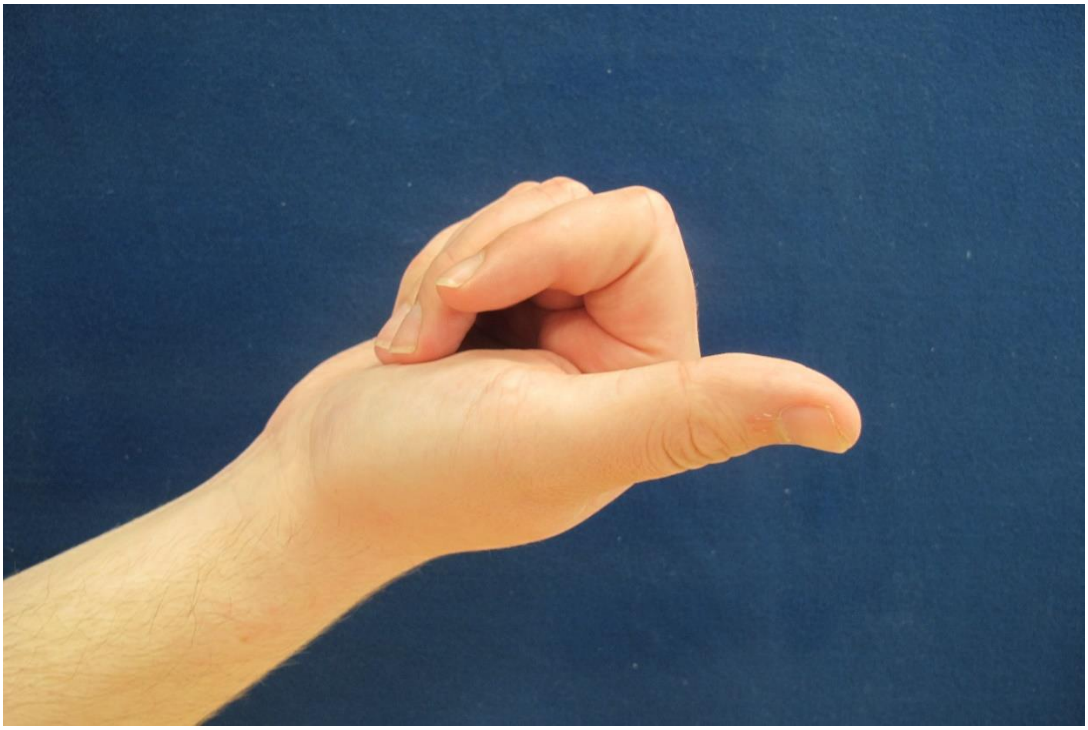
The most frequently used clinical outcome after flexor tendon injuries is ROM in the injured finger (119, 120). Outcome in terms of ROM can be reported separately for flexion and extension in each finger joint (121) or as a total (62), combining several joints into total active motion (TAM). There has been discussions on how to evaluate and report outcome after flexor tendon repair (122). However, there is still no consensus. TAM is frequently classified into ordinal categories of poor, fair, good or excellent based on classification systems. There are several classification systems in use; the original Strickland (27), adjusted Strickland, Buck-Gramcko (123), the Louisville (124), The American society for hand surgery (ASSH) also known as the TAM system (122), The International Federation of Societies for Surgery of the Hand (IFSSH) (125) and the Tang criteria (55). These classification systems may show different results in terms of poor, fair, good and excellent results (126-128), which makes the comparison of studies difficult.

The original Strickland classifications are widely used (35, 129) and are together with the Buck-Gramcko and ASSH classification considered to be the most commonly used (119) (36). The Original Strickland classification includes the TAM for PIP-joint (active flexion minus – active extension) and DIP-joint (active flexion minus – active extension) which is then divided by 175 to give a percentage score (Table). The Buck-Gramcko system can be considered more complex for clinical use as it includes a score of extension deficit, distance finger to crease and TAM. The ASSH criteria compares the TAM of the injured finger before and after surgery or to the same finger on the uninjured hand to give a percentage of normal. There are reports of between 69 – 90% of patients having good or excellent results (129) according to the original Strickland classification. The assessment time after a repair can differ between studies from six weeks to several years (35). Probably it affects the percentage of patients that is reported in different categories as the ROM has been reported to increase up to two years after repair in some patients (16). To classify the TAM into a rating scale has received some criticism because the classification has not been validated, and by converting a continuous variable into a ordinal one you probably loose information (130).

Table 1. The Original Strickland classification

Score	% of 175
Poor	<50
Fair	50-69
Good	70-84
Excellent	85-100

A strength measurement is reported to be used in 20% of the research as a clinical outcome measure after flexor tendon repair (119). One of the most used methods for strength assessment is grip strength using a Jamar dynamometer. The testing procedure is reliable for flexor tendon injuries (131) and standardised to be done with the elbow at 90 degrees of flexion, the wrist in a neutral position, and using the Jamar handle at the second position (132). During the first six months, patients recovered 81-89% of the strength of the normal side (133, 134). A less frequently used strength measure after flexor tendon repair is pinch strength. Su et al, reported pinch strength of 78-81% of the normal side at six months after repair (105). Other clinical assessments after flexor tendon repair have also been used such as, sensory assessment (127, 135), measures of swelling (134), and functional tests (136), but these are uncommon.



Picture 3. A patient classified as poor according to the Original Strickland classification at 12 months follow-up post repair of a FDP and FDS injury in the index finger.

1.5.2 Patient-reported outcome.

A wide variation of PROMs have been used after flexor tendon repair (119). To date there are no validated measures of PROMs specifically for flexor tendon repairs (137). A systematic review of outcomes linked to the International Classification of Functioning (ICF) showed limited reports of outcome in the domain of activity and participation (138).

The Disability of the Arm, Shoulder, and Hand (DASH) questionnaire is most frequently used when reporting PROMs after flexor tendon injuries in the literature (119, 120). It is also the PROM that is most clinically used by therapists (139). The DASH questionnaire constitutes of 30 items regarding the patient's disability and symptoms. The answers are the calculated to a total score between zero (no disability) and 100 (severe disability). The DASH questionnaire could be regarded as too unspecific for flexor tendon injuries because it was developed to evaluate disability in the whole upper extremity. Nevertheless, DASH has been validated, and tested for reliability and responsiveness in a traumatic hand population (140). Scores have been shown to moderately correlate to perceived finger function after flexor tendon repair (127). There is a shorter version of the questionnaire, the Quick-DASH which contains 11 items (141) and has similar psychometric properties as the DASH (142). The DASH and Quick-DASH scores after flexor tendon injuries are probably affected by assessment time, location, age and type of injury. Mean DASH scores between five and eight have been reported two years after flexor tendon repair in zone 1-5 (127, 128, 143). Starnes reported DASH scores of 12 and 16 depending on the type of injury (67). These scores are still all below or within the mean values of 13 in a healthy population (144). Minimal clinically important differences (MCID) have not been reported for flexor tendon injuries but have been reported to be 6.8 in a non-shoulder population (145) and 10.8 for DASH in an upper limb population (146). Although most research reports DASH values within or below the normal population there are reports of higher values. Kitsis reported a mean DASH score of 29.6 in patients treated with early active motion and 41.7 in patient treated with passive motion at 12 weeks after tendon repair (133).

Another PROM that has been suggested for use after finger injuries is the Michigan Hand Outcome Questionnaire (MHQ) (118). The MHQ has been used after flexor tendon injuries but not frequently (147), and the same goes for ABILHAND (136). Compared to the DASH the MHQ has some potential benefits. It differentiates the answers between hands, and it includes more activities that represent finger function.

Pain after flexor tendon repair is not frequently reported in the literature and is often described as a minor problem. In a study by Su et al (105), patients reported a mean of 0.5 on a numeric rating scale (0-100) 12 weeks after repair. Koehler reported no pain at a mean 34 months after repair on the Visual Analog Scale (143). Scar sensitivity and sensitivity to cold were reported in 32% and 47% of patients in a study by Riaz (148). The sensitivity is probably related to a concomitant digital nerve injury which is common (15). Although this relation, a flexor tendon injury has been shown to increase cold sensitivity symptoms after digital nerve injury (149).

The Swedish national health care registry for hand surgery (HAKIR) was developed in 2010 and collect PROMs at three time points (150). Before surgery, at three months and at 12 months after surgery. The PROM questionnaire consists of eight questions on symptoms (HQ-8) on an 11-point Likert scale ranging from zero (no-problems) to 100 (worst problems imaginable), and the Quick-DASH. The HQ-8 have been tested for validity (151). HAKIR enables a unique possibility to assess PROMs after surgery and it has been used after nerve disorders (149), trapeziectomy (152) and phalangeal fracturs (153) but not after flexor tendon repair.

Using PROMs has several advantages. They can help therapists understand the patient's situation and thereby promote a more client-centred practice. They have been shown to correspond to the length of sick leave after radius fracture (154), and they are better predictors of sick leave than clinical outcome (155). PROMs also correlate better with satisfaction with results after surgery (156). There is a need for better understanding of PROMs after flexor tendon repair and of their relation to the classification systems used.

2 RESEARCH AIMS

The overall aim of this thesis was to improve and explore rehabilitation adherence and outcome, including a smartphone intervention and patients´ perspectives, and to explore complications after flexor tendon repair and rehabilitation.

The aims of the specific papers were:

1. To explore a new and specifically designed smartphone application for flexor tendon rehabilitation and the effect on adherence to home-based exercise, self-efficacy and finger range of motion.
2. To explore patients` experience of flexor tendon rehabilitation in relation to adherence and the outcome of rehabilitation
3. To identify factors affecting the frequency of reoperations due to tendon rupture or adhesions, in a large cohort of patients operated with flexor tendon repair in zones one and two.
4. To examine the relationship between patient-reported outcomes, Strickland classification and satisfaction with treatment in patients after flexor tendon repair in zones one and two.

3 MATERIALS AND METHODS

POPULATION.

All papers included data on patients operated with a complete flexor tendon injury in zone one and two (Table 2). The specific inclusion criteria were patient rehabilitated with early active motion protocol (papers 1 and 2), patients fluent in Swedish (papers 1 and 2), patients owning a smartphone (paper 1). Exclusion criteria were concomitant fractures and extensor tendon injuries for all papers. Specific exclusion criteria were injury to the FPL tendon (papers 1 and 4), patients aged under 18 years (papers 1 and 2), patients aged under 16 (paper 4).

Table 2. Overview of paper 1-4.

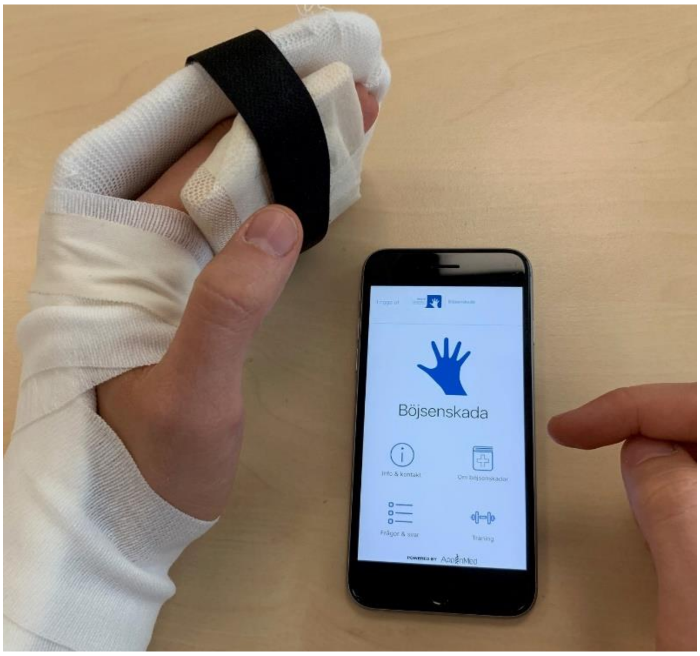
	Paper 1	Paper 2	Paper 3	Paper 4
Study design	RCT	Qualitative	Retrospective cohort	Retrospective cohort
Inclusion time	2017-2019.	2018-2019	2010-2019	2010-2020
Follow-up post repair	3 months	3 months	>12 months	3 and 12 months
Number of patients	101	17	1372	215 and 150
Patient identification method	Clinical	Clinical	HAKIR	HAKIR
Data collection	Adherence (SIRAS, self assessed), active ROM and self-efficacy (AISEQ)	Transcribed interviews	HAKIR and SCB data. Reoperations due to rupture or tenolysis	Strickland classification, HQ-8, Quick-DASH. Satisfaction with results
Data analysis method	Chi-square, t-test. Mixed model	Directed content analysis	Logistic regression	Ordinal and Multinominal logistic regression

3.1 PAPER 1

This was a randomised controlled trial. Patients were recruited from four specialised hand surgery units in Sweden (Stockholm, Uppsala, Örebro, and Malmö) starting in March 2017, with the last follow-up in May 2019.

Patients were randomised to control or intervention groups during their first appointment with a physiotherapist in the first week after flexor tendon repair.

Both groups received standard hand rehabilitation for flexor tendon repair which was initiated within the first seven days by a physiotherapist. Besides of the standard protocol the intervention group also received a smartphone application called “Böjsenskada” (flexor tendon injury). The application included a video on the exercises, push-notifications for exercises that were set at the prescribed exercise intensity, an exercise diary in a calendar view, questions and answers, written information about the surgery, anatomy, rehabilitation, restrictions on how to use the injured hand. The participants were then recommended to use the application as they wanted.



Picture 4. A patient using the smartphone application during rehabilitation.

The main outcome measure was adherence, measured with the SIRAS (91, 92) and ROM. The SIRAS score ranges from three to 15 (15 indicating maximum adherence). Secondary outcome measures were Athletic Injury Self-Efficacy Questionnaire (AISEQ) (157) and self-reported adherence in the domains of frequency, duration, and quality (158, 159). The AISEQ contains 10 questions which are summarised into a score ranging from zero to 100 (100 indicating complete self-efficacy). Self-reported adherence in the domain of frequency and duration were calculated by dividing reported exercises by recommended to attain a percentage score. Self-reported exercise qualities were assessed with one question were the patient stated in what percentage of time they experienced good exercise quality. Participants were assessed at baseline (AISEQ), and two, six (SIRAS and AISEQ), and 12 weeks (ROM) after repair by a physiotherapist during the regular appointments.

3.2 PAPER 2

Participants were recruited from three specialised hand surgery units in Sweden (Stockholm, Malmö and Linköping). The invitation to participate was based on a relevance sampling strategy striving for a variation in experience. This variation was partly done by a variation in rehabilitation outcome, age, sex and type of injury.

Interviews were conducted between the 74th and 111th day after surgery (median 94 days). Collection of data started in 2018 and ended in 2019 when it was perceived that data saturation has been achieved, in that information appeared redundant (160). Interviews were conducted by telephone using a semi-structured interview guide with open-ended questions influenced by the modified HBM (86). Probing questions were asked in relation to the aim of the study. All interviews were audio-recorded and then transcribed verbatim. To get an unbiased description of the participants´ experiences, the author of this thesis presented himself as a researcher instead of a physiotherapist, and there was no previous clinical contact between the participants and the interviewer.

