Title: Magnetic Resonance Imaging for common peroneal nerve injury in trauma patients: are routine knee sequences adequate for prediction of outcome?

Short Title: Knee MRI for common peroneal nerve injury

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Abstract

Introduction:

Common peroneal nerve (CPN) injury occurs in 10-40% of patients following knee dislocation. Is magnetic resonance imaging (MRI) using routine knee protocols able to adequately evaluate CPN injury and predict long term outcome?

Methods:

Trauma patients presenting for knee MRI at a single public hospital, between July 2007 and May 2017, were retrospectively identified using radiology and orthopaedic databases. Medical records were retrieved for clinical scores. MRI images were scored by 2 independent radiologists blinded to the clinical CPN status and scores correlated with initial clinical scores using the Pearson correlation coefficient.

Results:

Final cohort included 107 patients (81 males and 26 females) with a mean age of 39 (range 19-81 years). MRI was considered to be adequate for coverage of the CPN in 84 patients. Fourteen patients had CPN injury clinically (7 complete and 7 partial). Concordance between MRI scores and initial clinical scores was 0.456 (p=0.01). MRI sensitivity and specificity for CPN injury on the 84 adequate scans were 54.5 % and 93.2% respectively.

All 7 cases of partial CPN injury and 3 of 7 cases of complete CPN injury recovered fully. High MRI scores of 5 and 8 were given for the two patients with a persisting complete CPN palsy. Highest scores for partial CPN injury subjects were 2 and 4.

Conclusions:

MRI using a routine knee protocol is not adequate for assessment of CPN injury in many subjects. More specific MRI neural sequences with complete CPN coverage may be worth trialing.

Keywords: Knee injuries, magnetic resonance imaging, peroneal nerve.

Introduction:

The incidence of common peroneal nerve (CPN) injury following acute traumatic dislocation is between 10% and 40% [1-7]. Complete CPN palsy may recover after a period of time but may remain irreversible once foot drop is present [6,8,9].

The role of nerve conduction velocity (NCV) and electromyography (EMG) is limited because CPN damage is not reliably detected until 4-6 weeks following injury [10-13]. In addition, EMG and NCV only detect neuropraxia, not neurotmesis or axonotmesis [11,12]. The wide spectrum of CPN injury (ranging from contusion, stretching to complete rupture) and the lack of diagnostic tools have led to the inconsistency in managing CPN injury. Neurolysis/neuroexploration can be undertaken within 3 weeks of injury to visualize and treat the non-ruptured but injured CPN[1,2,5,13,14]. For complete nerve disruption, secondary interventions such as nerve transfer, posterior tibial tendon transfer (PTTT), nerve grafting or nerve repair may be warranted [2,5,10].

Current literature suggests magnetic resonance imaging (MRI) has a role in determining severity of CPN damage [10,15,16]. Nevertheless, no study has followed long term clinical outcome based on MRI findings.

The aim of this study was to determine whether routine knee MRI, performed to assess ligaments and menisci, could adequately evaluate the CPN, predict long term outcome and adequately predict which patients might benefit from earlier surgical intervention.

Methods:

a. Subjects:

Knee trauma patients at risk for CPN injury, presenting between July 2007 and May 2017 were retrospectively identified using the Royal Melbourne Hospital Bubble box (an in-house search engine) radiology database (TMAT) and the Filemaker pro orthopedic database (RS). Search terms on Bubble box were ‘knee dislocation’, ‘MRI knee’, ‘knee MRI’, ‘Schatzker’, ‘ACL tear’, ‘fibula head fracture’, ‘fibula neck fracture’, ‘knee ligamentous injury’ and ‘posterolateral corner injury’. Subjects were selected from Filemaker pro using the terms: ‘ACL reconstruction’, ‘dislocation knee’, ‘fracture dislocation’, ‘ligament rupture’, ‘multi-ligament knee reconstruction’, ‘PCL repair’, ‘proximal fibula fracture’ and ‘tibial plateau fracture’.

MRI reports were retrieved from the Karisma database (TMAT & PLR) for those knee trauma patients having MRI within 3 months of the initial injury. Subjects having a history of knee dislocation or an MRI pattern of injury suspicious for knee dislocation (multi-ligamentous injury, fibular neck fracture or posterolateral corner injury) were selected for inclusion.

