Magnetic resonance imaging 3 and 12 months after carpal tunnel release

Alex Ng, James Griffith, Ryan Lee, WL Tse, Clara WY Wong, PC Ho

SP012, scientific abstract

The Chinese University of Hong Kong
Department of Imaging and Interventional Radiology,
Prince of Wales Hospital
Email address: alex@sunghim.com
INTRODUCTION

• Persistent symptoms after carpal tunnel release occur in up to one-fifth of patients may be due to incomplete carpal tunnel release, post-surgical scarring or flexor tenosynovitis.

• Objective evidence helps to guide further treatment and decision making regarding re-exploration

• Ultrasound
  – limited by post-operative scarring and acoustic shadowing in region of the median nerve
High resolution MRI has the capability to fully visualize the post-operative carpal tunnel and median nerve.

- No universally agreed criteria have emerged.
- Richman et al studied carpal tunnel morphology 6 weeks and 8 months after surgery in 7 patients
- More recent studies addressed other parameters 3 months after carpal tunnel release
- Crnković et al measured the changes of the size of median nerve and carpal tunnel volume 6 months after surgery.
OBJECTIVES

- In this study, we investigated a large number of morphological parameters of the median nerve and carpal tunnel for up to one year after surgery.
MATERIALS AND METHOD

Patient selection

• Prospective study: May 2013 to January 2015
• 23 patients (3 men, 20 women; mean age 55.0 \( \pm \) 6.4 years, 7 right, 16 left wrists)
  – no recurrent symptoms
  – MRI 3 months and one year after endoscopic release.
• Exclusion:
  – Gout
  – an inflammatory arthropathy
  – previous severe wrist trauma were excluded.
Clinical outcome measure

• To ensure uniformity in assessment, patients conducted a telephone questionnaire pre-operatively and at 3 and 12 months post-surgery
  – grade the level of residual symptoms (numbness, paresthesia, pain, weakness) on an analogue scale of 0-10
    • zero representing no symptoms and 10 representing very severe symptoms
• In view of variably in patient response, the main outcome measure used was numbness.
• Satisfactorily release was defined as improvement in clinical scores relative to a preoperative score.
  – Outcome assessments were performed by a single examiner blinded to the MRI findings.
MR technique and analysis

- 3T imaging system (Philips X-series Best, Netherlands)
  - dedicated phased array 8 element wrist coil.
  - neutral position (superman).

- turbo-spin-echo axial intermediate-weighted imaging
  (TR=3000ms, TE =30ms, Bandwidth=219-256Hz, TSE factor=13, 2.5mm slice thickness, interslice gap=0.5mm, voxel size=0.17mm x 0.21mm, NEX=2, FOV=80mm)
  - with and without fat suppression
  - planned in a plane traversing the mid-portion of the scaphoid tubercle and the mid-portion of the pisiform bone.
Fig. 1 — A line (a) is drawn connecting the trapezium (Tm) and hook of hamate (H) at this level, representing the transcarpal line. Then a line (b) is drawn perpendicular to the transcarpal line to the undersurface of the transverse carpal ligament (black arrows) and represent the volar palmar bowing.

- Three months after surgery, there is significant increased palmar retinaculum bowing associated with volar displacement of the median nerve and flexor digitorum tendons.

- The gap of the resected retinaculum is well delineated between two ends (block arrow)

Td=trapezoid. C=capitate
Fig. 2.—Axial proton density MRI image at the level of outlet level of carpal tunnel (between the hamate and trapezium) : Continuous tracing method (white line) excluding the extrinsic ligament.

CSA=Circumferential surface
Fig. 3.- The flattening ratio is ratio of the major and minor axes (white lines) of the median nerve. The major axis is the maximum width of the median nerve and the minor axis is the length of the line perpendicular to the major axis.
Fig. 4.—ROI was put onto the median nerve. Another 4mm² ROI was put on the hypothenar muscle. The relative signal intensity of the median nerve was calculated by dividing the ROI of the median nerve by the ROI of the hypothenar muscle. The relative signal intensity in this case would be 1.20.