3.3 PAPERS 3 AND 4

Data from HAKIR (150) were assessed retrospectively for papers 3 and 4. Data from patients operated with a complete flexor tendon injury in zone one and two were assessed, between 2010-10-31 and 2018-12-31 for paper 3, and between 2010-10-31 and 2019-12-31 for paper 4. Patients in paper 3 were followed from repair to 2019-12-31 to assess reoperation due to rupture or adhesions. In paper 3 we also collected data on income and level of education from Statistical Sweden (SCB). In paper 4 we included patients with complete data at three and 12 months after repair regarding ROM and PROMs. The PROMs included the HQ-8 (151) (Figure 1), Quick-DASH, and perceived satisfaction with results. Satisfaction with results was rated on an 11-point Likert scale ranging from zero (completely satisfied) to 100 (completely dissatisfied).

HAKIR
HANDKIRURGISKT KVALITETSREGISTER

Date of birth (social security no) (yyyymmdd-nnnn): ☐☐☐☐☐☐☐☐—☐☐☐☐

Patient questionnaire HQ-8 (arm/hand)

Date (yyyy-mm-dd) ☐☐☐☐-☐☐-☐☐

I am (please indicate your writing hand): ☐ Left handed ☐ Right handed ☐ Ambidextrous

Arm/hand that was operated on: ☐ Left ☐ Right

This questionnaire reports on problems that you have had this past week in the hand/arm that was operated on. Please tick the alternative that best corresponds to any of your problems.

1. Pain on load

	0	10	20	30	40	50	60	70	80	90	100	
No problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Worst problems imaginable

2. Pain on motion without load

	0	10	20	30	40	50	60	70	80	90	100	
No problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Worst problems imaginable

3. Pain at rest

	0	10	20	30	40	50	60	70	80	90	100	
No problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Worst problems imaginable

4. Stiffness

	0	10	20	30	40	50	60	70	80	90	100	
No problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Worst problems imaginable

5. Weakness

	0	10	20	30	40	50	60	70	80	90	100	
No problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Worst problems imaginable

6. Numbness / tingling in fingers

	0	10	20	30	40	50	60	70	80	90	100	
No problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Worst problems imaginable

7. Cold Sensitivity (discomfort on exposure to cold)

	0	10	20	30	40	50	60	70	80	90	100	
No problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Worst problems imaginable

8. Ability to perform daily activities

	0	10	20	30	40	50	60	70	80	90	100	
No problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Worst problems imaginable

Figure 1. The HQ-8 questionnaire.

3.4 STATISTICS AND DATA ANALYSIS

Data analysis was conducted using the SPSS statistical software version 26-28 (IBM) for paper 1,3 and 4. Excel (Microsoft Office) for paper 2.

In paper 1, group demographics were tested with a chi-square test and an independent sample t-test. To test the effect of the intervention and time a mixed model test with an unstructured covariance structure was used. The level of significance was set to $p<0.005$.

Data was analysed using directed content analysis in paper 2 (161). A categorisation matrix based on the HBM was created with an additional category labelled “other” to have openness in the process. Meaning units related to the aim or the categorisation matrix were identified in the text and then subtracted to codes. Subcategories and generic categories were created by grouping codes based on their meaning, similarities and differences. The link between categories were based on a constant comparing technique.

In paper 3, logistic regression was used to examine the associations between the selected variables and the outcomes of reoperation due to adhesions or rupture. The selected variables were sex, age, income, level of education, injured finger/tendon/hand/nerve, time to surgery, type of core suture material, technique, strand number and thickness. The logistic regression was conducted in steps, first as an unadjusted association of each variable. Secondly, by using multivariable models to examine the adjusted associations (model 1). Last, by using a multivariable models with only significant variables $p < 0.05$ from the unadjusted model and model 1 (model 2). After adding significant variables to model 2, variables with missing values >10% and p-value >0.05 were removed. The presence of interaction was tested with variables from model 2. The Wald test was used to test the significance of each association and interaction at a level of $p<0.05$.

In the last paper, data was analysed by using ordinal regression to assess the association between all PROM and PREM values and the Strickland Original classification. Then, we assessed the association with each Strickland level using multinominal logistic regression in variables with $p<0.05$.

3.5 ETHICS

All papers in the thesis had ethical approval from the local ethics committee at Karolinska Institute and were performed according to the Helsinki declaration. In papers 1 and 2, informed consent was collected from all participants. In papers 3 and 4, informed consent was not mandatory.

4 RESULTS

4.1 A SMARTPHONE APPLICATION TO IMPROVE ADHERENCE

A total of 367 patients were assessed for eligibility and 101 participants were randomised to either a control or an intervention group. Figure shows the participants at different follow-up times of the study.

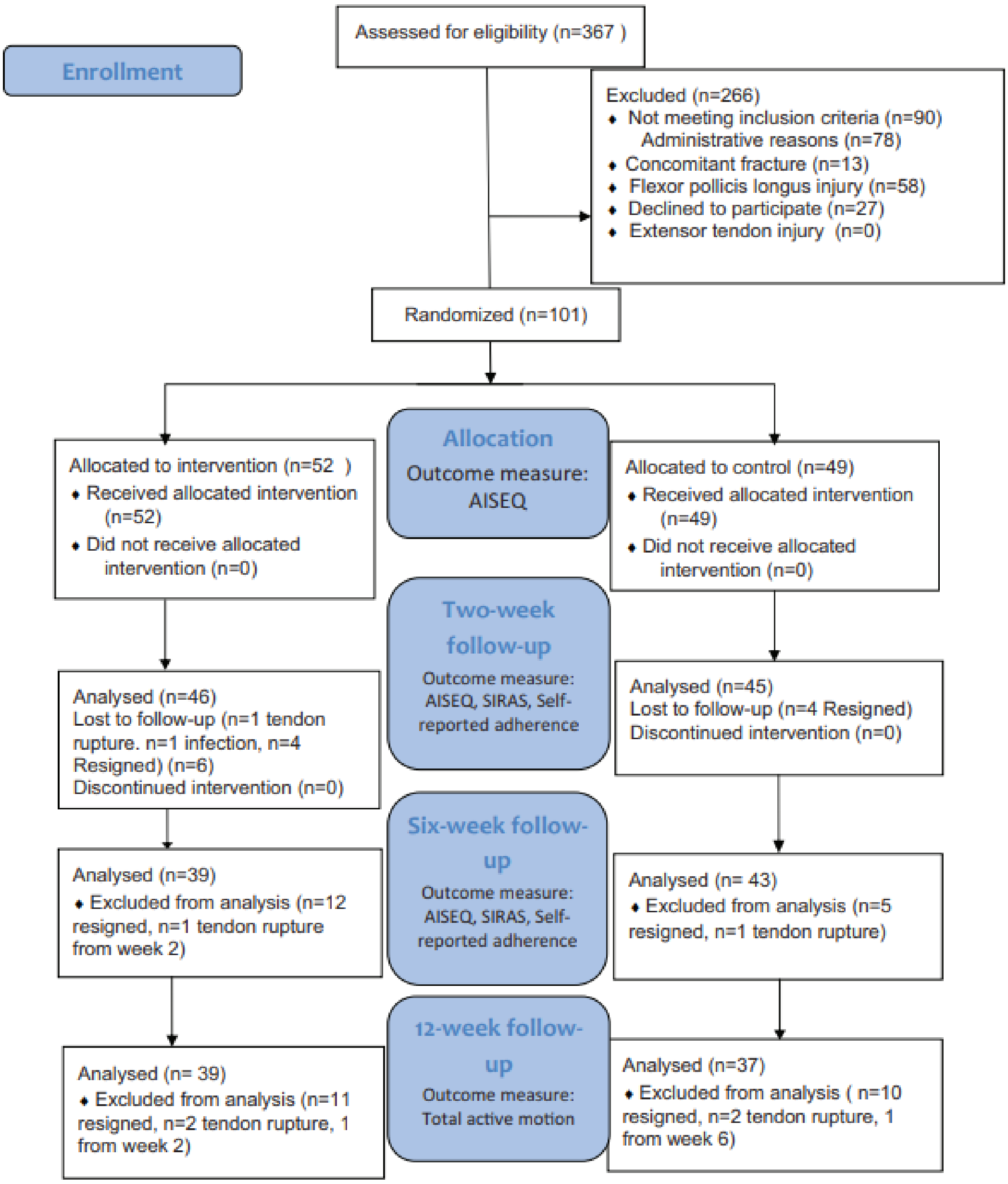


Figure 2. The CONSORT flow chart of the study.

A total of 52 patients were randomised to an intervention group and 49 to a control group. There was no significant difference in the demographics between the groups at baseline.

Table 3. Demographics of the participants in the intervention and control groups.

Demographic	Intervention group (n=52)	Control group (n=49)	P value
Age (mean ± SD)	38.8±13.4	36.2±12.1	0.283
Sex (women/men)	21/31 (40/60%)	14/35 (29/71%)	0.212
Injured hand (Right/left)	24/28 (46/54%)	25/24 (51/49%	0.553
Injured digits, n	60	53	0.292
Index	24 (40%)	12 (23%)	
Middle	10 (17%)	6 (11.5%)	
Ring	9 (15%)	7 (13.5%)	
Small	17 (28%)	28 (52%)	
Injured tendons, n	81	83	0.661
FDP	31 (56%)	29 (52%)	
FDP + partial FDS	6 (10%)	8 (14%)	
FDP + FDS	19 (34%)	19 (34%)	
Injured digital nerves, n	30	22	0.444
None	36 (60%)	34 (64%)	
Unilateral	18 (30%)	16 (30%)	
Bilateral	6 (10%)	3 (6 %)	

Data is presented as mean(m), standard deviation (SD), number of participants (n) and proportion (%). FDP: Flexor digitorum profundus. FDS: Flexor digitorum superficialis. Six participants in the intervention group and four participants in the control group had an injury to more than one finger

.

We found no overall difference in ROM, SIRAS, AISEQ or self-reported adherence between the groups. We tested the difference in any outcome measure at any follow-time between the groups. The only difference we found was in self-reported adherence for exercise frequency at the six-week follow-up. The intervention group had a higher mean score of 93.2 (CI 95% 86.9-99.5) compared to the control group, who had 82.9 (CI 95% 76.9-88.8) (p=0.02) (Table 2).

We found a significant overall effect of time, independent of group, for self-reported adherence for exercise frequency (p=0.007) and AISEQ (p=0.008). The values at two weeks were higher compared to six weeks and baseline. We found no effect of time in any other outcome measure.

Table 4. Scores on all outcome measures at different time points for the intervention and control groups.

Outcome variable	Follow-up	Intervention group Mean (95% CI)	Control group Mean (95% CI)	p-value
ROM*	baseline			
	2 week			
	6 week			
	12 week	95 (83-108)	108 (94-123)	0.180
SIRAS	baseline			
	2 week	12.5 (11.8-13.3)	13.3 (12.6-14.0)	0.155
	6 week	11.8 (11.0-12.8)	12.8 (12.0-13.7)	0.123
	12 week			
SR adherence for	baseline			
exercise frequency	2 week	94.3 (90.7-98.0)	94.6 (90.8-98.3)	0.933
	6 week	93.2 (86.9-99.5)	82.9 (76.9-88.8)	**0.020**
	12 week			
SR adherence for	baseline			
exercise duration	2 week	94.9 (90.6-99.3)	93.3±16 (88.9-97.6)	0.586
	6 week	93.8 (89.1-98.5)	92.6 (88.2-97.0)	0.721
	12 week			
SR adherence for	baseline			
exercise quality	2 week	86.7 (83.3-90.1)	87.1 (83.8-90.5)	0.866
	6 week	87.6 (83.4-91.9)	82.5 (78.4-86.7)	0.092
	12 week			
AISEQ	baseline	91.5 (88.8-94.2)	90.5 (87.6-93.7)	0.994
	2 week	92.8 (90.7-94.9)	92.9 (90.2-95.6)	0.614
	6 week	91.5 (89.3-93.8)	90.4 (87.4-93.5)	0.600
	12 week			

ROM: range of motion in the proximal interphalangeal and distal interphalangeal joint. SR: Self-reported. SIRAS: Sport Injury Rehabilitation Adherence Scale. AISEQ: Athletic Injury Self-Efficacy Questionnaire. *ROM outcomes assessed only at 12weeks.

4.2 PATIENT EXPERIENCE OF FLEXOR TENDON REHABILITATION IN RELATION TO ADHERENCE

A total of 17 participants were interviewed. The age of the participants was between 26 and 58. Five of the participants were women. About half of the participants had injuries to the dominant hand, four had FDP injuries, five had injuries to the FPL, and eight had injuries to both the FDP and FDS. A total of six participants experienced tendon rupture. The other participants had a variation in the ROM outcome according to the Original Strickland classification. The result of the analysis is presented in six categories as shown in the figure below.

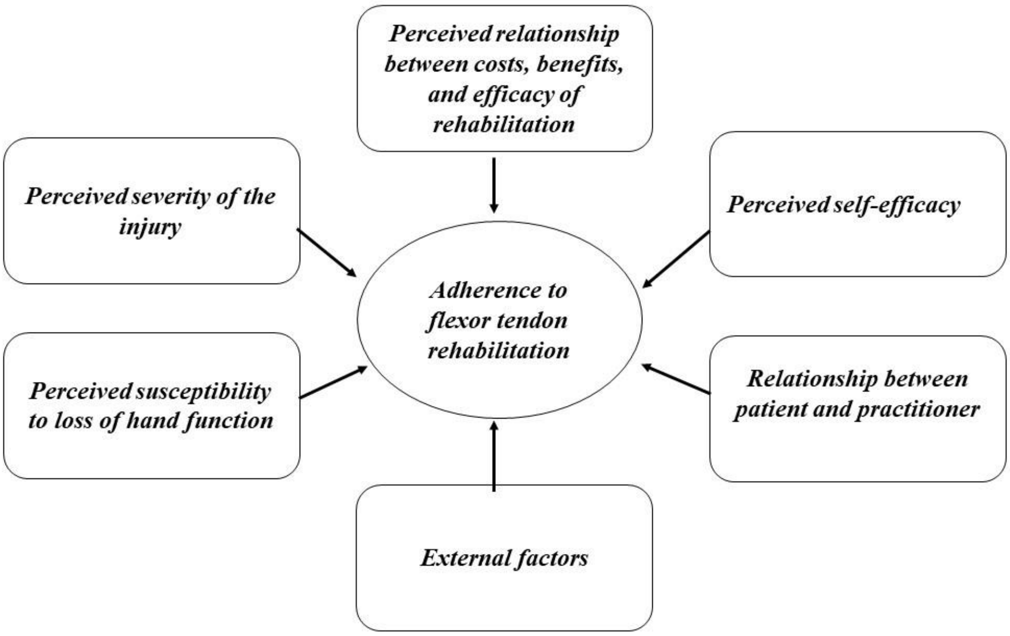


Figure 3. An overview of the results of the six main categories.