Those with missing medical records, diabetic neuropathy, advanced knee osteoarthritis, or concurrent foot injury that precluded clinical CPN assessment were excluded.

Ethics approval for low risk research was obtained from the Melbourne Health, Human Research ethics committee (QA 2016.209).

b. Data collection:

i. Clinical data:

Subject age, gender, mechanism of injury, surgical intervention type, and EMG and NCV reports (if available) were obtained from hospital medical records (TMAT). Medical notes were searched for clinical evidence of CPN injury, including extensor hallucis longus (EHL) and tibialis anterior (TA) power and for a description of any CPN distribution sensory abnormality both at the time of presentation and at follow up. Neurovascular charts, if available, were reviewed. For subjects with a normal CPN at presentation, clinical notes were reviewed out to at least 30 days to exclude delayed onset CPN injury. For those with clinical evidence of CPN injury, clinical notes were followed until the CPN was recorded to be clinically normal or for up to 365 days, whichever came first.

ii. Clinical scores of CPN injury:

Clinical data at the time of hospital admission were used to divide the study cohort into 3 subgroups: normal CPN, partially injured CPN and completely injured CPN using the definitions in Table 1[17].

iii. MRI scans:

MRI images were scored for adequacy of CPN coverage, T2 signal intensity and CPN size or transection (Table 2). The MRI examination was deemed to be adequate for evaluating the CPN if the adequacy score was 1, 3 or 4. Images were scored inadequate if CPN coverage was incomplete at the fibula neck or there was poor signal or artifact precluding CPN assessment. Total MRI score was the sum of CPN size score and CPN signal intensity score.

MRI scans from included subjects were scored by two independent radiologists (PLR & BGL) blinded to the patients CPN clinical status. MRIs were reread in consensus if there was any discrepancy.

All MRI scans were performed using a routine knee protocol on one of the department 1.5 Tesla (T) or 3T magnets (Prismafit 3T, Siemens, Erlangen, Germany; Trio 3T, Siemens, Erlangen, Germany; Aera 1.5T, Siemens, Erlangen, Germany or Echospeed 1.5T, General Electric, Milwaukee, USA) and using a transmit receive quadrature coil (Siemens or General Electric). The routine knee series included the following: axial fat-suppressed (FS) proton density (PD) (TR 3000-4200, TE 32-34, matrix 256-384/307-512); coronal FS PD (3000-3650, 33-34, 224-278/256-384); coronal T1 weighted (600-700, 10, 224-371/256-512); sagittal PD (3000-4120, 32-36, 384-512/256-421) and sagittal FS T2 weighted (5940-7000, 53-56, 320-384/307-332).

c. Statistical analysis:

Descriptive statistics characterized the included subjects in terms of mean age, age range, mechanism of injury, recovery progress and surgical intervention.

Sensitivity, specificity, negative predictive value (NPV) and positive predictive value (PPV) were calculated using consensus MRI scores from adequate scans. Pearson correlation coefficient was used to investigate the concordance between adequate MRI scans and initial clinical scores. Significance was set at $p < 0.05$. The inter-observer reliability for determining normal CPN (MRI score ≤1) versus injured CPN (MRI score ≥ 2) between 2 radiologists was demonstrated using the Kappa statistic. Agreement using kappa was graded as minimal (κ = 0.21-0.39); weak (κ = 0.40-0.59); moderate (κ = 0.60 – 0.79); strong (κ = 0.80 – 0.90) or almost perfect (κ > 0.90) [18].

All statistical analysis tests were performed using SPSS version 23.

Results:

a. Subjects:

After review of the MRI reports, 111 subjects were identified for inclusion. One subject was excluded because there was a history of diabetic neuropathy. Medical notes were lost for 2 subjects. One subject had a toe fracture, precluding adequate clinical assessment of the CPN.

The final cohort included 107 patients (81 males and 26 females) with a mean age of 39 years (range 19-81) (Table 3). Ninety-three patients had a normal CPN and 14 patients had CPN injury (7 partial and 7 complete) based on clinical scores at initial presentation. All subjects with a partial CPN injury and 3 of those with a complete CPN injury recovered fully. Table 4 provides further detail regarding the complete CPN injury group. Three subjects with a partial CPN injury underwent neurolysis while five of 7 subjects with a clinical complete CPN injury had neurolysis at the time of other surgeries such as fracture repair, ligamentous repair/reconstruction or posterolateral corner repair. Of the 4 subjects with persisting symptoms post complete CPN injury, 2 partially recovered CPN function at follow up.