Fig. 5.—1 year after surgery showed that the transverse carpal ligament was reformed but attenuated (black arrow). The palmar retinaculum bowing is slightly less bowed when compared to previous scan done in 3 months after surgery (Fig. 1B).
• The change in caliber is defined as the ratio change in median nerve CSA at the tunnel inlet was expressed by \( \text{CSAp}/\text{CSAi} \) (\( \text{CSAp/i} \)) and at the tunnel outlet by \( \text{CSAd}/\text{CSAo} \) (\( \text{CSAd/o} \)).

• Expansion ratio at inlet and outlet was calculated by dividing the post-operative CSA by the pre-operative CSA.

• To test measurement inter-reader reliability, another musculoskeletal radiologist (6 years MR experience) (Reader 2) measured the same parameters on the same image database.

• The parameters were further measured after 4 weeks by the same radiologist who did the initial MR readings and blinded to the initial findings.
Statistical analysis

- Statistical software was used (SPSS, version 16.0.1 for Windows) for data analysis. To compare differences between parameters measured on pre and post-surgical MRI scan, the paired t-test was used. P<0.05 was regarded as significant difference.

- Correlation of the numbness and weakness scores with the changes of MR parameters were assessed by Pearson’s correlation. The r=1 is perfect correlation; 0.5-0.99=high correlation; 0.3-0.49 is moderate correlation; <0.3 is low correlation; 0 is no correlation.

- The Cohen weighted k statistic was used to assess the level of inter- and intra-observer agreement for all parameters. A value of less than 0.20 implied poor agreement; 0.21-0.40, fair agreement; 0.41-0.60, moderate agreement; 0.61-0.80, substantial agreement; and 0.81-1.00 excellent agreement.
## RESULTS

Parameters show significant difference ($p<0.05$) --bolded in yellow

<table>
<thead>
<tr>
<th></th>
<th>Before operation (mm²) average+/−sd</th>
<th>3 months after surgery (mm²)</th>
<th>p value (3month)</th>
<th>1 year after surgery (mm²)</th>
<th>p value (1 year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSAp</td>
<td>21.4±8.6</td>
<td>18.7±6.3</td>
<td>0.231</td>
<td>17.0±5.4</td>
<td><strong>0.044</strong></td>
</tr>
<tr>
<td>CSAi</td>
<td>16.8±4.4</td>
<td>19.2±5.5</td>
<td>0.108</td>
<td>17.6±5.7</td>
<td>0.566</td>
</tr>
<tr>
<td>CSAo</td>
<td>14.1±3.8</td>
<td>15.4±4.2</td>
<td>0.287</td>
<td>15.6±4.2</td>
<td>0.207</td>
</tr>
<tr>
<td>CSAd</td>
<td>21.3±6.1</td>
<td>22.1±6.8</td>
<td>0.711</td>
<td>20.1±6.2</td>
<td>0.711</td>
</tr>
<tr>
<td>CSAp/i</td>
<td>1.31±0.52</td>
<td>0.98±0.18</td>
<td><strong>0.0062</strong></td>
<td>0.99±0.20</td>
<td><strong>0.0082</strong></td>
</tr>
<tr>
<td>CSAd/o</td>
<td>1.61±0.67</td>
<td>1.53±0.56</td>
<td>0.65</td>
<td>1.39±0.48</td>
<td>0.21</td>
</tr>
<tr>
<td>FRi</td>
<td>2.44±0.74</td>
<td>2.52±0.66</td>
<td>0.746</td>
<td>2.36±0.67</td>
<td>0.67</td>
</tr>
<tr>
<td>FRo</td>
<td>2.46±0.67</td>
<td>2.31±0.55</td>
<td>0.415</td>
<td>2.55±0.69</td>
<td>0.65</td>
</tr>
<tr>
<td>Slp</td>
<td>1.23±0.27</td>
<td>1.12±0.27</td>
<td>0.172</td>
<td>1.08±0.22</td>
<td><strong>0.050</strong></td>
</tr>
<tr>
<td>Sli</td>
<td>1.31±0.28</td>
<td>1.15±0.21</td>
<td><strong>0.027</strong></td>
<td>1.13±0.20</td>
<td><strong>0.015</strong></td>
</tr>
<tr>
<td>Slo</td>
<td>1.19±0.20</td>
<td>1.17±0.16</td>
<td>0.794</td>
<td>1.13±0.20</td>
<td>0.367</td>
</tr>
<tr>
<td>Sld</td>
<td>1.18±0.17</td>
<td>1.19±0.13</td>
<td>0.314</td>
<td>1.12±0.23</td>
<td>0.312</td>
</tr>
</tbody>
</table>

