INTRODUCTION
Erik Moberg was a pioneer of hand surgery in Sweden (Image 1), having spent some months with Sterling Bunnell in Chicago shortly after the World War II. He was head of a department of Extremity and hand Surgery, which included a ward with 10 beds reserved for hand surgery patients. He was a great authority, both demanding and supportive. Every weekday afternoon he held a preoperative conference together with the whole staff of doctors. The treatment of every patient was discussed, but all the hand patients were, one by one examined at the conference. That resulted in an excellent theoretical training in hand surgery.

Sterling Bunnell had given the area in the hand from the flexion crease in the palm to the fingertips the name “no man’s land”. This also included the thumb (FPL) from the distal thanar region to the insertion on the distal phalanx. Flexor tendon injuries in that part of the hand were to be treated only by surgeons skilled in surgery of the hand. Primary care for these injuries consisted in wound debridement and skin suture. Then the patient was referred to a specialist for elective free tendon transplantation from the fingertip to proximal palm or distal wrist. Erik Moberg had adopted these principles and they were standard when I 1969 became a member of his staff.

In 1971 Erik Moberg retired from his position as professor. At that time hand surgery had officially become a specialty in Sweden. Ten years later I got the privilege to have him as my teacher and tutor in the field of reconstructive surgery of the arm in tetraplegia.

Professor Alf Nachemson, a spine surgeon, succeeded Erik Moberg as head of the department and an associate professor in hand surgery was in charge of the hand surgery unit. During a few years it gradually expanded to a hand surgical clinic, from which I retired 2007.

Direct repair of flexor tendon lesions was evolved during the 1960ies by pioneers in hand surgery as Verdan¹ and Kleinert² who showed that it was possible to obtain results comparable to free tendon grafts. In Göteborg the method was taken in practice 1974.

ANATOMY
Each finger has two flexor tendons, the flexor digitorum profundus (FDP) and the flexor digitorum superficialis (FDS), which are surrounded by a tight flexor tendon sheath. It holds the flexor tendons close to the phalanges to optimize the biomechanical properties of the flexor tendons. The sheath is enforced by four annular ligaments, number 1 (A1) at the level of the metacarpal head just distal to the flexion crease in the palm, A2 is located over the base of the first phalanx (at the first flexion crease of the finger), A3 is under the middle flexion crease and A4 in distal part of the middle phalanx. The profundus is attached to the distal phalanx and flexes the distal interphalangeal joint (DIP), while the FDS is divided in two parts creating an oblique channel for the profundus tendon to pass through. It is attached to the radial and ulnar edges of the middle phalanx with the profundus passing in between. The lumbrical muscles of the four fingers originate from each FDP in the palm and reduce the retraction of the FDP in the case of a distal lesion in the finger.
The thumb has only one long flexor (FPL) and its tendon sheath is reinforced by mainly two annular ligaments, one at the base of the proximal phalanx (A1) and the other (A2) close to the interphalangeal (IP) joint. In between you can find some oblique fibers. FPL has no lumbrical muscle. An open injury to the flexor tendon will inevitably also injure the tendon sheath and will easily give rise to adhesions between the tendon, the bone and tendon sheath resulting in a reduced range of motion.

**SITE OF INJURY AND LOSS OF FUNCTION**
An injury located distal to the proximal interphalangeal joint (PIP) will result in loss of active flexion in the DIP joint with maintained active flexion in the PIP joint. An injury at the level of the PIP joint or more proximal will cause a loss of active flexion of both PIP and DIP joints of the finger. An injury to FPL results in ability to flex the IP joint. A combination of a total FDP lesion and an incomplete lesion of the FDS is rather common and activePIP flexion does not exclude a 90% subtotal injury of the FDS.

**PRIMARY OR SECONDARY REPAIR**
Primary repair is the optimal treatment. Generally, this can be performed up to 72 hours after the injury if there is no sign of infection. In case of a delay of 4 days or more it is in my experience safer to wait and let the skin heal and then do a delayed tendon repair 10-12 days after the injury. An isolated profundus tendon is sometimes possible to repair even after a long period when the site of injury is distal to the insertion of the FDS and the FDP has not retracted out of the decussation of the superficial tendon.