The category *perceived susceptibility of loss of hand function*, included the thoughts and feelings about future ability to perform activities and the relation to adherence. There were expressions of fear and uncertainty about the hand function in the future, a fear of making the injury worse. This perception affected their exercise and made them avoid excessive hand use. The personal impact of the injury was contextualised in terms of how activities important to the patient were affected. This gave them motivation to do the exercises.

The *perceived severity of the injury* was different among the participants, and it could also change during the rehabilitation. In the case of an experience of a rupture or poor ROM, participants could perceive the injury as more severe in retrospect. They also described a lack of understanding of the fragility of the tendon, which may have led to the behaviour causing the rupture. In contrast, others experienced the seriousness of the injury from the start. The cast increased the sense of being injured which could lead to caution in exercise and activities.

The *perceived relationship between costs, benefits and efficacy of rehabilitation* affected adherence. To see the benefits of doing the exercises was a driver of motivation but it was hard for the participants to notice the results. Others believed in the benefits of the exercises. This could be based on experience and knowledge. Some felt no usefulness of doing the exercises, which could be regretted later. A better understanding of the aim of each exercise and what could be anticipated would have helped. Participants also said that it was insignificant to do the exercises exactly as they were shown, and that everyday hand use replaced doing the exercises. One important cost of adhering to rehabilitation was the struggle to manage everyday life with the restrictions and the cast on the injured hand, which they felt was frustrating. This led to the view that it was inevitable not to use the injured hand in some way. Developing strategies was one way to manage this. Pain was a common occurrence in the rehabilitation, which contributed to modification of the exercises and avoidance of hand use. The exercises were perceived to consume time and energy. Available time during the day dictated how many exercises were done. The time were managed by developing strategies, setting a clock as an exercise reminder, and making exercise a daily habit.

Participants´ view of their own ability to succeed with the rehabilitation recommendations (*perceived self-efficacy*) were multifaceted. Some of the participants described themselves as optimistic, and able to manage. In contrast, some perceived a lack of control at the beginning. Experience of previous injury, exercise and competition in sports was an advantage and increased their self-efficacy.

The *relationship between the patient and the practitioner,* occupational therapist and physiotherapist influenced adherence. The relationship was perceived as good in general. It increased exercise motivation and was comforting as answer to raised questions were addressed. Despite this, there were reports that the instructions were too complicated and hard to take in. Instructions were also described as not personalised enough. Some participants also addressed the impact of time off from work. A longer sick leave would have been beneficial as it could increase time for exercise and facilitate caution in activities.

The *external factors* outside the health care services influenced adherence. The family situation, friends and associates facilitated understanding of the injury. They helped in the management of everyday life and in perceiving progress. In contrast, some viewed the injury as a burden for others, and they avoided performing their exercises in some social contexts.

4.3 RISK FACTORS FOR REOPERATIONS

In this paper the study sample included 1 372 patients with injury to 1 585 fingers. A total of 156 (9.8) % of the fingers were reoperated. A total of 80 (5%) fingers were reoperated due to tendon rupture and 76 (4.8%) fingers due to tenolysis. We found that patients within the age group of 25-50 years and older than 50 years had an increased risk of rupture compared to patients below 25 years of age (Appendix 1). Men had an increased risk to tendon rupture, 6.1 % had reoperation due to rupture compared to 2.3 % in women. (table 5)

Table 5. Information regarding the individual variables and their adjusted associations with rupture after flexor tendon repair in zones 1 and 2 in 1585 fingers.

	Model 1 Adjusted for all variables		Model 2 Adjusted for sex, age and injured tendon.	
Variables	OR (CI 95%)	p-value	OR (CI 95%)	p-value
Sex				
Women	Reference		Reference	
Men	3.5 (1.3-9.0)	0.01	2.7 (1.4-5.4)	0.004
Age				
< 25	Reference		Reference	
25 - 50	6.5 (1.5-28.6)	0.014	5.6 (2.4-13.2)	<0.001
> 50	10.7 (2.3-50.1)	0.003	5.5 (1.4-5.4)	<0.001
Injured tendon				
FDP	Reference		Reference	
FDP + partial	1.8 (0.6-5.4)	0.275	1.3 (0.6-3.1)	0.492
FDS				
FDP+FDS	3.5 (1.4-8.4)	0.006	2.4 (1.3-4.4)	0.005
FPL	4.6 (1.1-19.9)	0.041	3.8 (1.9-7.3)	<0.001

OR: odds ratio. CI: confidence interval. FDP: Flexor digitorum profundus. FDS: Flexor digitorum superficialis. FPL: Flexor pollicis longus.

We found an interaction between sex and age group on the risk of rupture. In the age group 25-50 years men had an rupture rate of 8.7% compared to 0.9% in women (Table 6).

Table 6. Interaction between sex and age on the adjusted association with rupture after flexor tendon repair in zones 1 and 2.

Sex	Age group	Number of fingers (% with rupture)	Adjusted for type of tendon injury[a] OR (CI 95%)	p-value
Women	<25	106 (2)	Reference	
	25-50	232 (1)	0.5 (0.1-3.3)	0.445
	>50	83 (7)	3.8 (0.7-19.4)	0.112
Men	<25	357 (1)	0.6 (0.1-3.2)	0.528
	25-50	527 (9)	4.9 (1.2-20.6)	**0.030**
	>50	206 (7)	3.5 (0.8-15.6)	0.104

[a] Tendon injury type categorized as, Flexor digitorum profundus, or Flexor digitorum profundus and partial or complete Flexor digitorum superficialis, or Flexor pollicis longus. OR: odds ratio. CI: confidence interval.

Injuries to both the FDP and FDS tendon had a greater association with both rupture and tenolysis reoperation compared to injuries involving only the FDP tendon (table 5 and 7). The frequency of rupture reoperations in FPL tendons was 10%, which corresponds to an OR of 4.6 compared to FDP injuries (table 5). The frequency of tenolysis reoperation increased in each income group. The frequency was zero in the group with low-income. In the group with middle-income the frequency was 5.4% and in the high-income group it was 8.7%. This finding indicates that the level of income influence tenolysis reoperation although the statistical model used indicated no association.

The variables of education, days to surgery, injured hand, injured nerves, injured finger, number of fingers, technique, circumference, material and number of strands in the core suture were not associated with reoperation risk.

Table 7. Information regarding the individual variables and their adjusted associations with tenolysis after flexor tendon repair in zone 1 and 2 in 1585 finger.

	Model 1 Adjusted for all variables		Model 2 Adjusted for age, income, injured tendon, number of fingers	
Variables	OR (CI 95%)	p-value	OR (CI 95%)	p-value
Age				
< 25	Reference		Reference	
25 - 50	0.3 (0.1-0.9)	**0.032**	1.0 (0.6-1.8)	0.965
> 50	1.5 (0.6-3.9)	0.425	1.3 (0.6-2.5)	0.509
Income[a]				
low	n.a	0.996	n.a	0.994
middle	0.4 (0.4-0.9)	**0.036**	0.7 (0.3-1.4)	0.307
high	Reference		Reference	
Injured tendon				
FDP	Reference		Reference	
FDP+partial FDS	0.9 (0.3-2.6)	0.848	1.2 (0.9-4.1)	0.057
FDP+FDS	1.6 (0.7-3.7)	0.277	2.7 (1.5-4.9)	**0.001**
FPL	0.2 (0.0-0.1.0)	**0.046**	0.9 (0.4-2.4)	0.877
Number of fingers				
Single	9.9 (1.2-81.5)	**0.033**	0.8 (0.5-1.4)	0.525
Multiple	Reference		Reference	

[a] low income: disposable income per consumption unit below 60 % of median income for all. Middle income: income between low and high definition. High income: above double the median income. OR: odds ratio. CI: confidence interval. N.a: not applicable, due to zero observation with tenolysis. FDP: Flexor digitorum profundus. FDS: Flexor digitorum superficialis. FPL: Flexor pollicis longus.

4.4 PATIENT-REPORTED OUTCOME IN RELATION TO STRICKLAND CLASSIFICATION.

A total of 215 patients were included at three months and 150 patients at 12 months follow-up. These patients had a complete data set including repair data, PROM, ROM and satisfaction with results. At three months we found an association with Original Strickland and Satisfaction with results (OR 1.016 p<0.001), and the PROM; stiffness (OR 0.977 p<0.001), ability to perform daily activities (OR 0.981 p=0.002) and Quick-DASH (OR 0.972 p<0.001). At 12 months there was an association with Satisfaction with results (OR 1.021 p<0.001), and the PROMs; Stiffness (OR 0.975 p<0.001) and Quick-DASH (OR 0.980 p=0.026).

Table 8. Patient reported outcome at different levels of Original Strickland at three and 12 months after flexor tendon repair in zones 1 and 2.

Table 2. Patient reported outcome at different levels of Original Strickland at three and twelve months after flexor tendon repair in zone 1-2.

Strickland level	Poor		Fair		Good		Excellent	
Month	3	12	3	12	3	12	3	12
n (%)	55 (25.6)	26 (17.3)	60 (27.9)	31 (20.7)	60 (27.9)	33 (22)	40 (18.6)	60 (40)
Quick-DASH	30 25)	14 (29)	14 (21)	11 (14)	18 (18)	9 (18)	14 (17)	9 (17)
Pain at load (HQ-8)	30 (30)	20 (50)	25 (30)	10 (30)	20 (20)	10 (40)	20 (30)	20 (45)
Pain on motion without load (HQ-8)	10 (20)	0 (20)	10 (20)	0 (20)	5 (20)	0 (20)	0 (20)	0 (20)
Pain at rest (HQ-8)	0 (10)	0 (20)	0 (10)	0 (10)	0 (10)	0 (10)	0 (10)	0 (10)
Stiffness (HQ-8)	50 (40)	50 (40)	40 (40)	50 (40)	40 (30)	30 (30)	30 (25)	20 (35)
Weakness (HQ-8)	40 (40)	30 (30)	35 (30)	30 (40)	30 (30)	20 (40)	40 (40)	30 (40)
Numbness /tingling in fingers (HQ-8)	20 (40)	10 (40)	5 (35)	10 (30)	10 (30)	10 (35)	10 (40)	10 (30)
Cold Sensitivity (discomfort on exposure to cold) (HQ-8)	20 (70)	60 (70)	30 (60)	40 (70)	20 (55)	30 (65)	15 (50)	30 (70)
Ability to perform daily activity (HQ-8)	30 (40)	15 (40)	20 (35)	10 (20)	10 (30)	20 (30)	10 (30)	10 (30)
Satisfaction with results[a]	70 (40)	70 (30)	85 (45)	70 (40)	90 (30)	90 (30)	95 (20)	90 (30)

Values in table represent median and Interquartile range in parenthesis. HQ-8: The eight-item HAKIR questionnaire. 11-point Likert scale ranging from 0-100 (0=no problems, 100= worst problems imaginable). [a]11-point Likert scale ranging from 0-100 (0=completely satisfied, 100=completely dissatisfied).

We assessed the association between each level of the Original Strickland and the variables with significant associations from the ordinal regression. This was done due to a violation of proportional odds. Stiffness had an association only at three (p=0.021) and at 12 (p=0.003) months that was between the levels of Good and Fair. The Quick-DASH only had an association that was between the levels of Fair and Poor at three months (p=0.008). Satisfaction had an association that was only between the level of Good and Fair at 12 months (p=0.009). We did not assess the association between the Original Strickland classification and ability to perform daily activities. This was done because of a high correlation (>0.70) between ability to perform daily activities and Quick-DASH.

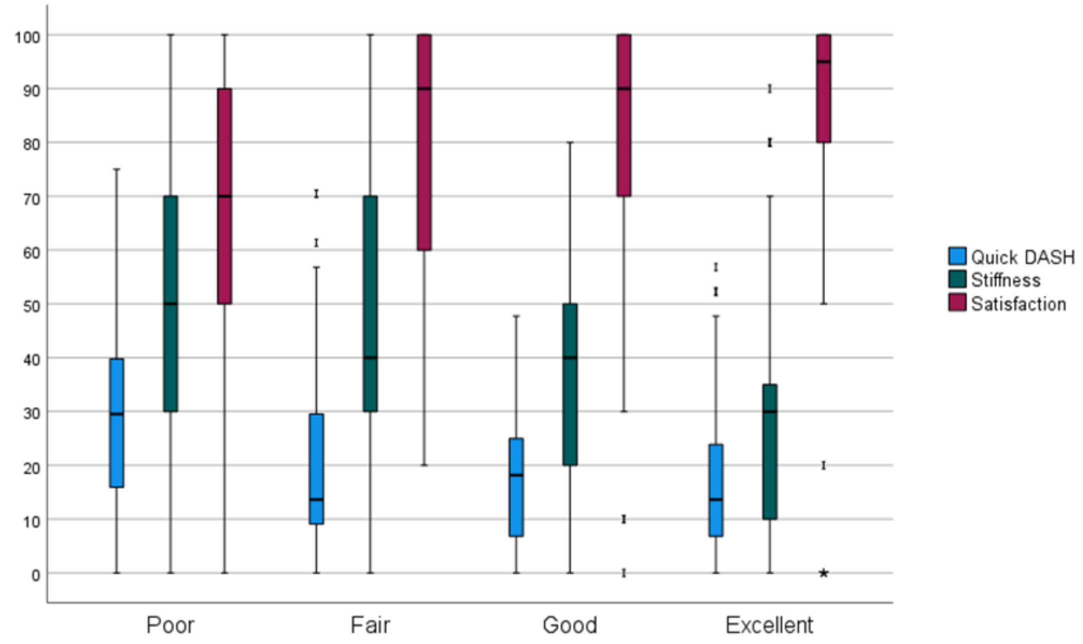


Figure 4. PROM values associated with the Original Strickland classification at the three-months follow-up. Quick-DASH, 0-100 (no disability-sever disability). Stiffness, 0-100 (no problems-worst problems imaginable). Satisfaction, 0-100 (completely dissatisfied-completely satisfied).