P-value (3 month) and P-value (1 year) represent the significant level of postsurgical change when compared to the parameter before the surgery at 3 month and 1 year time interval respectively

p=proximal to carpal tunnel; i=at inlet level; p=at outlet level; d=at immediate distal to outlet level
CSA=circumferential surface area; FR=flattening ratio; SI=signal intensity of median nerve;
RESULTS

• Median nerve CSA proximal to the tunnel
  – significantly decreased one year after surgery but not three months after surgery (p=0.231) and decreased from an average of 21.4\(\text{mm}^2\) to 17\(\text{mm}^2\) (p=0.044).

• Signal intensity of the median nerve proximal to the tunnel
  – significantly decreased at 12 months (p=0.050)

• Signal intensity at the tunnel inlet
  – significantly decreased at both 3 (p=0.027) and 12 months (p=0.015) post-surgery.
## RESULTS

Parameters show significant difference ($p<0.05$) --bolded in yellow

<table>
<thead>
<tr>
<th></th>
<th>Before operation (mm²)</th>
<th>3 months after surgery (mm²)</th>
<th>p value (3 month)</th>
<th>1 year after surgery (mm²)</th>
<th>p value (1 year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BRi</strong></td>
<td>4.34±0.85</td>
<td>6.13±1.01</td>
<td>6.36×10⁻⁸</td>
<td>5.59±0.93</td>
<td>2.04×10⁻⁵</td>
</tr>
<tr>
<td><strong>BRo</strong></td>
<td>1.63±0.68</td>
<td>4.3±0.86</td>
<td>&lt;1×10⁻⁸</td>
<td>3.3±1.13</td>
<td>2.52×10⁻⁷</td>
</tr>
<tr>
<td><strong>CTi</strong></td>
<td>171.6±20.8</td>
<td>198.5±19.9</td>
<td>5.24×10⁻⁵</td>
<td>183.2±25.8</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>CTo</strong></td>
<td>157.4±22.0</td>
<td>181.9±25.2</td>
<td>0.001</td>
<td>166.1±23.2</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>TCL gap</strong></td>
<td>---</td>
<td>5.70±2.3</td>
<td>---</td>
<td>1.89±2.7</td>
<td>6.33×10⁻⁶</td>
</tr>
</tbody>
</table>

BR=height of palmar bowing retinaculum;  
CT=carpal tunnel cross sectional area;  
TCL gap=transverse carpal ligament
RESULTS

• Carpal tunnel CSA
  – significantly expanded at 3 and 12 months post-surgery with the largest expansion being seen at 3 months.

• palmar retinacular bowing
  – significantly increased at both the inlet and the outlet from with the largest expansion being seen at 3 months.

• The gap the transverse carpal ligament
  – seen in 22 (96%) of the 23 patients at 3 months and measured 5.7±2.3mm in average.
  – at 12 months only 9 (37%) of the 23 patients had a detectable gap which was much smaller than at 3 months measuring 1.89±2.7mm in average. The transverse carpal ligament in the remaining 14 patients had reformed.
RESULTS

• Clinical scores
  – For the numbness score
    • all patients had a decrease in numbness (5.8 points)
    • moderate positive correlation of the degree of bowing retinaculum at the outlet level ($r=0.30$) and CTVi ($r=0.33$) with the reduction in numbness at three month time.
    • At one year time, CSA of median nerve and carpal tunnel area at inlet and outlet have moderate correlation (0.34-0.52) with the reduction in numbness.

•
RESULTS

– For the power score
  • 3 out of 17 (18%) patients have decreased and the rest (82%) show improvement or no change as compared to preoperative status.
  • Moderate positive correlation of the degree of reduction in signal intensity of the median nerve at the inlet and improvement of the power experienced by patient (r=0.38) at three month time.
  • Moderate positive correlation was also found at outlet level (r=0.33) at one year time.
DISCUSSION

• Recurrent/persistent CTS?