Ten subjects with either muscle weakness or sensory disturbance at initial presentation were included in the normal CPN group because signs and symptoms of CPN injury had resolved by 3 days following the initial injury.

b. **MRI scans**:

Eighty-four MRI scans (78.5 %) were adequate while 23 MRI scans (21.5%) were inadequate for evaluating the CPN, 18 (78%) because of inadequate coverage and 5 (22%) because of poor MR signal or artifact.

On adequate scans, sensitivity and specificity for any CPN injury at the time of presentation were 54.5% and 93.2 % respectively. PPV and NPV were 54.5% and 93.2% respectively (Table 5).

MRI scores from adequate scans for those with partial CPN injury were 0 for three subjects, 2 for two subjects and 4 for one subject.

The only scores on adequate MRI scans higher than 2 (scores of 5 and 8) were given to the two subjects with persisting poor CPN function at long term follow-up and one subject (score of 4) with partial CPN injury who recovered fully post neurolysis.

c. **Relationship between MRI scores and clinical scores:**

Pearson correlation coefficient between clinical scores at initial presentation and consensus MRI scores from adequate scans was 0.456. This concordance was significant at $p = 0.01$.

Kappa value for agreement on the presence of any CPN injury between 2 independent radiologists was 0.323 (minimal). However, Kappa value for the complete CPN injury group alone was 0.70 (moderate)

Discussion:

Routine knee MRI scans

Twenty three (21.5 %) of MRI scans were inadequate for evaluating CPN status. This was due mainly to inadequate CPN coverage on routine knee sequences.

Sensitivity of 54.5% for CPN injury on adequate scans was lower than expected. This is likely because axial PD images are not as sensitive for abnormal neural T2 signal as fat suppressed T2 weighted images used in other studies [16, 19]. Recent work on the brachial plexus has shown the value of T2 weighted imaging for nerve injury, specifically using what is called MR neurography or 3D SPACE short tau inversion recovery (STIR) sequences [19]. These sequences are more sensitive for increased neural T2 signal in trauma and may be more sensitive to traction injury. Until now 3D SPACE has not been commercially available for the knee. Assessing for abnormal fat signal around the nerve on T1 weighted images might also be useful [19].

A low positive predictive value (54.5%) is not ideal. However, PPV is directly proportional to the prevalence. In a retrospective study, prevalence will equal to incidence. The incidence of CPN injury in the current literature is between 10% and 40% [1-7]. In our study, the incidence of CPN injury is 13.1% so the PPV is relatively low.

Concordance between MRI scores and clinical scores:

The concordance between consensus MRI scores from adequate scans and clinical scores at initial presentation was 0.456 (p= 0.01), positive but relatively weak.

In the Reddy et al.[16], clinical injury score strongly correlation with the MRI injury score for CPN (r= 0.75, p< 0.001). Reddy used axial fat suppressed T2 weighted images that may have been more sensitive to abnormal T2 signal. However, Reddy did not subdivide CPN injury into complete and partial CPN injury or evaluate long term outcome.

Outcome of CPN injury

Since many subjects with CPN injury recover, overall sensitivity of MRI may not be so important if MRI can predict which subjects will likely have persisting CPN symptoms without surgical intervention

The complete CPN injured group is the one requiring more attention since recent literature suggests timely surgical intervention may be required to prevent permanent foot drop [6]. Of the small group of 7 patients with complete CPN injury, 2 with persisting symptoms at long term follow up, had high MRI scores at presentation of 5 and 8. Both subjects had poor CPN function at follow up despite having neurolysis at the time of ligamentous reconstruction and fracture repair, 9 days post injury. Details of nerve findings at surgery were not available from the medical notes so that it was not known whether neurolysis was performed at the MRI site of nerve abnormality or at site of other surgery [3]. The MRI site of injury in one of these was close to the popliteal fossa, distant from the likely surgical site. Neurolysis is generally done either at nerve exploration and repair or if the nerve is close to the site of other surgery such as posterolateral corner reconstruction, at the fibula neck. Whether this patient had or may have benefited from neurolysis at the MRI injury site, or from surgical repair, is unknown.