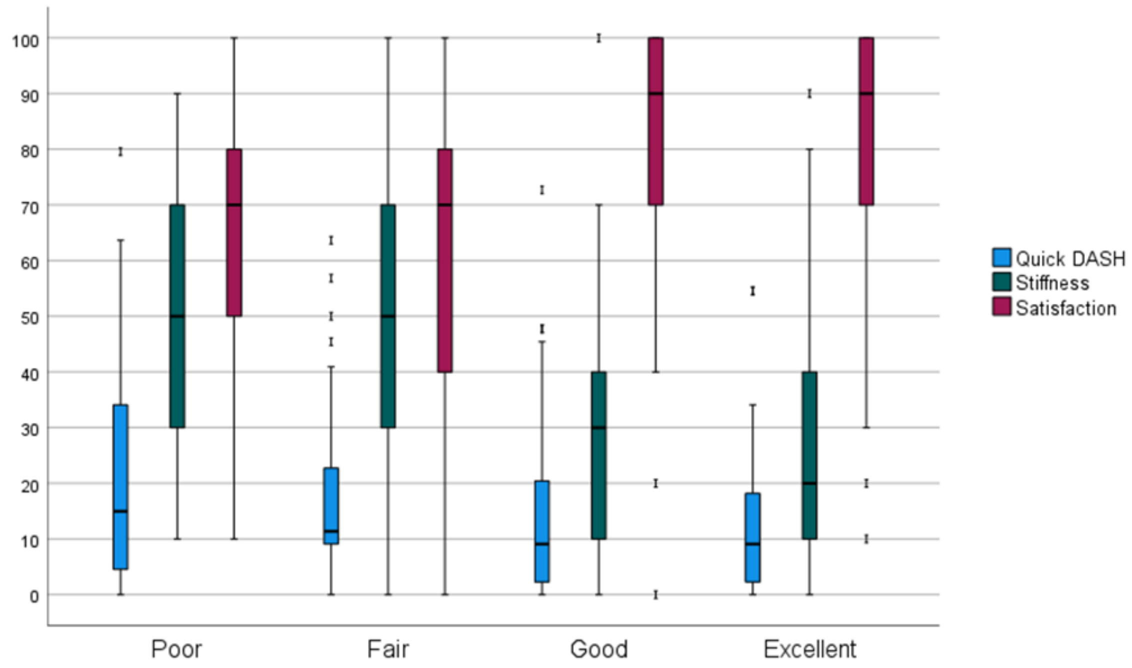


Figure 5. PROM values associated with the Original Strickland classification at the 12-months follow-up. Quick-DASH, 0-100 (no disability-sever disability). Stiffness, 0-100 (no problems-worst problems imaginable). Satisfaction, 0-100 (completely dissatisfied-completely satisfied).

5 DISCUSSION

The work of this thesis was prompted by an interest in trying to understand why some patients have complications after flexor tendon repair, and how we could improve and understand adherence. This understanding could facilitate future intervention and research to reduce complications. The overall aim of this thesis was to improve and explore rehabilitation adherence and outcome, including a smartphone intervention and patients´ perspectives, and to explore complications after flexor tendon repair and rehabilitation.

The idea for paper 1 arose from a collaboration with the company Appinmed located in Lund. The company specialises in the development of medical applications, and they were interested in a collaboration regarding development of a smartphone application for flexor tendon rehabilitation. The development process gave us both possibilities and restrictions regarding the incorporation of features in the application to increase adherence. The main finding in the study was that there was no difference in adherence, ROM or self-efficacy between the groups. Although our hypothesis did not hold, this was one of the first papers trying to increase adherence to home-based exercise after flexor tendon repair. Previous smartphone apps that have improved adherence successfully have incorporated some personalised features or gamification, which our app did not include. Personal feedback on exercise performance during knee extension with a smartphone app improved errors during exercise (162). Patients using a smartphone app that allowed communication between patients and health care workers had higher medication adherence and higher accuracy in insulin injections (163). Personal monitoring of registered adherence in a smartphone app, together with other functions such as text messages improved home-based exercise in patients with musculoskeletal conditions (164). Patients may also have different preferences and reasons regarding the ways they receive information about rehabilitation, on paper, by video or both (165, 166). Smartphone games that incorporated finger motion improved adherence to exercise after metacarpal fractures compared to standard physiotherapy (114). The smartphone application could not improve ROM compared to standard rehabilitation in our study. This is in contrast with previous studies using a tablet application (ReHand) and a smartphone application (CareHand) which improved functional outcome (167) and sick leave (168). Compared to our application, ReHand and CareHand used feedback during the exercises and a personalised progression system in their rehabilitation. One restriction during the development of the application was that we were unable to incorporate some of these features. In paper 2 there were participants that perceived the information as too general and not personalised. They also highlighted that their perception of the injury and rehabilitation changed over time. This also suggests that future smartphone apps to improve adherence during flexor tendon rehabilitation should be personalised and should incorporate different features in different parts of the rehabilitation.

Self-efficacy is a construct that increase adherence to rehabilitation (115, 116) and was used in papers 1 and 2. In paper 1 we wanted to investigate whether the smartphone application could increase self-efficacy. In paper 2 we investigated the experience of it in relation to adherence. Self-efficacy can be increased via personal experience of mastery, observation of others, verbal persuasion, and emotional arousal (81, 169). We used push-notifications of exercise as a verbal-persuasion, along with observation of others via encouragements during the video exercises. In paper 2, experience of previous injury or exercise increased self-efficacy, and this has also been shown in previous research on rehabilitation after athletic injuries (158). The theory of self-efficacy states that these types of previously performance accomplishments affect self-efficacy more strongly than verbal persuasion and observation of others (85). In clinical practice this experience could be attained during visits to the physiotherapist, which was done by both groups in paper 1. This may be one explanation for why the smartphone could not increase self-efficacy.

Papers 2 and 3 were inspired by an interest in trying to understand why some patients have complications as a result of repair and rehabilitation of flexor tendon injuries. We hypothesised that the reasons for complications could be complex, and that adherence, along with risk factors is of importance. Because of this, we approached the topic with two different study designs, qualitative interviews and a retrospective cohort. In paper 2 we showed that patients´ experience in relation to adherence can be multifaceted and may change over time. We also showed that a patient's perception in relation to the construct of the HBM may influence adherence to exercise and restricted hand use. Patients described that it was unavoidable not to use their injured hand because of a feeling of frustration and the struggle to use only one hand in daily life. This corresponds to previous research where patients have described a frustration (50) during rehabilitation and reported removing their orthosis during flexor tendon rehabilitation in order to use their hand in activities (47, 100). Using the injured hand during the immobilisation period could potentially overload the repair tendon and cause rupture. In our paper, we found that to learn to manage with only one hand and develop strategies helped in this struggle. To support patients in this process has been highlighted previously as beneficial to reducing the cost of adherence to restrictions in hand use (47, 111). The process of adherence to restrictions in hand use as suggested in paper 2 is affected by a combination of perceptions about the injury and the rehabilitation. Following a rupture, patients in paper 2 described a poor understanding of the strength of the tendon as one reason for the rupture. Patients also described the instructions as being too general, complicated, and hard to take in. Previous research has also shown that patients struggle to remember all information during flexor tendon rehabilitation (170). To simplify instructions and address patients concerns and expectations could be one way to facilitate the processing of information (171). Patients have also highlighted the importance of participation in decision-making and individualisation to make rehabilitation more meaningful (172). To incorporate the patients more generally regarding their perceptions of the injury, the rehabilitation and the support create opportunities to understand adherence in a better way.

In paper 3 age, male sex and injury to FPL or both FDP and FDS were associated with an increased reoperation risk due to rupture. Patients´ age has been shown to affect the healing properties of the tendon, which may increase the rupture risk (173) (65). Lalchandani (174) found that patients between 20 and 29 years and above 60 years had fewer reoperations compared to patients between 30 and 39 years. We found a similar pattern in the male population in our study. This suggests that the reoperation rate is not only a consequence of healing properties associated with the age of the tendon. Reports of reoperations often include all types of reoperations and to show an increased risk of reoperations only due to rupture you need to study more patients. Bruin (175) and Dy (60) also found that older age affects the overall risk for reoperation. Dy (61), however they demonstrated in a different paper that age did not affect the risk for reoperation due to rupture alone. We also found an interaction between sex and age, where males in the 25-50 years age group had a rupture reoperation rate of 8.7% compared to 0.9% in women in the same age group. There are some conflicting results in previous research regarding whether male sex increases the risk of rupture. Harris (63) reported a non-significant difference in rupture rates between men and women, a 6% rupture rate in males and 4% in females. Dy (61) reported rupture repair as not dependent on sex. One can only speculate on the underlying reasons for our results of a higher reoperation rate due to rupture in males between 25 and 50 years. Adherence could be one of these confounding reasons as adherence has been reported to be reduced in males after flexor tendon injuries (100). But in contrast Ahmad (102) reported no gender difference in adherence or rupture after tendon repair in the shoulder. The group with FPL injuries demonstrated the highest rupture rates in our study. Previous research has reported rupture rates of between 0 and17% in FPL injuries (176-178). Although rehabilitation with early active motion has been shown to be safe in FPL injuries (179), the FPL and the opposable thumb have some unique features that may be considered regarding our findings of high rupture rate. The FPL has higher muscle activity during normal grasping activities compared to the FDP muscle (180) and it is the primary mover of not only the IP joint but also the MCP-joint (5). One could also argue that it is more difficult to avoid using the thumb during everyday activities compared to other fingers. This indicates that patients with FPL injuries may encounter challenges that should be considered during rehabilitation in order to help patients avoid overloading their tendon.

In paper 3, injuries to both the FDS and FDP increased the risk of tenolysis and rupture reoperation. In a study by Moriya (69), all the tenolysis performed had injuries to both tendons and six out of seven fingers had adhesions between the FDP and FDS. In the two studies by Rigo (62) and Edsfeldt (16) the extent of FDS injury did not affect the ROM. Although not all patients with poor ROM choose to be reoperated with tenolysis, it can be seen as an indicator of the level of adhesions. Level of income was not significantly associated with tenolysis in paper 3 although the frequency increased with each income level. The logistic regression model used does not work when the frequency is zero for an outcome which is a disadvantage of the method. In the paper by Moriya, only 20% of patients with poor and fair results had tenolysis which means most patients do not want reoperation despite a low level of active ROM. Our interpretation of the results of paper 3 is that patients income affects the patient’s willingness to undergo reoperation with tenolysis rather than reflecting ROM. There is a great uncertainty in the literature regarding which factors influence the decision to undergo secondary surgery with tenolysis after flexor tendon repair besides poor ROM. As shown in paper 4, despite poor ROM, patients may perceive symptoms and function differently. Probably both PROM and satisfaction with the result affect the decision on reoperation, along with the patient´s financial situation.

In paper 4 we examined the association between patient-reported outcome and clinical outcome in terms of the original Strickland classification. This was done because we wanted to raise the question of the value of these classifications in relation to PROMs. There are several types of classification systems but we chose to assess the Original Strickland because it is the most commonly used in the literature (119). Perceived stiffness, ability to perform daily activities, Quick-DASH and satisfaction with results were associated with the Original Strickland. However, only between independent levels of Strickland. This is similar to Karjalainen where PROMs had a limited correlation to Original Strickland (127). When interpreting our results at the final assessment patients need to recover at least 70% of ROM to perceive themselves as satisfied and less stiff. Bain assessed the ROM in the PIP and DIP-joint needed to perform normal daily activities (181). When translating his results into the Strickland score it corresponded to 67% of normal ROM. It is logical to assume that the patient needs to recover the amount of ROM need to perform daily activities to perceive a difference in satisfaction and stiffness.

DASH is seen as the standard PROM of hand injuries and is the most frequently used PROM after flexor tendon injuries (119). The Quick-DASH scores in paper 4 were only associated to the Strickland classification at the three-month follow-up between patients classified as fair and good. DASH has previously shown a modest or weak correlation to clinical assessments of ROM, strength, and sensation after hand injuries (182, 183), and moderate correlation to patient-reported finger function after flexor tendon repair (127). One interpretation of our results is that patients need 50% of ROM to perform the tasks stated in the Quick-DASH questionnaire with less difficulty at three months. At 12 months, most patients have gained enough hand strength and adaptation in hand use to be able to perform the tasks without major difficulties.

The low association between the Original Strickland classification and PROMs show that ROM classification only explains a small portion of the patient’s perceived disability after flexor tendon repair. To better understand the disability and its underlying causes could be helpful for therapists when prioritising their treatment of patients. If therapists emphasise the importance of ROM and not the patient’s perception of the finger they may also miss an important component that may affect adherence (184). This suggests the importance of taking patients´ perceptions into account, both when assessing outcome and when mediating improvements during rehabilitation to facilitate adherence.

5.1 METHODOLOGICAL CONSIDERATIONS

The heterogeneity of methods used in this thesis entails different methodological considerations when interpreting the results. These considerations have been made in the different contexts of each paper.

Paper 1 had limitations which should be considered when interpreting the results. There is no validated way or gold standard in terms of measuring adherence to rehabilitation after flexor tendon repair (87). A device for measuring exercise has been reported (185) but we could not use it in our study and the technicality of the device is a disadvantage for clinical use. We tried to assess adherence to home-based exercises in different ways to capture all dimensions of exercise. SIRAS assesses adherence during a physiotherapist session and has been tested for validity and reliability in patients during rehabilitation of knee surgery (91, 92) and, musculoskeletal conditions (93). To assess adherence to home-based exercise the term “during today´s appointment” was removed as suggested by Brewer (92). We tried to minimise the impact of this by discussing the implementation of the questionnaire in the research context with a physiotherapist assigned to conduct the assessments. Both the change of the questionnaire and the limited validation in an acute hand rehabilitation context may affect validity and reliability. The self-reported adherence was assessed in a similar way as Milne describes (158), and patients in paper 1 reported adherence rates of above 90% for duration and frequency. Lyngcole reported adherence rates of 70% in patients undergoing radius fracture rehabilitation (96). To measure adherence, Lyngcole used the self-reported exercise count divided by the exercise count recommended by the therapist. This way of measuring adherence has been shown to be more accurate because the patient may be less accurate in reporting recommended exercise amount (94). The way we measured adherence in paper 1 should be considered when interpreting the results, and the high adherence rate reported by the patients may be influenced by an inaccurate reporting of the recommended exercise amount. Nevertheless, the way we used self-reported adherence could be seen as corresponding to intentional non-adherence, which is important and corresponds to the result of paper 2.

Self-efficacy is not a general construct, it is related to the specific task of interest, which in our case is home-based rehabilitation after flexor tendon repair. Because of this, the measure of self-efficacy should also be specific to the task of interest (186). A review of self-efficacy scales on home-based rehabilitation in musculoskeletal conditions could not find any measures used for that specific task (187). Our solution to be able to assess self-efficacy in paper 1 was to translate the scale we found to be most task-specific. This approach obviously does not involve psychometric testing, which renders problems that should be considered during the interpretation of our results. On problem may be a celling effect in the responses which compromises the ability to detect change. In our study, 38% of participants had AISEQ scores >95, which may indicate a ceiling effect (188).

The randomised trial has the highest scientific value when comparing treatments, however, the sometimes-narrow inclusion criteria may decrease the generalizability of a study. In paper 1, patients were asked to participate if they owned a smartphone and were able to speak Swedish. This means that non-Swedish speaking patients who may already have compromised communication were excluded. Socially deprived patients have been shown to have lower attendance to therapy sessions and lower ROM after flexor tendon repairs (189). The best way would have been to make the smartphone application and questionnaires available in different languages and to all patients, but the resources for paper 1 did not allow this.