  – Clinical examination
    • patients usually suffer from pain and numbness at the wound site
  – Nerve conduction test
    • sometimes the persistent abnormal result may be due to chronic neuropathy rather than residual nerve compression
  – Ultrasound
    • incised margins of the transverse carpal ligament are not easily discerned while post-surgical fibrosis can limit delineation of the median nerve and visibility of the carpal tunnel
DISCUSSION

• MRI is the preferred modality
  – Most of the previous follow up MR studies were performed at 3 to 6 month time after surgery
    • one MRI study evaluated the carpal tunnel at 8 months
    • These studies either specifically addressed the median nerve or the carpal tunnel.
  – current study uses a wide range parameters to study both the median nerve and the carpal at 3 and 12 months post-surgery.
CSA and FR of median nerve after CTR

- The morphology of the median nerve, including the calibre and flattening ratio are frequently used as diagnostic criteria for CTS
- However, whether these parameters are useful to indicate satisfactory release of carpal tunnel is still controversial and under-investigated
CSA proximal to the median nerve

- We found significant decreased in median nerve calibre proximal to carpal tunnel 12 months after surgery ($p<0.05$) but not at 3 months.
  - Though some investigators could not find any resolution of the swelling of median nerve after surgery
  - several ultrasound studies and one MRI study have shown a significant decrease at 3 to 6 months
- CSA proximal to the tunnel at 3 to 6 months though remaining abnormally large in over two-thirds of patients
- The type of surgery performed may in part account for these findings.
  - In our study, all the patients underwent endoscopic release which is less invasive than other approaches.
CSAp of median nerve

• Swelling of the median nerve in carpal tunnel syndrome is thought to be due to compromised intraneural blood flow resulting in neural oedema
  – Decompression of the median nerve should increase blood flow and reduce oedematous swelling of the median nerve.
• However, irreversible changes in the median nerve may be present after long standing compression with fibroblast accumulation, endoneural fibrosis, demyelination and axonal degeneration
• Our study found that the median nerve remained swollen (17±5.4mm²) at 12 months following decompression, which is more swollen than normal subjects.
The median nerve is normally compressed at either the tunnel inlet or the tunnel outlet leading to an hour-glass configuration or at both levels.

- Several MRI and ultrasound studies have shown that the median nerve at the inlet or outlet can re-expand at 3 to 6 month time after CTR.
- Similar findings were found in this study.
- Together with decreased swelling proximal to the carpal tunnel, there is an increase in nerve calibre at the tunnel inlet (p<0.01) at 3 and 12 months after surgery though not at the tunnel outlet.

These contribute to the less change in calibre of the median nerve contributes less hourglass appearance.
FR of median nerve

• Although the median nerve expanded at the tunnel inlet, there was no change in flattening ratio at 3 or 12 months.
  – This finding was similar to some but not all studies.
• The reasoning behind of lack of improvement in flattening ratio is not clear.
• It most likely represents the effect of chronic median nerve compression
  – Limited perineural soft tissue dissection is not likely to be the cause as it also seen after open release
SI of median nerve

- Increased signal intensity of the median nerve is used as a diagnostic criterion of CTS
- Increased signal intensity before decompression and reduction in signal intensity after decompression are associated with good clinical outcome
- Both Allmann et al and Horch et al found that the signal intensity of median nerve postoperatively decreased by more than 10% in about two-thirds of patients
- In our study, we found similar results though in addition showed that median nerve signal intensity decreased significantly at the inlet as early as 3 months post-surgery but this effect was only seen proximal to the tunnel at 12 months.
BR and CSA of carpal tunnel

- The carpal tunnel size and the degree of palmar retinacular bowing increased rather than decreased particularly at the outlet level after surgery. Palmar bowing was less pronounced at 12 months.
- Carpal tunnel CSA also increased significantly at the inlet and outlet levels similar to the findings of a previous study which showed that carpal tunnel CSA at inlet and outlet to significantly increase at 3 months after surgery and also at eight months post-surgery.
- An increase in palmar bowing and carpal tunnel CSA is a reflection of good surgical decompression.
TCL gap

- Incomplete resection of the transverse carpal ligament (TCL) is the most frequent cause of persistent carpal tunnel syndrome symptoms
  - direct visualization of this ligament is an important feature of MRI assessment.