In one case of complete CPN injury, CPN was normal in appearance on an adequate MRI scan and eventually recovered partially at follow up. On review of the medical records, the onset of complete CPN injury was one day post fracture repair and neurolysis, performed at day 9 post initial injury, whereas the MRI scan was done at day 5 post injury. Hence, it was unclear whether this patient had a traction injury at the time of the MRI scan with the late onset of clinical CPN signs and symptoms or whether there was CPN damage at the time of surgery.

Compared to complete CPN injury, partial CPN injury has a much better prognosis with expected spontaneous recovery [9,12,14,20-22]. However, the motor and sensory changes can be subtle and, where pain, swelling and casting are present, the detection of these changes can be difficult to appreciate accurately [1,23]. Of 6 adequate MRI scans for those with partial CPN injury, only 3 scored over 2 or more (MRI scores of 2, 2 and 4). Three of the 7 patients with partial CPN injury had neurolysis at the time of ligamentous reconstruction; 4 were managed conservatively. All of these patients achieved full recovery on an average of 44 days. Partial CPN injury may be due to traction injury where subtle increases in T2 signal may need more sensitive sequences than those used in our current routine MRI protocol. If those with partial CPN injury are identified properly then it may be that a non-surgical waiting trial (+/- neurolysis) can be offered to these patients with the expectation of spontaneous recovery.

If we suggested all patients with an MRI score of 2 or more had surgical CPN exploration and neurolysis +/- repair, neurolysis would have been performed on five additional patients who were normal (Table 5) or one who recovered without neurolysis (Table 4). If the cut off score for MRI was 4, no additional patients would have had exploration and neurolysis. However, since neurolysis was undertaken in a number of other cases on clinical grounds, we are as yet not able to suggest which patients might benefit from neurolysis using MRI.

Incidence of CPN injury

The low incidence of CPN injury in our study is due mainly to selection criteria. First, patients were included if they had a history of knee dislocation or if MRI reports indicated the presence of dislocation-like event based on the knee injury pattern. Those at lower risk of CPN injury would likely have been included.

Second, in the early years of the study period, MRI was performed less frequently following knee injury.

d.Inter-observer reliability:

Kappa agreement between two independent radiologists was stronger in the complete CPN injury group compared to the partial CPN injury group. This indicates that complete CPN injury was more consistently detected.

Limitations:

a. **Medical records:**

The low number of complete CPN injury patients means our study is more prone to type II errors, affecting the ability to generalize findings to the whole population.

In this retrospective study, loss of data and inaccurate data are inevitable. In addition, details regarding surgical intervention were limited. We were unsure of the details regarding the site of neuro-exploration/ neurolysis as well as of whether these procedures were done as routine preventive measure or carried out to manage an injured CPN.

Retrospective clinical scores using physical examination reports from the medical notes used to classify our cohort into normal CPN, partial CPN and complete CPN injuries may have been inaccurate.

b. Long term outcome:

Long term outcome in our study was determined from medical records using recorded assessment of TA and EHL muscle strength and CPN sensory abnormalities. However, ideally long term outcome should be interpreted in the context of useful clinical recovery by using International knee documentation committee (IKDC) and Lyshom's scores [9,14,21] or short form health questionnaire (SF-36) and the visual analogue scale (VAS) scores [9].

Future directions:

In a future study, patients with clinical evidence of any CPN injury might have MRI performed with specific neural sequences, in addition to subjective physical examination, to aid the accurate division into 2 groups: partial CPN injury for 'watch and wait' management with or without neurolysis and complete CPN injury for exploration and neurolysis with or without repair. An updated scoring system could include perineural changes on T1 weighted imaging.

Conclusion:

Routine knee MRI is frequently inadequate for the assessment of CPN injury. Even allowing for that, MRI findings of significant injury were present in this study in 2 patients with complete CPN injury who had persistent symptoms at follow up. This suggests that there is a role for knee MRI in guiding surgical management for complete

CPN injury that might be enhanced with more specific neural sequences using adequate coverage.

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Table 1- Definition of clinical scores at initial presentation

Normal CPN	**Partially injured CPN**	**Completely injured CPN**
Muscle power*: **EHL=5/5** **TA=5/5**	**Muscle power*:** **EHL = [1/5 , 4/5]** **TA = [1/5 , 4/5]**	**Muscle power*:** **EHL=0/5** **TA=0/5**

And **Sensation intact for CPN distribution**	**And** **Sensory abnormality(numbness, tingling, absent sensation or paraesthesia)**	**And** **Sensory abnormality (numbness, tingling, absent sensation or paraesthesia)**

EHL= Extensor hallucis longus, TA= tibialis anterior
Muscle power*= grading using medical research council (MRC) scale (Maak, 17).
Subjects with muscle weakness or sensory disturbance alone were included in the normal group.