In paper 2 we used the HBM as a theoretical framework in the data collection and the deductive analysis process. A deductive approach can be used when there is some existing knowledge about the study phenomenon (190). The HBM is one of the most established theories regarding health-related behaviour. Previous adherence research in the context of upper limb rehabilitation using health theories has also used the HBM (86) and WHO´s five dimensions of adherence (109). To assess the trustworthiness of qualitative research the most used concepts are, credibility, transferability, dependability, and confirmability according to the paper by Guba in 1981 (191). Authenticity was later added to these concepts. These could be seen as the validity, reliability, and objectivity aspects of qualitative research. Using a directed content analysis approach has advantages and disadvantages. One advantage is that it can increase credibility as it systematises the data collection and analysis process. Credibility concerns the plausibility of the research, if the results of the research correspond to the participant's view and if the analysis process corresponds to the intended focus (192, 193). To increase credibility further we aimed to create a variation in the description of the phenomenon via inclusion of participants with different ages, genders and outcomes (193). The disadvantage of directed content analysis is that the researcher can be restricted and biased by the theoretical framework in data collection and analysis (194), which affects the research confirmability. Confirmability in the qualitative method is comparable with objectivity or neutrality (192). We handled this by considering new categories for data not captured by the categorisation matrix. To further show the confirmability of the paper we reported quotes for each category along with a table to show the connection to the data (195). Dependability concerns the consistency of the research in general and in relation to the method used (196). In order to ensure dependability, we followed the steps in the paper by Assarroudi (161) and made notes on meetings and decisions made during the research process. Although the reported findings in paper 4 are related to its context, the rich description of the outcome may enable transferability to other contexts (197). The findings could be of value for clinicians working with patients with flexor tendon injuries or other hand conditions with high demands on patient participation and adherence to rehabilitation protocols. Authenticity includes the aspect that the qualitative research process can change participants´ and the researcher´s perceptions of the research phenomenon (198). To minimise the impact of this, the interviewer presented himself as researcher, instead of a physiotherapist with experience of treating patients after flexor tendon repair. The use of the theoretical framework may also enhance authenticity along with the collaboration between the authors.

Paper 3 and 4 were retrospective cohort studies based on register data from HAKIR and Statistics Sweden. Register data and the retrospective cohort design have some disadvantages and advantages. One advantage is that the data has already been collected. Moreover, one could also argue that there is a lack of bias as the data has already been collected without the specific study purpose in mind (199). Another advantage of register data in paper 4 was that it enabled a uniform assessment of data at three and 12 months after repair. Previously published papers on relation the between PROMs and clinical outcome have had great variability in follow-up time (127, 182, 183). One limitation to consider is the missing data. In paper 3 this was a concern mainly regarding data from the suture procedure and educational level. All variables regarding the suture had between 15 and 20% missing data and level of education had 26% (Appendix). This left model 1 in the multiple logistic regression with only 764 complete cases. We tried to assess the effect of missing data by comparing the frequency of the outcome and distribution within each subcategory between the models. In paper 4, the number of patients with complete post operative data from HAKIR was 215 at the three months follow-up, and 150 at the 12 months follow-up. Although paper 4 had a higher number of patients compared to the similar study by Karjalainen (127) the amount of missing data may affect the generalizability. Papers 3 and 4 used a similar cohort of patients, expect one years longer inclusion time, exclusion of FPL injuries and patients below the age of 16 in paper 4. The distribution of injury characteristics in both papers is similar, paper 4 had a higher number of women and a slightly higher median age in the population.

The HQ-8 questionnaire used in paper 4 has previously been psychometrically tested to some extent to a hand surgery population but not to the specific population after flexor tendon repair. This limits some potential further interpretations of the results. To use DASH after flexor tendon repair is not unproblematic. It was developed to assess disability in the upper extremities, and it has not been psychometrically tested for flexor tendon injuries The score is sometimes reported within the scores of a normal population, which could indicate a flooring affect. The MHQ has been suggested as a better PROM to use after finger injuries (118) but it is not frequently used after flexor tendon repair. A recent Rasch analysis has shown that the validity of the MHQ scoring may be questioned (200), which adds further uncertainty to the question of which PROM to use after flexor tendon injury.

Another limitation of paper 3 was that we could not assess some potential important risk factors or confounders. Injury mechanism has been shown to affect reoperation rates (67). Smoking is another factor that we did not assess that may affect ROM (62) and rupture risk (65). The large amount of missing data on the rehabilitation protocol in paper 3 made us exclude that variable. As mentioned in the introduction, the rehabilitation protocol is also a variable to consider when assessing rupture risk and tenolysis.

6 CONCLUSIONS

- The smartphone application evaluated in paper 1 could not improve adherence, self-efficacy or ROM. Further research is needed on interventions for improving adherence to home-based exercise after flexor tendon repair.

- Patients' perceptions of the injury, the cost and benefits of rehabilitation, context, and support to manage daily activities affect adherence to restrictions on hand use and exercises during the first three months of rehabilitation. The theoretical framework of the HBM could be considered when trying to understand adherence to flexor tendon rehabilitation.

- Several risk factors were associated with reoperation risk. Male sex, age and injury to the FPL increased the risk of reoperation due to tendon rupture. Injury to the FDS and FDP increased the risk for reoperation both for rupture and tenolysis. The frequency of reoperation with tenolysis increased with income. Understanding these risk factors provides important knowledge.

- Patient-reported stiffness, ability to perform daily activities, Quick-DASH score and perceived satisfaction had an association with the levels of the original Strickland classification, but only between some independent levels of classification. This means that the classification did not correspond well with the patients perception of the outcome.

7 CLINICAL IMPLICATIONS

- Based on our research in paper 1 we could not recommend using the smartphone application used in paper 1 in its current form for all patients to improve adherence. However, some patients may benefit from using it as a complement to standard rehabilitation. Improved techniqal features for personalised feedback and communication with the therapist could be benifical in similar applications in the future.

- The results of paper 2 provide a patient-based view of the complex underlying reasons for adherence to rehabilitation after flexor tendon repair. Several clinical implications can be suggested. Information regarding the potential consequences of the injury and rehabilitation should be presented in an individual way and at different times during rehabilitation. To facilitate the patient's perception of the small improvement in hand function during rehabilitation is important in order to facilitate motivation to continue with the exercises. It is also important to help patients reduce the cost of adhering to restrictions in hand use by using individual based strategies to cope with daily activities. The instructions could also be less complex and could consider patients' needs to a higher extent.

- Much previous research has focused on the suture, techniques for flexor tendon repair making them strong enough to withstand active mobilisation. The results of paper 3 show the importance of also considering the characteristics of the injury and patient related factors when assessing complication risk. How to best mediate the higher risk of complications identified in this thesis is an interesting question outside the scope of our research, but clinical implications to improve adherence mentioned above could be one way to do so.

- In paper 4 we showed that classifying the outcome in terms of fair, poor, good or excellent according to the Original Strickland system have limited value for how the patients perceive their disability, their symptoms and the satisfaction with the results. This understanding is helpful during rehabilitation as it could suggest different treatment options in the future which target these areas. We also identified 70% of normal ROM as the most important cut-off point in terms of PROMs. This suggests that about 120 degrees of TAM in the PIP and DIP joints is important to reach during rehabilitation.

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8 FUTURE RESEARCH

Adherence to exercise and restrictive hand use during rehabilitation is probably a key to reducing the complications after flexor tendon repair, but still there is little known about how to facilitate adherence. This thesis has shown that several factor can increase the risk for complications after flexor tendon repair. A great amount of research done has focused on surgical techniques and rehabilitation protocols, but few studies have tried to mediate the increased risk associated with demographic- or injury-related factors. Future studies should aim to decrease complications by focusing on these factors along with adherence. If we understand the reasons for lack of adherence better, along with the influence of the individual patient and their specific injury, I believe that it may allow better accuracy in future interventions regarding rehabilitation. The technological development including the role of smartphone applications in hand therapy has developed since the work on this thesis started (112). Technologies such as ROM assessments through smartphones (201, 202), feedback guide in touch screens during exercises (168) and gamification of rehabilitation (203). The role of these developments regarding adherence to flexor tendon rehabilitation, as well as future developments, should be assessed. After we identified a poor association between clinical categorisation of outcome and PROMs I started to contemplate the underlying causes of this and whether patients or injury factors could explain some of the results in PROM. It is unclear how the location of the injury affects the perception of disability, or if patients´ perceptions of the outcome are affected by their stages in life or mood. Although the findings of this thesis suggest that the patient’s perception of their injury may affect adherence there is still room for future research assessing this role.

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10 REFERENCES

1. Adamson JE, Wilson JN. The History of Flexor-Tendon Grafting. Journal of bone and joint surgery American volume. 1961;43(5):709-16.

2. Kleinert HE, Špokevičius S, Papas NH. History of flexor tendon repair. The Journal of hand surgery (American ed). 1995;20(3):S46-S52.

3. HAUGE MF. The results of tendon suture of the hand; a review of 500 patients. Acta Orthop Scand. 1955;24(3):258-70.

4. Pulvertaft RG. TENDON GRAFTS FOR FLEXOR TENDON INJURIES IN THE FINGERS AND THUMB. Journal of bone and joint surgery British volume. 1956;38-B(1):175-94.

5. Smutz WP, Kongsayreepong A, Hughes RE, Niebur G, Cooney WP, An KN. Mechanical advantage of the thumb muscles. J Biomech. 1998;31(6):565-70.

6. Wehbé MA, Hunter JM. Flexor tendon gliding in the hand. Part I. In vivo excursions. J Hand Surg Am. 1985;10(4):570-4.

7. Goodman HJ, Choueka J. Biomechanics of the flexor tendons. Hand Clin. 2005;21(2):129-49.

8. Rosberg H-E, Dahlin LB. Epidemiology of hand injuries in a middle-sized city in Southern sweden: a retrospective comparison of 1989 and 1997. 2004;38(6):347-55.

9. de Jong JP, Nguyen JT, Sonnema AJ, Nguyen EC, Amadio PC, Moran SL. The incidence of acute traumatic tendon injuries in the hand and wrist: a 10-year population-based study. Clin Orthop Surg. 2014;6(2):196-202.

10. Tang JB. Flexor Tendon Injuries. Clin Plast Surg. 2019;46(3):295-306.

11. Voleti PB, Buckley MR, Soslowsky LJ. Tendon Healing: Repair and Regeneration. Annual review of biomedical engineering. 2012;14(1):47-71.

12. Lilly SI, Messer TM. Complications after treatment of flexor tendon injuries. Journal of the American Academy of Orthopaedic Surgeons. 2006;14(7):387-96.

13. Beredjiklian PK. Biologic aspects of flexor tendon laceration and repair. Journal of bone and joint surgery. 2003;85(3):539-50.

14. Titan AL, Foster DS, Chang J, Longaker MT. Flexor Tendon: Development, Healing, Adhesion Formation, and Contributing Growth Factors. Plastic and reconstructive surgery (1963). 2019;144(4):639e-47e.

15. Manninen M, Karjalainen T, Määttä J, Flinkkilä T. Epidemiology of Flexor Tendon Injuries of the Hand in a Northern Finnish Population. Scandinavian Journal of Surgery. 2017;106(3):278-82.

16. Edsfeldt S, Eklund M, Wiig M. Prognostic factors for digital range of motion after intrasynovial flexor tendon injury and repair: Long-term follow-up on 273 patients treated with active extension-passive flexion with rubber bands. J Hand Ther. 2018.

17. Rosberg HE, Carlsson KS, Höjgård S, Lindgren B, Lundborg G, Dahlin LB. What determines the costs of repair and rehabilitation of flexor tendon injuries in zone II? A

multiple regression analysis of data from southern Sweden. J Hand Surg Br. 2003;28(2):106-12.

18. Ishak A, Rajangam A, Khajuria A. The evidence-base for the management of flexor tendon injuries of the hand: Review. Annals of medicine and surgery. 2019;48:1-6.

19. Strickland JW. The scientific basis for advances in flexor tendon surgery. Journal of hand therapy official journal of the American Society of Hand Therapists.18(2):94-110; quiz 1.

20. Wu YF, Tang JB. Recent developments in flexor tendon repair techniques and factors influencing strength of the tendon repair. J Hand Surg Eur Vol. 2014;39(1):6-19.

21. Hardwicke JT, Tan JJ, Foster MA, Titley OG. A systematic review of 2-strand versus multistrand core suture techniques and functional outcome after digital flexor tendon repair. J Hand Surg Am. 2014;39(4):686-95.e2.

22. Moriya K, Yoshizu T, Tsubokawa N, Narisawa H, Hara K, Maki Y. Clinical results of releasing the entire A2 pulley after flexor tendon repair in zone 2C. J Hand Surg Eur Vol. 2016;41(8):822-8.

23. Tang JB, Cao Y, Wu YF, Wang GH. Effect of A2 pulley release on repaired tendon gliding resistance and rupture in a chicken model. J Hand Surg Am. 2009;34(6):1080-7.

24. Cao Y, Zhu B, Xie RG, Tang JB. Influence of core suture purchase length on strength of four-strand tendon repairs. J Hand Surg Am. 2006;31(1):107-12.

25. Kim JB, de Wit T, Hovius SE, McGrouther DA, Walbeehm ET. What is the significance of tendon suture purchase? J Hand Surg Eur Vol. 2009;34(4):497-502.

26. Rawson S, Cartmell S, Wong J. Suture techniques for tendon repair; a comparative review. Muscles Ligaments Tendons J. 2013;3(3):220-8.

27. Strickland JW, Glogovac SV. Digital function following flexor tendon repair in Zone II: A comparison of immobilization and controlled passive motion techniques. J Hand Surg Am. 1980;5(6):537-43.

28. Feehan LM, Beauchene JG. Early tensile properties of healing chicken flexor tendons: Early controlled passive motion versus postoperative immobilization. The Journal of hand surgery (American ed). 1990;15(1):63-8.

29. Bigorre N, Delaquaize F, Degez F, Celerier S. Primary flexor tendons repair in zone 2: Current trends with GEMMSOR survey results. Hand Surgery and Rehabilitation. 2018;37(5):281-8.

30. Neiduski RL, Powell RK. Flexor tendon rehabilitation in the 21st century: A systematic review. J Hand Ther. 2019;32(2):165-74.

31. Kleinert HE, Kutz JE, Atasoy E, Stormo A. Primary repair of flexor tendons. Orthop Clin North Am. 1973;4(4):865-76.

32. Duran R, Houser R, Hunter J, Schneider L. AAOS symposium on tendon surgery in the hand. CB Mosby Co. St. Louis; 1975.

33. Silfverskiöld KL, May EJ. Flexor tendon repair in zone II with a new suture technique and an early mobilization program combining passive and active flexion. J Hand Surg Am. 1994;19(1):53-60.

34. Elliot D, Moiemen NS, Flemmings AFS, Harris SB, Foster J. The rupture rate of acute flexor tendon repairs mobilized by the controlled active motion regim. Journal of hand surgery1994. p. 607-12.

35. Starr HM, Snoddy M, Hammond KE, Seiler JG. Flexor tendon repair rehabilitation protocols: a systematic review. J Hand Surg Am. 2013;38(9):1712-7.e1-14.