- Beck et al could not identify the transverse carpal ligament in any of 15 patients
- Cudlip et al and Momose et al could demonstrate division of the flexor retinaculum in all patients
TCL gap

• In our study, the TCL was unequivocally seen in all patients and a complete gap in the ligament was seen at 3 months all but one patient (96%) at 3 months.
  – The average size of this gap was 5.7mm.
  – In 60% of cases, the ligament had completely re-formed at 12 months.
  – The remaining patients showed a reduced transaction gap
  – If one wants to evaluate transverse ligament transaction, this is best done at 3 months since, as shown for the first time in this study, the majority of ligaments will have reconstituted by 12 months.
CLINICAL CORRELATION

- Clinical recovery of symptoms at one year, moderately correlated with an increase in carpal tunnel size (retinacular bowing, carpal tunnel CSA) and increase in median nerve CSA.
LIMITATIONS

1. Sample size was relatively small. This makes subgroup analysis not possible. Further prospective study is required to confirm the findings.

2. No parameters were compared to the clinical severity of carpal tunnel syndrome.

3. The control cases were presumed to be normal but no nerve conduction test to confirm. However, as stated in the manuscript, consensus of high accuracy of NCT was still controversial.

4. Our patients were selected from those who underwent surgery usually after failed conservative treatment. The result might be confounded by the treatment type.

5. In our study cases were subsequently underwent endoscopic surgery. Direct comparison with most of other studies either by open surgery or mixed endoscopic and open surgery might be mistaken. However, in our centre, all the idiopathic first time surgery of carpal tunnel release were performed under endoscopically. Further studies are needed to see the difference between the open and endoscopic surgeries were needed.
CONCLUSION

• Study of the post-operative carpal tunnel is useful in the assessment of persistent symptoms as well as providing **added information on the pathophysiology of carpal tunnel syndrome**.

• If only a post-operative study has been performed
  – as no clearcut discriminatory criteria are available, the main feature that can be assessed is the presence of a **transaction gap** in the transverse carpal ligament.
CONCLUSION

• If a baseline study is performed
  – the change in different parameters can be assessed.
  – At 3 months
    • one can appreciate *reexpansion* of the median nerve, *palmar retinacular bowing* and the *transaction gap*.
  – At 12 months
    • *Normalization of signal intensity* and *less swelling* of median nerve at the proximal and inlet levels.
  – *Flattening of the median nerve does not improve.*
CONCLUSION

• MRI will become increasingly used to assess failed carpal tunnel release.

• Recognition of the expected serial changes of the median nerve and carpal tunnel following release will allow greater appreciation of what to interpret and what to expect at different time intervals following carpal tunnel release.
REFERENCES

• Okutsu I, Ninomiya S, Takatori Y, Ugawa Y. Endoscopic management of carpal tunnel syndrome.
• Hybbinette CH, Mannerfelt L. The carpal tunnel syndrome. A retrospective study of 400 operated patients.
• Jablecki CK, Andary MT, So YT, Wilkins DE, Williams FH. Literature review of the usefulness of nerve conduction studies and electromyography for the evaluation of patients with carpal tunnel syndrome. AAEM Quality Assurance Committee. Muscle Nerve. 1993;16(12):1392-414


Horch RE, Allmann KH, Laubenberger J, Langer M, Stark GB. Median nerve compression can be detected by magnetic resonance imaging of the carpal tunnel. Neurosurgery. 1997;41(1):76-82; discussion 82-3.


• Nakamichi KI, Tachibana S. Enlarged median nerve in idiopathic carpal tunnel syndrome.
• Crnkovic T, Trkulja V, Bilić R, Gašpar D, Kolundžić R. Carpal tunnel and median nerve volume changes after tunnel release in patients with the carpal tunnel syndrome: a magnetic resonance imaging (MRI) study. Int Orthop. 2016 May;40(5):981-7.


Smidt MH, Visser LH. Carpal tunnel syndrome: clinical and sonographic follow-up after surgery.


Declaration

• Authors declare that there is no conflict of interest in this study