**OPERATIVE TECHNIQUE**
An axillary block is used for anesthesia. Careful wash of the hand with soap and water not forgetting the fingernails before the use of alcohol or iodine solution for disinfection. A tourniquet is applied to obtain a bloodless field.

The injury is exposed by means of a volar zig-zag incision (Bruner). In some cases it may be possible to include the initial skin injury. The skin flaps should include subcutaneous fat as soon as the incision has passed the digital nerve and vessel bundle and leave the tendon sheath exposed. The digital nerves are examined for concurrent nerve injuries. The tendon sheath is opened to get space enough to repair the tendon(s) including annular ligament at the site of the repair. It is often necessary to divide the A3 ligament for this purpose, but none of the ligaments are sacred. The repair site is often more distal than the skin lesion might indicate, as many accidents occur when the finger is flexed. The operation takes place with the hand on the operating table and with the finger(s) fully extended. Thus, the distal stump is in most cases located distal to the lesion in the sheath.

Next step is to retrieve the proximal stumps of the tendon(s). If only the profundus tendon is injured the retraction might be moderate due to the small vessel in the vincula of the tendon coming from the decussion of the superficialis tendon. In those cases it is often possible to bring it forward by means of a forceps and by full flexion of the wrist and milking movement over the proximal tendon sheath. Always try to take hold of the tendon only on the cut surface. The tendon is locked by means of a thin injection needle. In some cases the profundus tendon has retracted to the vola of the hand especially if both tendons are divided. Then I find it easiest to make an incision proximal to A1 and by means of a thin catheter from distal to proximal through the sheath, suture the tendon to the catheter and pull the tendon stump gently distally to the site of injury. One good alternative is to place the proximal part of the final core suture in the tendon, pull through the thread and the needle by means of the catheter and then use the suture to bring the tendon distally. Thereby is operative trauma to the tendon end minimized. The tendon is locked by a needle proximal to the suture area.

Then the repair of the tendon(s). In double tendon lesions I have routinely repaired both, starting with the superficial flexor, which at the level of the base phalanx is a broad flat tendon or two smaller flat tendon and with an internal structure, which differs from the profundus at the same level. Thus, it is easy to repair the superficialis by means of two mattress sutures with e.g 4-0 Ticron.

In very distal lesions of a profundus tendon one can use a Bunnell suture brought through the distal stum by means of a suture (non-woven fibre) with two straight needles, on each side of the distal phalanx and through the nail and knotted on top of the nail. In general direct tendon repair is the best choice. For more than 30 years I have used a modified Kessler suture with 4-0 Ticron® (Figure 1).

The Ticron suture requires the use of 4 double knots to stay together. It may seem a bit bulky, but it is placed in between the cut ends of the tendon.

Initially no epitenidous sutures but later the criss-cross suture described by Silfverskiöld (3) (Figure 2) using 6-0 nylon. This combination doubled the strength compared to the single Kessler suture. After completion of the suture it is important to check that the tendon can pass under proximally located annular ligaments. If not one should divide enough of the ligament in order to prevent impingment of the tendon(s). The tendon sheath is not repaired. Suture of the skin and a separate dressing for each injured finger. On top of that a compressive dressing and a plaster splint from the forearm and dorsum of the hand out to the fingertips carefully moulding
the plaster so the wrist is in 10° degrees of flexion, the metacarpophalangeal joints (MCP) is in 60° of flexion and the IP joints as straight as possible.

When the FPL is injured the proximal tendon stump is in general found in the thenar region and one has to bring it distally by means of a catheter. The repair is similar to those in the four fingers but I have used 3-0 Ticron due to a greater degree of freedom of movements in the thumb compared to the four fingers. The FPL has no lumbrical muscle which can prevent the proximal stump to retract and reducing the load of active contraction of the FPL. Postoperatively the wrist should be immobilized in 30° of flexion, the CMC joint in moderate radial abduction and MCP joint in 30 degrees of flexion and the IP joint in full extension.

POSTOPERATIVE TRAINING
One to three days after surgery the dressing of the wound is reduced to a thin compressive bandage. The plaster is changed (or replaced of a plastic splint) to hold the wrist and MCP joint position as described above. However, it must not pass distal of the PIP joints to allow full active extension of the PIP joints. Rubber bands are attached to the all four fingernails (and not just the injured one(s), and pass under a pulley in the distal palm and attached to a hook in the distal forearm.