36. Chesney A, Chauhan A, Kattan A, Farrokhyar F, Thoma A. Systematic review of flexor tendon rehabilitation protocols in zone II of the hand. Plast Reconstr Surg. 2011;127(4):1583-92.

37. Xu H, Huang X, Guo Z, Zhou H, Jin H. Outcome of Surgical Repair and Rehabilitation of Flexor Tendon Injuries in Zone II of the Hand: Systematic Review and Meta-Analysis. J Hand Surg Am. 2022.

38. Wang J, Qian L, Liu Z, Wang X, Li-Tsang C, Li J, et al. Ultrasonographic assessment in vivo of the excursion and tension of flexor digitorum profundus tendon on different rehabilitation protocols after tendon repair. J Hand Ther. 2021.

39. Korstanje JW, Soeters JN, Schreuders TA, Amadio PC, Hovius SE, Stam HJ, et al. Ultrasonographic assessment of flexor tendon mobilization: effect of different protocols on tendon excursion. J Bone Joint Surg Am. 2012;94(5):394-402.

40. Silva MJ, Brodt MD, Boyer MI, Morris TS, Dinopoulos H, Amiel D, et al. Effects of increased in vivo excursion on digital range of motion and tendon strength following flexor tendon repair. J Orthop Res. 1999;17(5):777-83.

41. Peters SE, Jha B, Ross M. Rehabilitation following surgery for flexor tendon injuries of the hand. Cochrane library. 2021;2021(1):CD012479-CD.

42. Jokinen K, Häkkinen A, Luokkala T, Karjalainen T. Clinical Outcomes After Aggressive Active Early Motion and Modified Kleinert Regimens: Comparison of 2 Consecutive Cohorts. Hand (New York, NY). 2021:155894472110172-15589447211017222.

43. Peck FH, Bücher CA, Watson JS, Roe A. A comparative study of two methods of controlled mobilization of flexor tendon repairs in zone 2. J Hand Surg Br. 1998;23(1):41-5.

44. Kursa K, Lattanza L, Diao E, Rempel D. In vivo flexor tendon forces increase with finger and wrist flexion during active finger flexion and extension. J Orthop Res. 2006;24(4):763-9.

45. Savage R. The influence of wrist position on the minimum force required for active movement of the interphalangeal joints. J Hand Surg Br. 1988;13(3):262-8.

46. Woythal DL. Splints, with or without wrist immobilization, following surgical repair of flexor tendon lesions of the hand: a systematic review. Hand Surgery and Rehabilitation. 2019.

47. Kaskutas V, Powell R. The impact of flexor tendon rehabilitation restrictions on individuals' independence with daily activities: implications for hand therapists. J Hand Ther. 2013;26(1):22-8; quiz 9.

48. Schier JS, Chan J. Changes in life roles after hand injury. J Hand Ther. 2007;20(1):57-68; quiz 9.

49. Gustafsson M, Persson L-O. A qualitative study of coping in the early stage of acute traumatic hand injury. Journal of Clinical nursing. 2002;11:594-602.

50. Fitzpatrick N, Finlay L. Frustrating disability: The lived experience of coping with the rehabilitation phase following flexor tendon surgery. International Journal of Qualitative Studies on Health and Well-Being, 2008, Vol3(3), p143-154. 2008;3(3):143-54.

51. Trumble TE, Vedder NB, Seiler JG, Hanel DP, Diao E, Pettrone S. Zone-II Flexor Tendon Repair: A Randomized Prospective Trial of Active Place-and-Hold Therapy Compared with Passive Motion Therapy. Journal of bone and joint surgery American volume. 2010;92(6):1381-9.

52. Wu YF, Tang JB. Tendon healing, edema, and resistance to flexor tendon gliding: clinical implications. Hand Clin. 2013;29(2):167-78.

53. Zhao C, Amadio PC, Paillard P, Tanaka T, Zobitz ME, Larson DR, et al. Digital Resistance and Tendon Strength During the First Week After Flexor Digitorum Profundus Tendon Repair in a Canine Model In Vivo. Journal of bone and joint surgery American volume. 2004;86(2):320-7.

54. Cao Y, Tang JB. Resistance to motion of flexor tendons and digital edema: An in vivo study in a chicken model. J Hand Surg Am. 2006;31(10):1645-51.

55. Tang JB. Indications, methods, postoperative motion and outcome evaluation of primary flexor tendon repairs in Zone 2. J Hand Surg Eur Vol. 2007;32(2):118-29.

56. P P. Outcome of zon 2 flexor tendon injuries: Kleinert versus controlled active motion therapy regimens. In: MN, Joannis Constantinides, Janet Hunter, Angela Henry, Lore Feldberg., editor. Hand Therapy: sagepub; 2011. p. 102-6.

57. Gelberman RH, Nunley JA, Osterman AL, Breen TF, Dimick MP, Woo SL. Influences of the protected passive mobilization interval on flexor tendon healing. A prospective randomized clinical study. Clin Orthop Relat Res. 1991(264):189-96.

58. Takai S, Woo SL, Horibe S, Tung DK, Gelberman RH. The effects of frequency and duration of controlled passive mobilization on tendon healing. J Orthop Res. 1991;9(5):705-13.

59. Momeni A, Grauel E, Chang J. Complications after flexor tendon injuries. Hand Clin. 2010;26(2):179-89.

60. Dy CJ, Daluiski A, Do HT, Hernandez-Soria A, Marx R, Lyman S. The epidemiology of reoperation after flexor tendon repair. J Hand Surg Am. 2012;37(5):919-24.

61. Dy CJ, Hernandez-Soria A, Ma Y, Roberts TR, Daluiski A. Complications after flexor tendon repair: a systematic review and meta-analysis. J Hand Surg Am. 2012;37(3):543-51.e1.

62. Rigo IZ, Røkkum M. Predictors of outcome after primary flexor tendon repair in zone 1, 2 and 3. J Hand Surg Eur Vol. 2016;41(8):793-801.

63. Harris SB, Harris D, Foster AJ, Elliot D. The aetiology of acute rupture of flexor tendon repairs in zones 1 and 2 of the fingers during early mobilization. J Hand Surg Br. 1999;24(3):275-80.

64. Effect of Time to Hand Therapy following Zone II Flexor Tendon Repair. Plastic and reconstructive surgery Global open. 2020;8(12):e3278-e.

65. Hurley CM, Reilly F, Callaghan S, Baig MN. Negative Predictors of Outcomes of Flexor Tendon Repairs. Cureus. 2019;11(3):e4303.

66. Reito A, Manninen M, Karjalainen T. The Effect of Delay to Surgery on Major Complications after Primary Flexor Tendon Repair. J Hand Surg Asian Pac Vol. 2019;24(2):161-8.

67. Starnes T, Saunders RJ, Means KR. Clinical outcomes of zone II flexor tendon repair depending on mechanism of injury. J Hand Surg Am. 2012;37(12):2532-40.

68. Strickland JW. Flexor tendon surgery Part 2: Free tendon grafts and tenolysis. Journal of Hand Surgery. 1989;14(4):368-82.

69. Moriya K, Yoshizu T, Tsubokawa N, Narisawa H, Maki Y. Incidence of tenolysis and features of adhesions in the digital flexor tendons after multi-strand repair and early active motion. J Hand Surg Eur Vol. 2019;44(4):354-60.

70. Civan O, Gürsoy MK, Cavit A, Özcanlı H, Karalezli MN. Tenolysis rate after zone 2 flexor tendon repairs. Jt Dis Relat Surg. 2020;31(2):281-5.

71. McKay CD, Verhagen E. ‘Compliance’ versus ‘adherence’ in sport injury prevention: why definition matters. British journal of sports medicine. 2016;50(7):382-3.

72. Cramer J A, Roy A, Burrell A, Fairchild C J, Fuldeore M, Ollendorf D, et al. Medication Compliance and Persistence: Terminology and Definitions. Value in health. 2008;11(1):44-7.

73. Tilson HH. Adherence or Compliance? Changes in Terminology. The Annals of pharmacotherapy. 2004;38(1):161-2.

74. World Health O. Adherence to Long-term Therapies : Evidence for Action. Geneva: Geneva: World Health Organization; 2003.

75. Argent R, Daly A, Caulfield B. Patient Involvement With Home-Based Exercise Programs: Can Connected Health Interventions Influence Adherence? JMIR mHealth and uHealth. 2018;6(3):e47-e.

76. Bissell P, May CR, Noyce PR. From compliance to concordance: barriers to accomplishing a re-framed model of health care interactions. Social science & medicine (1982). 2004;58(4):851-62.

77. Bell JS, Airaksinen MS, Lyles A, Chen TF, Aslani P. Concordance is not synonymous with compliance or adherence. British journal of clinical pharmacology. 2007;64(5):710-1.

78. Steward B. Compliance, Adherence and Concordance: A Review of Engaging Patients in their Treatment. Hand Therapy. 2004;9(3):88-95.

79. Johnson MJ, Williams M, Marshall ES. Adherent and Nonadherent Medication-Taking in Elderly Hypertensive Patients. Clinical nursing research. 1999;8(4):318-35.

80. Kirwan T, Tooth L, Harkin C. Compliance with hand therapy programs: therapists' and patients' perceptions. J Hand Ther. 2002;15(1):31-40.

81. Michie S, West R, Campell R, Brown J, Gainforth H. ABC of behaviour change theories. Great Britain: Silverback Publishing; 2014.

82. Davis R, Campbell R, Hildon Z, Hobbs L, Michie S. Theories of behaviour and behaviour change across the social and behavioural sciences: a scoping review. Health psychology review. 2015;9(3):323-44.

83. Rosenstock IM. Historical Origins of the Health Belief Model. Health education & behavior. 1974;2(4):328-35.

84. Rosenstock IM, Strecher VJ, Becker MH. Social learning theory and the Health Belief Model. Health Educ Q. 1988;15(2):175-83.

85. Bandura A. Self-efficacy: toward a unifying theory of behavioral change. The psychological review. 1977;84(2):191-215.

86. Groth GN, Wulf MB. Compliance with hand rehabilitation: health beliefs and strategies. J Hand Ther. 1995;8(1):18-22.

87. Frost R, Levati S, McClurg D, Brady M, Williams B. What Adherence Measures Should Be Used in Trials of Home-Based Rehabilitation Interventions? A Systematic Review of the Validity, Reliability, and Acceptability of Measures. Archives of Physical Medicine and Rehabilitation. 2017;98(6):1241-56.e45.

88. Bollen JC, Dean SG, Siegert RJ, Howe TE, Goodwin VA. A systematic review of measures of self-reported adherence to unsupervised home-based rehabilitation exercise programmes, and their psychometric properties. BMJ Open. 2014;4(6).

89. Newman-Beinart NA, Norton S, Dowling D, Gavriloff D, Vari C, Weinman JA, et al. The development and initial psychometric evaluation of a measure assessing adherence to prescribed exercise: the Exercise Adherence Rating Scale (EARS). Physiotherapy. 2017;103(2):180-5.

90. Kirby S, Donovan-Hall M, Yardley L. Measuring barriers to adherence: validation of the problematic experiences of therapy scale. Disability & Rehabilitation, 2014, Vol36(22), p1924-1929. 2014;36(22):1924-9.

91. Brewer, W B. Preliminary psychometric evaluation of a measure of adherence to clinic-based sport injury rehabilitation. Physical therapy in sport. 2000;1:68-74.

92. Brewer BW, Avondoglio JB, Cornelius AE, Van Raalte JL, Brickner JC, Petitpas AJ, et al. Construct validity and interrater agreement of the sport injury rehabilitation adherence scale. Journal of Sport Rehabilitation. 2002;11(3):170-8.

93. Gregory, Kolt. S, W B, Brewer., Tania, Pizzari., et al. The sport injury rehabilitation adherence scale: a reliable scale for use in Clinical physiotherapy. Physiotherapy. 2007;93:17-22.

94. Chen C, Neufeld P, Feely C, Skinner C. Factors influencing compliance with home exercise programs among patients with upper-extremity impairment. American Journal of Occupational Therapy. 1999;53(March/April):171-80.

95. Groth GN, Wilder DM, Young VL. The impact of compliance on the rehabilitation of patients with mallet finger injuries. J Hand Ther. 1994;7(1):21-4.

96. Lyngcoln A, Taylor N, Pizzari T, Baskus K. The relationship between adherence to hand therapy and short-term outcome after distal radius fracture. J Hand Ther. 2005;18(1):2-8; quiz 9.

97. Hickey S, Rodgers J, Wollstein R. Barriers to Adherence with Post-Operative Hand Therapy Following Surgery for Fracture of the Distal Radius. 2015;7(1):55-60.

98. Davies G, Yeomans D, Tolkien Z, Kreis IA, Potter S, Gardiner MD, et al. Methods for assessment of patient adherence to removable orthoses used after surgery or trauma to the appendicular skeleton: a systematic review. Trials. 2020;21(1):507-.

99. Savaş S, Aydoğan Ç. Factors affecting orthosis adherence after acute traumatic hand tendon repairs: A prospective cohort study. J Hand Ther. 2020.

100. Sandford F, Barlow N, Lewis J. A study to examine patient adherence to wearing 24-hour forearm thermoplastic splints after tendon repairs. J Hand Ther. 2008;21(1):44-52; quiz 3.

101. DiMatteo MR, Patrick JG, Heidi SL, Thomas WC. Patient Adherence and Medical Treatment Outcomes A Meta-Analysis. Medical care. 2002;40(9):794-811.

102. Ahmad SMO, Haber MF, Bokor DJF. The influence of intraoperative factors and postoperative rehabilitation compliance on the integrity of the rotator cuff after arthroscopic repair. Journal of shoulder and elbow surgery. 2015;24(2):229-35.

103. Kolt GS, McEvoy JF. Adherence to rehabilitation in patients with low back pain. Manual therapy. 2003;8(2):110.

104. Toker S, Oak N, Williams A, Ipaktchi K, Ozer K. Adherence to therapy after flexor tendon surgery at a level 1 trauma center. Hand. 2014;9(2):175-8.

105. Su BW, Solomons M, Barrow A, Senoge ME, Gilberti M, Lubbers L, et al. Device for zone-II flexor tendon repair. A multicenter, randomized, blinded, clinical trial. J Bone Joint Surg Am. 2005;87(5):923-35.

106. Abraham C, Michie S. A Taxonomy of Behavior Change Techniques Used in Interventions. Health psychology. 2008;27(3):379-87.

107. Michie S, Richardson M, Johnston M, Abraham C, Francis J, Hardeman W, et al. The Behavior Change Technique Taxonomy (v1) of 93 Hierarchically Clustered Techniques: Building an International Consensus for the Reporting of Behavior Change Interventions. Annals of behavioral medicine. 2013;46(1):81-95.

108. Cole T, Robinson L, Romero L, O'Brien L. Effectiveness of interventions to improve therapy adherence in people with upper limb conditions: A systematic review. J Hand Ther. 2017.

109. Lisa OB. Adherence to therapeutic splint wear in adults with acute upper limb injuries: a systematic review. Hand therapy. 2010;15:3-12.