Table 2- MRI scoring.

Adequacy of coverage	MRI CPN size score	CPN signal intensity (compared to normal tibial nerve or muscle)
1: CPN seen from sciatic nerve to fibula neck **2: CPN coverage incomplete at fibula neck** **3: CPN coverage incomplete at division sciatic nerve but seen to fibula neck** **4: Anatomic variation present-comment on exact anatomic variation**	**0: normal size** **1: focal increase** **2: focal decrease** **3: focal transection** **4: focal transection with length of separation measured in mm.**	**0: normal signal** **1: mildly increased T2 signal** **2: moderately increased T2 signal** **3: severe T2 hyper-intensity** **4: complete transection**

5: Inadequate for CPN assessment (poor signal or artefact)		

Table 3- Long term outcome.

	Normal CPN group (93 patients)	**Partial CPN injury group (7 patients)**	**Complete CPN injury group (7 patients) see table 4 for detail**
Age (years)			
Mean	40	38.4	37.4
Range	[19, 81]	[20, 57]	[22, 53]
Mechanism of injury (cases)			
High velocity of injury (MBA, MVA, PVV)	76	2	6
Sports related injury	14	1	0
Other injury	3	4	1

Recovery	1 case - TA = 3/5, EHL = 5/5 with normal sensation 3 days post injury recovered fully after 1 week. None had clinical evidence of CPN injury at an average of 34.5 days post initial injury.	All had full recovery at an average of 44 days post initial injury	3 had recovered at an average of 114 days post injury. 4 had persistent symptoms.
Number having knee surgery of any sort (cases) **Time from injury to surgery:** **Mean (days)** **Range**	57 34.5 [1, 610]	3 15.6 [6, 24]	6 106.8 [9, 515]
Cases having neurolysis	0	3	5

Table 4- Complete CPN injury group.

No.	**Initial presentation**		**MRI scans**			**Final follow-up**			**Surgical Intervention**	**NCV /EMG**
	Muscle Power	**Sensation**	**Adequacy**	**Scores**	**Time from injury (days)**	**Muscle Power**	**Sensation**	**Time From Injury (days)**		

1	TA:0/5 EHL:0/5	Abnormal	Adequate	2	0	TA:3/5 EHL:3/5	Normal	95	F*,P*,CPN* 15 days post injury	No
2	TA:0/5 EHL:0/5	Paraesthesia	Adequate	5	0	TA:1/5 EHL:1/5	Abnormal	402	F*,P*,CPN* 9 days post injury	Yes*
3	TA:0/5 EHL:0/5	Numbness	Adequate	8	3	TA:0/5 EHL:0/5	Abnormal	292	F*,L*,CPN* 9 days post injury	No
4	TA:0/5 EHL:0/5	Paraesthesia	Adequate	0	5	TA:4/5 EHL:4/5	Paraesthesia	78	F*,CPN* 9 days post injury	No
5	TA:0/5 EHL:0/5	Paraesthesia	Inadequate	0	12	TA:5/5 EHL:5/5	Normal	280	P*,L*,CPN* 88 days post injury	No
6	TA:0/5 EHL:0/5	Absent sensation	Inadequate	5	4	TA:5/5 EHL:5/5	Normal	22	L* 11 days post injury	No
7	TA:0/5 EHL:0/5	Numbness	Adequate	0	25	TA:5/5 EHL:5/5	Normal	40	None	No

TA=tibialis anterior, EHL=extensor hallucis longus

F*=Fracture repair

CPN*= Common peroneal nerve neurolysis or neuro-exploration

P*=posterolateral corner repair

L*= Ligamentous repair/reconstruction

Yes*= NCV: Absent CPN motor and sensory components, EMG: antalgic inhibition of right TA and EHL

Table 5. Clinical scores versus MRI scores on adequate scans.

	Clinical scores

	Normal CPN	Partially injured CPN	Completely injured CPN
Normal CPN on MRI	**68**	**3**	**2**
Injured CPN on MRI	**5**	**3**	**3**
Total	**73**	**6**	**5**