The patient is encouraged to extend the fingers fully, after removing the rubber bands from the hook on the forearm. Then reattach the rubber band to let the fingers flex, followed by passive maximal flexion of the IP joints. After a few repetitions the patient is instructed to actively try to hold the fingers maximally flexed while removing the uninjured hand. This maximizes the sliding of the tendon in the tendon sheath. The patient is encouraged to actively flex the fingers for 2-3 seconds. The effect of this is checked by the hand surgeon and or therapist when relieving the manual pressure (active hold). The whole cycle is repeated 2-5 times at the first postoperative session of training. A small plastic splint is applied volarly to hold the IP joints in full extension during night-time. The training is repeated under supervision once or twice during that day, with a final goal of 10 repetitions every hour during daytime. The patient leaves the hospital when having learnt to exercise correctly, usually on the 3rd day after the operation. All patients are also instructed to fully raise both arms fully above their head 100 times per day to counteract the postoperative swelling and residual postoperative pain. In practice it means once every 10 minutes throughout the day.

The patient visits the outpatient clinic after one and two weeks when the range of passive and active motion is checked and the splint and bandage are checked. At four weeks the rubber bands, the dressing and the sutures are removed, and the patient starts active extension-flexion movements but without any resistance or gripping. At six weeks postoperatively active training is started allowing gripping of light objects. Eight weeks postoperatively a gradual increase of the load is allowed without any strenuous tasks. Return to heavy work is advised after three months. The total active motion in the injured finger(s) may not be fully restored at three months but often slowly improves up to 12 months postoperatively.

COMPLICATIONS
There are three threats for a failure: Infection, tendon rupture and longstanding postoperative swelling of the hand.

1) Infection is prevented by careful preoperative cleansing of the skin, as atraumatic surgery as possible, adequate dressing postoperatively. A single dose of antibiotics in connection to the operation can be motivated. Postoperatively antibiotics is only prescribed in case of an apparent infection, in combination with immobilisation of the finger, or at least reduced number of exercises.

2) Tendon re-rupture is routinely found in all reports on flexor tendon surgery in about 3-4% of the cases. The cause is in my experience often that the patient has unintentionally taken a stronger grip than instructed and experiences a momentaneous reduced flexion in the injured finger. In these cases there are two options for treatment. Depending on the time after primary surgery and the degree of postoperative oedema of the hand and the internal scar at the site of injury one has to
decide whether a direct repair is possible or if a tendon transplant is a better alternative, most often in a two-stage procedure. In the first stage the tendon is replaced by a silicone rod from the fingertip to the wrist, followed minimum 3 months later by a free tendon graft from the fingertip either to the level of the palm or to the wrist.

3) Postoperative oedema often most pronounced in the operated finger is to some extent present in all cases during a short time. Some individuals seen to have greater difficulties to get rid of the swelling which results in reduced range of motion in the finger both actively and passively. It also gives rise to tenderness during manual compression side-to-side over the PIP joint. This is an important diagnostic sign in combination with lack of full extension of the PIP joint. The oedema is reduced by lifting the hand high up regularly during daytime and by active movement of the fingers. Small cylindrical tubes of plaster for affected finger used night-time is helpful.

DISCUSSION
It is since long known that healing of a repaired tendon is favoured by moderate activity in the injured muscle up to a certain degree. Too much activity will cause a disruption or elongation of the repair with less good result. The problem is always to balance the strength of the repair to the amount of load, which will affect the repair during the healing process. In case of finger flexor injuries one important factor is that the motion should bring about a sliding of the tendon in relation to the tendon sheath and surrounding phalanges. The described method is developed to maximize this motion without overloading the tendon repair. However, a successful result requires a good interaction between the patient and the hand surgeon/ergo therapist so that the patient fully understands how to protect his/her hand from overload and in worst case a postoperative rupture.

During recent years many articles have been published concerning stronger suture techniques, like 4- and 6-strands sutures. The argument has been that a stronger tendon repair would allow a more active mobilization of the injured finger and thereby shorten the time of healing and a shorter sick leave. The problem of informing the patient which kind of active gripping is acceptable without overloading of the repair site is the same but on another level.

SUMMARY
Flexor tendon injuries can nowadays be repaired directly with good results in a great majority of cases if they are treated by a well-trained hand surgeon and ergo therapist followed up with a good postoperative program.

References