110. O'Brien L, Presnell S. Patient experience of distraction splinting for complex finger fracture dislocations. J Hand Ther. 2010;23(3):249-9; quiz 60.

111. Powell RK, von der Heyde RL. The inclusion of activities of daily living in flexor tendon rehabilitation: a survey. J Hand Ther. 2014;27(1):23-9.

112. Valdes K, Gendernalik E, Hauser J, Tipton M. Use of mobile applications in hand therapy. J Hand Ther. 2020;33(2):229-34.

113. Algar L, Valdes K. Using smartphone applications as hand therapy interventions. Journal of hand therapy. 2014;27(3):254-7.

114. Then JW, Shivdas S, Choo PT, Then JW, Shivdas S, Tunku Ahmad Yahaya TS, et al. Gamification in rehabilitation of metacarpal fracture using cost-effective end-user device: A randomized controlled trial. Journal of hand therapy : official journal of the American Society of Hand Therapists. 2020;33(2):235-42.

115. Essery R, Geraghty AWA, Kirby S, Yardley L. Predictors of adherence to home-based physical therapies: a systematic review. Taylor & Francis; 2017. p. 519-34.

116. Jack K, McLean SM, Moffett JK, Gardiner E. Barriers to treatment adherence in physiotherapy outpatient clinics: a systematic review. Man Ther. 2010;15(3):220-8.

117. Peek K, Sanson-Fisher R, Mackenzie L, Carey M. Interventions to aid patient adherence to physiotherapist prescribed self-management strategies: a systematic review. Physiotherapy. 2016;102(2):127-35.

118. Wouters RM, Jobi-Odeneye AO, de la Torre A, Joseph A, Hovius SER, Group IHaWW. A Standard Set for Outcome Measurement in Patients With Hand and Wrist Conditions: Consensus by the International Consortium for Health Outcomes Measurement Hand and Wrist Working Group. J Hand Surg Am. 2021;46(10):841-55.e7.

119. Shaw AV, Holmes DG, Rodrigues JN, Lane JC, Gardiner MD, Wormald JC. Outcome measurement in adult flexor tendon injury: A systematic review. Journal of plastic, reconstructive & aesthetic surgery. 2021.

120. Mallina R, Bamford E, Shelton I, Selby A, Russell P, Johnson N. A Review of Outcome Reporting Practices after Flexor Tendon Repair in Zones 1 and 2. J Hand Surg Asian Pac Vol. 2022;27(2):226-32.

121. Silfverskiöld KL, May EJ, Oden A. Factors affecting results after flexor tendon repair in zone II: a multivariate prospective analysis. J Hand Surg Am. 1993;18(4):654-62.

122. Kleinert HE, Verdan C. Report of the Committee on Tendon Injuries (International Federation of Societies for Surgery of the Hand). J Hand Surg Am. 1983;8(5 Pt 2):794-8.

123. Buck-Gramcko D, Dietrich FE, Gogge S. [Evaluation criteria in follow-up studies of flexor tendon therapy]. Handchirurgie. 1976;8(2):65-9.

124. Lister GD, Kleinert HE, Kutz JE, Atasoy E. Primary flexor tendon repair followed by immediate controlled mobilization. J Hand Surg Am. 1977;2(6):441-51.

125. Braga-Silva J, Kuyven CR. Early active mobilization after flexor tendon repairs in zone two. Chir Main. 2005;24(3-4):165-8.

126. So YC, Chow SP, Pun WK, Luk KD, Crosby C, Ng C. Evaluation of results in flexor tendon repair: a critical analysis of five methods in ninety-five digits. J Hand Surg Am. 1990;15(2):258-64.

127. Karjalainen T, Jokinen K, Sebastin SJ, Luokkala T, Kangasniemi OP, Reito A. Correlations Among Objectively Measured Impairment, Outcome Classification Systems, and Subjectively Perceived Disability After Flexor Tendon Repair. J Hand Surg Am. 2019;44(5):361-5.

128. Libberecht K, Lafaire C, Van Hee R. Evaluation and functional assessment of flexor tendon repair in the hand. Acta Chir Belg. 2006;106(5):560-5.

129. Tang JB. Clinical outcomes associated with flexor tendon repair. Hand Clin. 2005;21(2):199-210.

130. MacDermid JC. Measurement of health outcomes following tendon and nerve repair. J Hand Ther. 2005;18(2):297-312.

131. Coldham F, Lewis J, Lee H. The reliability of one vs. three grip trials in symptomatic and asymptomatic subjects. J Hand Ther. 2006;19(3):318-26; quiz 27.

132. Mathiowetz V, Weber K, Volland G, Kashman N. Reliability and validity of grip and pinch strength evaluations. J Hand Surg Am. 1984;9(2):222-6.

133. Kitis PT, Buker N, Kara IG. Comparison of two methods of controlled mobilisation of repaired flexor tendons in zone 2. Scandinavian journal of plastic and reconstructive surgery and hand surgery / Nordisk plastikkirurgisk forening [and] Nordisk klubb for handkirurgi. 2009;43(3):160-5.

134. Meals RA. Device for zone-II flexor tendon repair. J Bone Joint Surg Am. 2005;87(11):2590-1; author reply 1.

135. Wiig ME, Dahlin LB, Fridén J, Hagberg L, Larsen SE, Wiklund K, et al. PXL01 in sodium hyaluronate for improvement of hand recovery after flexor tendon repair surgery: randomized controlled trial. PLoS One. 2014;9(10):e110735.

136. Chevalley S, Tenfält M, Åhlén M, Strömberg J. Passive Mobilization With Place and Hold Versus Active Motion Therapy After Flexor Tendon Repair: A Randomized Trial. J Hand Surg Am. 2022.

137. Woythal L, Comins JD, Brorson S. Patient-reported outcome measures for patients with hand-specific impairments-A scoping review. Journal of hand therapy : official journal of the American Society of Hand Therapists. 2020;34(4):594-603.

138. Oltman R, Neises G, Scheible D, Mehrtens G, Grüneberg C. ICF components of corresponding outcome measures in flexor tendon rehabilitation - a systematic review. BMC Musculoskelet Disord. 2008;9:139.

139. Valdes K, MacDermid J, Algar L, Connors B, Cyr L, Dickmann S, et al. Hand therapist use of patient report outcome (PRO) in practice: A survey study. Journal of hand therapy. 2014;27(4):299-308.

140. Dacombe PJ, Amirfeyz R, Davis T. Patient-Reported Outcome Measures for Hand and Wrist Trauma: Is There Sufficient Evidence of Reliability, Validity, and Responsiveness? Hand. 2016;11(1):11-21.

141. Beaton DE, Wright JG, Katz JN, Group UEC. Development of the QuickDASH: comparison of three item-reduction approaches. J Bone Joint Surg Am. 2005;87(5):1038-46.

142. Wong J, Fung B, Chu M, Chan R. The Use of Disabilities of the Arm, Shoulder, and Hand Questionnaire in Rehabilitation After Acute Traumatic Hand Injuries. Journal of hand therapy. 2007;20(1):49-56.

143. Koehler SV, Sauerbier M, Terzis A. Rupture Rate, Functional Outcome and Patient Satisfaction after Primary Flexor Tendon Repair with the Modified 4-Strand Core Suture Technique by Tsuge and Using the Arthrex FiberLoop. J Clin Med. 2021;10(19).

144. Aasheim T, Finsen V. The DASH and the QuickDASH instruments. Normative values in the general population in Norway. J Hand Surg Eur Vol. 2014;39(2):140-4.

145. Kazmers NH, Qiu Y, Yoo M, Stephens AR, Tyser AR, Zhang Y. The Minimal Clinically Important Difference of the PROMIS and QuickDASH Instruments in a Nonshoulder Hand and Upper Extremity Patient Population. J Hand Surg Am. 2020;45(5):399-407.e6.

146. Franchignoni F, Vercelli S, Giordano A, Sartorio F, Bravini E, Ferriero G. Minimal clinically important difference of the disabilities of the arm, shoulder and hand outcome measure (DASH) and its shortened version (QuickDASH). J Orthop Sports Phys Ther. 2014;44(1):30-9.

147. Stenekes MW, Geertzen JH, Nicolai JP, De Jong BM, Mulder T. Effects of motor imagery on hand function during immobilization after flexor tendon repair. Arch Phys Med Rehabil. 2009;90(4):553-9.

148. Riaz M, Hill C, Khan K, Small JO. Long term outcome of early active mobilization following flexor tendon repair in zone 2. J Hand Surg Br. 1999;24(2):157-60.

149. Frostadottir D, Ekman L, Zimmerman M, Andersson S, Arner M, Brogren E, et al. Cold sensitivity, functional disability and predicting factors after a repaired digital nerve injury. Scientific reports. 2022;12(1):4847-.

150. Arner M. Developing a national quality registry for hand surgery: challenges and opportunities. EFORT Open Reviews. 2016;1(4):100-6.

151. Carlsson I, Ekstrand E, Åström M, Stihl K, Arner M. Construct validity, floor and ceiling effects, data completeness and magnitude of change for eight-item HAKIR questionnaire: a patients-reported outcome in the Swedish National Healthcare Quality Registry for hand surgery. Hand Therapy. 2020;0:1-14.

152. Wilcke MK, Evans K, Franko MA, Arner M. Trapeziectomy with or without a tendon-based adjunct: a registry-based study of 650 thumbs. The Journal of hand surgery, European volume. 2022;47(7):728-33.

153. von Kieseritzky J, Nordström J, Arner M. Reoperations and postoperative complications after osteosynthesis of phalangeal fractures: a retrospective cohort study. Journal of plastic surgery and hand surgery. 2017;51(6):458-62.

154. Egund L, Önnby K, McGuigan F, Åkesson K. Disability and Pain are the Best Predictors of Sick Leave After a Distal Radius Fracture in Men. Journal of occupational rehabilitation. 2020;30(4):656-64.

155. MacDermid JC, Roth JH, McMurtry R. Predictors of time lost from work following a distal radius fracture. Journal of occupational rehabilitation. 2007;17(1):47-62.

156. Jayakumar P, Teunis T, Vranceanu AM, Lamb S, Ring D, Gwilym S. Relationship Between Magnitude of Limitations and Patient Experience During Recovery from Upper-Extremity Fracture. JB JS Open Access. 2019;4(3).

157. Sordoni C, Hall C, Forwell L. The use of imagery in athletic injury rehabilitation and its relationship to self-efficacy. Physiotherapy Canada. 2002;Summer:177-85.

158. Milne M, Craig H, Lorie F. Self-efficacy. imagery use, and adherence to rehabilitation by injured athletes. J sport rehabil. 2005;14(2):150-67.

159. Wesch N, Hall C, Prapavessis H, Maddison R, Bassett S, Foley L, et al. Self-efficacy, imagery use, and adherence during injury rehabilitation. Scand J Med Sci Sports. 2012;22(5):695-703.

160. Saunders B, Sim J, Kingstone T, Baker S, Waterfield J, Bartlam B, et al. Saturation in qualitative research: exploring its conceptualization and operationalization. Quality & quantity. 2017;52(4):1893-907.

161. Assarroudi A, Heshmati Nabavi F, Armat MR, Ebadi A, Vaismoradi M. Directed qualitative content analysis: the description and elaboration of its underpinning methods and data analysis process. Journal of research in nursing. 2018;23(1):42-55.

162. Bittel CD, Bittel JA, Williams JC, Elazzazi JA. Improving Exercise Performance with an Accelerometer-Based Smartphone App: A Randomized Controlled Trial. American Journal of Physical Medicine & Rehabilitation. 2017;96(5):307-14.

163. Zhuo Y, Pan Y, Lin K, Yin G, Wu Y, Xu J, et al. Effectiveness of clinical pharmacist-led smartphone application on medication adherence, insulin injection technique and glycemic control for women with gestational diabetes receiving multiple daily insulin injection: A randomized clinical trial. Primary care diabetes. 2022.

164. Lambert TE, Harvey LA, Avdalis C, Chen LW, Jeyalingam S, Pratt CA, et al. An app with remote support achieves better adherence to home exercise programs than paper handouts in people with musculoskeletal conditions: a randomised trial. J Physiother. 2017;63(3):161-7.

165. Novak CB, Mak L, Chang M. Evaluation of written and video education tools after mallet finger injury. J Hand Ther. 2019;32(4):452-6.

166. Ouegnin A, Valdes K. Client preferences and perceptions regarding a written home exercise program or video self-modeling: A cross-sectional study. Journal of hand therapy : official journal of the American Society of Hand Therapists. 2019.

167. Rodríguez Sánchez-Laulhé P, Luque-Romero LG, Barrero-García FJ, Biscarri-Carbonero Á, Blanquero J, Suero-Pineda A, et al. An Exercise and Educational and Self-management Program Delivered With a Smartphone App (CareHand) in Adults With Rheumatoid Arthritis of the Hands: Randomized Controlled Trial. JMIR mHealth and uHealth. 2022;10(4):e35462-e.

168. Blanquero J, Cortés-Vega MD, Rodríguez-Sánchez-Laulhé P, Corrales-Serra BP, Gómez-Patricio E, Díaz-Matas N, et al. Feedback-guided exercises performed on a tablet touchscreen improve return to work, function, strength and healthcare usage more than an exercise program prescribed on paper for people with wrist, hand or finger injuries: a randomised trial. J Physiother. 2020;66(4):236-42.

169. Bandura A. Self-efficacy mechanism in human agency. The American psychologist. 1982;37(2):122-47.

170. Kortman B. Patient recall and understanding of instructions concerning splints following a zone 2 flexor tendon repair. The australian occupational therapy journal. 1992;39(2):5-11.

171. Supp G, Schoch W, Baumstark MW, May S. Do patients with low back pain remember physiotherapists' advice? A mixed-methods study on patient-therapist communication. Physiotherapy research international : the journal for researchers and clinicians in physical therapy. 2020;25(4):e1868-n/a.

172. Hansen AØ, Kristensen HK, Cederlund R, Lauridsen HH, Tromborg H. Client-centred practice from the perspective of Danish patients with hand-related disorders. Disability and rehabilitation. 2018;40(13):1542-52.

173. Ackerman JE, Bah I, Jonason JH, Buckley MR, Loiselle AE. Aging does not alter tendon mechanical properties during homeostasis, but does impair flexor tendon healing. J Orthop Res. 2017;35(12):2716-24.

174. Lalchandani GR, Halvorson RT, Zhang AL, Lattanza LL, Immerman I. Patient outcomes and costs after isolated flexor tendon repairs of the hand. J Hand Ther. 2021.

175. Bruin LL, Lans J, Wang F, Eberlin KR, Chen NC. Reoperation Following Zone II Flexor Tendon Repair. Hand. 2022:15589447211043220.

176. Kasashima T, Kato H, Minami A. Factors influencing prognosis after direct repair of the flexor pollicis longus tendon: multivariate regression model analysis. Hand Surg. 2002;7(2):171-6.

177. Sirotakova M, Elliot D. Early active mobilization of primary repairs of the flexor pollicis longus tendon. J Hand Surg Br. 1999;24(6):647-53.

178. Bruin LL, Lans J, Eberlin KR, Chen NC. Zone II Flexor Pollicis Longus Repair: Thumb Flexion and Complications. Hand. 2020:1558944720930294.

179. Rappaport PO, Thoreson AR, Yang T, Reisdorf RL, An K, Amadio PC. Effect of Wrist and Inter-phalangeal Thumb Movement on Zone II Flexor Pollicis Longus Tendon Tension in a Human Cadaver Model. Journal of hand therapy. 2016;29(3):361-2.

180. Lee KS, Jung MC. Effect of hand postures and object properties on forearm muscle activities using surface electromyography. Int J Occup Saf Ergon. 2020;26(1):91-100.

181. Bain GI, Polites N, Higgs BG, Heptinstall RJ, McGrath AM. The functional range of motion of the finger joints. The Journal of hand surgery, European volume. 2015;40(4):406-11.

182. Farzad M, Asgari A, Dashab F, Layeghi F, Karimlou M, Hosseini SA, et al. Does Disability Correlate With Impairment After Hand Injury? Clin Orthop Relat Res. 2015;473(11):3470-6.

183. van Oosterom FJT, Ettema AM, Mulder PGH, Hovius SER. Impairment and Disability After Severe Hand Injuries With Multiple Phalangeal Fractures. The Journal of hand surgery (American ed). 2007;32(1):91-5.

184. Smith-Forbes EV, Howell DM, Willoughby J, Armstrong H, Pitts DG, Uhl TL. Adherence of Individuals in Upper Extremity Rehabilitation: A Qualitative Study. Archives of Physical Medicine and Rehabilitation. 2016;97(8):1262-8.e1.

185. Dobbe J, Trommel N, Freitas Baptista J, Ritt M, Steenbeek A, Molenaar H. A portable device for finger tendon rehabilitation that provides an isotonic training force and records exercise behaviour after finger tendon surgery. Medical & Biological Engineering & Computing. 1999;37(3):396-9.

186. Bandura a. Guide for constructing self-efficacy scales. In: Pajares F, Urdan T, editors. Self-efficacy beliefs of adolecents. United states of america: Information age publilishing inc; 2006. p. 307- 36.

187. Picha KJ, Jochimsen KN, Heebner NR, Abt JP, Usher EL, Capilouto G, et al. Measurements of self-efficacy in musculoskeletal rehabilitation: A systematic review. Musculoskeletal care. 2018;16(4):471-88.

188. Terwee CB, Bot SDM, de Boer MR, van der Windt DAWM, Knol DL, Dekker J, et al. Quality criteria were proposed for measurement properties of health status questionnaires. Journal of clinical epidemiology. 2006;60(1):34-42.

189. Stonner MM, Keane G, Berlet L, Goldfarb CA, Pet MA. The Impact of Social Deprivation and Hand Therapy Attendance on Range of Motion After Flexor Tendon Repair. J Hand Surg Am. 2022.

190. Elo S, Kyngäs H. The qualitative content analysis process. Journal of advanced nursing. 2008;62(1):107-15.

191. Guba EG. ERIC/ECTJ Annual Review Paper: Criteria for Assessing the Trustworthiness of Naturalistic Inquiries. Educational communication and technology. 1981;29(2):75-91.

192. Tobin GA, Begley CM. Methodological rigour within a qualitative framework. Journal of advanced nursing. 2004;48(4):388-96.

193. Graneheim UH, Lundman B. Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. Nurse Education Today. 2004;24(2):105-12.

194. Hsieh H-F, Shannon SE. Three Approaches to Qualitative Content Analysis. Qualitative Health Research. 2005;15(9):1277-88.

195. Cope DG. Methods and meanings: credibility and trustworthiness of qualitative research. Oncology nursing forum. 2014;41(1):89-91.

196. Korstjens I, Moser A. Series: Practical guidance to qualitative research. Part 4: Trustworthiness and publishing. The European journal of general practice. 2017;24(1):120-4.

197. Polit DF, Beck CT. Generalization in quantitative and qualitative research: Myths and strategies. International journal of nursing studies. 2010;47(11):1451-8.

198. Johnson S, Rasulova S. Qualitative research and the evaluation of development impact: incorporating authenticity into the assessment of rigour. Journal of development effectiveness. 2017;9(2):263-76.

199. Mann CJ. Observational research methods. Research design II: cohort, cross sectional, and case-control studies. Emergency medicine journal : EMJ. 2003;20(1):54-60.

200. Farzad M, Lu Z, MacDermid JC, Kachooei AR, Shafiee E. Measurement properties of the Michigan hand outcomes questionnaire: Rasch analysis of responses from a traumatic hand injury population. Disability and rehabilitation. 2021:1-9.

201. Keogh JWL, Cox A, Anderson S, Liew B, Olsen A, Schram B, et al. Reliability and validity of clinically accessible smartphone applications to measure joint range of motion: A systematic review. PloS one. 2019;14(5):e0215806-e.

202. Chen J, Xian Zhang A, Jia Qian S, Jing Wang Y. Measurement of finger joint motion after flexor tendon repair: smartphone photography compared with traditional goniometry. The Journal of hand surgery, European volume. 2021;46(8):825-9.

203. Meijer HA, Graafland M, Goslings JC, Schijven MP. Systematic Review on the Effects of Serious Games and Wearable Technology Used in Rehabilitation of Patients With Traumatic Bone and Soft Tissue Injuries. Archives of physical medicine and rehabilitation. 2018;99(9):1890-9.

11 APPENDICES

Supplementary table 1. Demographic of variables of patients and injury in the study cohort. Rate of rupture and tenolysis within each variable. (PAPER 3)

Variable	Total number of patients (% of cohort)	Total number of fingers (% of cohort)	Rupture rate (% fingers in variable)	Tenolysis rate (% fingers in variable)
Sex				
Women	392 (28.6)	429 (27)	10 (2.3)	25 (5.8)
Men	980 (71.4)	1156 (73)	70 (6.1)	51 (4.4)
Age				
< 25	379 (27.6)	463 (29.2)	6 (1.3)	20 (4.3)
25 - 50	707 (51.5)	811 (51.2)	52 (6.4)	38 (4.7)
> 50	286 (20.8)	311 (19.6)	22 (7.1)	18 (5.8)
Income[a]				
low	195 (14.2)	223 (14.1)	13 (5.8)	0 (0.0)
middle	1043 (76)	1213 (76.5)	61 (5.0)	65 (5.4)
high	104 (7.4)	115 (7.3)	4 (3.5)	10 (8.7)
missing	30 (2.2)	34 (2.1)		
Education[b]				
low	222 (16.2)	270 (17)	8 (3.0)	13 (4.8)
middle	502 (36.6)	588 (37.1)	34 (5.8)	31 (5.3)
high	294 (21.4)	324 (20)	6.2	5.6
missing	354 (25.8)	403 (25.4)		
Days to surgery				
< 48h	853 (62.2)	1012 (63.9)	57 (5.6)	49 (4.9)
> 48h	231 (16.8)	255 (16.1)	16 (6.1)	10 (3.9)
> 7 days	158 (11.5)	166 (10.5)	6 (3.6)	10 (6.0)
missing	130 (9.5)	152 (9.6)		
Injured hand				
Left	724 (52.8)	820 (51.7)	37 (4.5)	35 (4.3)
Right	644 (46.9)	761 (48)	42 (5.5)	41 (5.4)
missing	4 (0.3)	4 (0.3)		
Number of fingers				
Single	1201 (87.5)	1201 (75.8)	67 (5.6)	53 (4.4)
Multiple	171 (12.5)	384 (24.2)	13 (3.4)	23 (6.0)

[a] low income: disposable income per consumption unit below 60 % of median income for all. Middle income: income between low and high definition. High income: above double the median income.

[b] Education was defined as low: pre-high school, middle: high school, and high: post high school.

Supplementary table 2. Demographic of variables from surgery and injury in the study cohort. Rate of rupture and tenolysis within each variable. (PAPER 3)

Variable	Total number of fingers (% of cohort)	Rupture rate (% fingers in variable)	Tenolysis rate (% fingers in variable)
Injured tendon			
FDP	620 (39)	17 (2.7)	19 (3.1)
FDP+partial FDS	236 (14.9)	9 (3.8)	14 (6.0)
FDP+FDS	458 (28.9)	30 (6.6)	33 (7.2)
FPL	223 (14.1)	23 (10.3)	10 (3.1)
missing	48 (3.0)		
Injured finger			
dig 1	223 (14.1)	23 (10.3)	10 (3.1)
dig 2	350 (22.1)	14 (4.0)	16 (4.6)
dig 3	223 (14.1)	14 (6.3)	8 (3.6)
dig 4	253 (16)	8 (3.2)	16 (6.3)
dig 5	534 (33.7)	21 (3.9)	27 (5.2)
missing	3 (0.1)		
Injured digital nerves			
none	970 (61.2)	49 (5.1)	44 (4.5)
one	497 (31.4)	27 (5.4)	23 (4.6)
both	114 (7.2)	4 (3.5)	9 (7.9)
missing	4 (0.3)		
Core suture technique			
Mod kessler	302 (19.1)	22 (7.3)	16 (5.3)
Tsuge/loop	821 (51.8)	44 (5.4)	43 (5.2)
reinsertion	95 (6)	4 (4.2)	0 (0.0)
criss cross	55 (3.5)	2 (3.6)	0 (0.0)
other	53 (3.3)	0 (0.0)	1 (1.9)
missing	259 (16.3)		

Core suture material			
braided polyester	553 (34.9)	27 (4.9)	34 (6.2)
Non-resorbable monofilament	156 (9.8)	10 (6.4)	4 (2.6)
Resorbable monofilament	95 (6)	5 (5.3)	1 (1.0)
Braided polyblend	478 (30.2)	29 (6.1)	19 (4.0)
other	24 (1.5)	0 (0.0)	1 (4.2)
missing	279 (17.6)		
Core suture number			
2	221 (13.9)	15 (6.8)	7 (3.2)
4	1033 (65.2)	52 (5.0)	50 (4.8)
5 or 6	38 (2.4)	2 (5.3)	1 (2.6)
missing	293 (18.5)		
Core suture circumference			
3-0	403 (25.4)	25 (6.2)	21 (5.2)
4-0	839 (52.9)	44 (5.2)	33 (3.9)
2-0 or 5-0	33 (2)	0 (0.0)	0 (0.0)
missing	310 (19.6)		

FDP: Flexor digitorum profundus. FDS: Flexor digitorum superficialis. FPL: Flexor pollicis longus.

Supplementary table 3. Information regarding individual variables and their unadjusted associations to rupture or tenolysis after flexor tendon repair in zone 1 and 2 in 1585 fingers. (PAPER 3)

	Unadjusted association to ruptur		Unadjusted association to tenolysis	
Variables	OR (CI 95%)	p-value	OR (CI 95%)	p-value
Sex				
Women	Reference		Reference	
Men	2.7 (1.4-5.3)	**0.004**	0.7 (0.5-1.2)	0.242
Age				
< 25	Referencef		Reference	
25 - 50	5.2 (2.2-12.2)	**<0.001**	1.1 (0.6-1.9)	0.763
> 50	5.8 (2.3-14.5)	**<0.001**	1.4 (0.7-2.6)	0.361
Income[a]				
low	1.7 (0.5-5.4)	0.4	n.a	0.994
mid	1.5 (0.5-4.1)	0.464	0.6	0.143

high	Reference		Reference	
Education[b]				
low	0.5 (0.2-1.1)	0.072	0.9 (0.4-1.8)	0.686
mid	0.933 (0.5-1.6)	0.811	0.9 (0.5-1.7)	0.856
high	Reference	ref	Reference	
Days to surgery				
< 48h	Reference		Reference	
> 48h	0.9 (0.5-1.7)	0.739	0.8 (0.4-1.6)	0.494
> 7 days	0.6 (0.3-1.5)	0.288	1.2 (0.6-2.5)	0.557
Injured hand				
left	Reference		Reference	
right	1.2 (0.8-1.9)	0.359	1.9 (0.8-2.0)	0.300
Injured tendon				
FDP	Reference		Reference	
FDP+partial FDS	1.4 (0.6-3.2)	0.416	2.0 (0.9-4.0)	0.056
FDP+FDS	2.5 (1.4-4.6)	**0.003**	2.5 (1.4-4.4)	**0.002**
FPL	3.9 (2.0-7.5)	**<0.001**	1.0 (0.4-2.5)	0.940
Number of fingers				
single	1.7 (0.9-3.1)	0.091	1.4 (0.8-2.3)	0.210
multiple	Reference		Reference	
Injured finger				
dig 1	3.5 (1.5-8.0)	**0.003**	0.5 (0.2-1.2)	0.113
dig 2	1.3 (0.5-3.1)	0.589	0.7 (0.3-1.4)	0.345
dig 3	2.1 (0.8-5.0)	0.113	0.6 (0.2-1.3)	0.179
dig 4	Reference		Reference	
dig 5	1.3 (0.5-3.1)	0.593	0.8 (0.4-1.5)	0.538
Injured digital nerves				
none	Reference		Reference	
one	1.1 (0.7-1.7)	0.755	1.0 (0.6-1.7)	0.924
both	0.7 (0.2-1.9)	0.473	1.8 (0.9-3.8)	0.121
Core suture technique				
Mod Kessler	1.4 (0.8-2.4)	0.226	1.0 (0.6-1.8)	0.968
Tsuge/loop	Reference		Reference	
reinsertion	0.8 (0.3-2.2)	0.635	n.a	0.996
criss cross	0.7 (0.2-2.8)	0.582	n.a	0.997
other	n.a	0.997	0.3 (0.0-2.6)	0.301
Core suture material				

braided polyester	0.8 (0.5-1.4)	0.404	1.6 (0.9-2.8)	0.118
Non-resorbable monofilament	1.1 (0.5-2.2)	0.877	0.6 (0.2-1.9)	0.417
Resorbable monofilament	0.9 (0.3-2.3)	0.762	0.3 (0.0-1.9)	0.188
Braided polyblend	Reference		Reference	
other	n.a	0.998	1.0 (0.1-8.2)	0.963
Core suture number				
2	1.4 (0.8-2.5)	296	0.6 (0.3-1.4)	0.281
4	Reference		Reference	
5 or 6	1.0 (0.2-4.5)	0.951	0.5 (0.1-3.9)	0.536
Core suture circumference				
3-0	1.2 (0.7-2.0)	0.490	1.3 (0.8-2.4)	0.303
4-0	Reference		Reference	
2-0 or 5-0	n.a	0.998	n.a	0.998

[a] low income: disposable income per consumption unit below 60 % of median income for all. Middle income: income between low and high definition. High income: above double the median income.

[b] Education was defined as low: pre-high school, middle: high school, and high: post high school.

OR: odds ratio. CI: confidence interval. N.a: not applicable, due to zero observation with rupture or tenolysis. FDP: Flexor digitorum profundus. FDS: Flexor digitorum superficialis. FPL: Flexor pollicis longus.