A COMPARISON OF FINE WIRE INSERTION TECHNIQUES FOR DEEP FINGER FLEXOR MUSCLE ELECTROMYOGRAPHY

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ABSTRACT

Introduction: Intramuscular electromyography electrodes targeting flexor digitorum profundus (FDP) are inserted via the anterior or medial aspect of the forearm. These two methods pose different risks to neurovascular structures which overly FDP. This study aimed to compare the insertion depth and consider advantages and limitations of two different techniques to insert intramuscular electrodes into FDP.

Methods: Using ultrasound imaging, neurovascular structures were identified along the path of FDP electrode insertion at the junction of the proximal and middle third of the ulna, bilaterally, in ten healthy individuals. Insertion depth was compared between the anterior and medial approaches for the mid muscle belly and targeted insertion to the index finger fascicle of FDP.

Results: In our sample the ulnar artery was superficial to the FDP muscle when viewed anteriorly and was beyond the furthest border of FDP when viewed medially. Compared to the anterior approach, the medial insertion depth was 1.5cm (95%CI 1.4–1.7, $p<0.001$) less to the mid-belly of FDP and 0.6cm (95%CI 0.4-0.7, $p<0.001$) less to the index finger fascicle of FDP.

Discussion: The medial approach involves less depth and lower risk for perforation of neurovascular structures when inserting intramuscular electrodes into the FDP muscle.

INTRODUCTION

The flexor digitorum profundus (FDP) muscle originates from the proximal three quarters of the medial and anterior aspects of the ulna, the coronoid process and the interosseous membrane, and inserts into the distal phalanges [Saladin 2011] (Fig. 1). The FDP muscle includes fascicles for each digit (II to V) [Wheeless et al., 2012]. Proximally, the index finger fascicle divides from the medial three fascicles, which permits greater independence of the index finger [Wheeless et al., 2012]. The median nerve innervates the lateral two digits (II and III) and the ulnar nerve innervates the medial two digits (IV and V) [Saladin 2011].

Electromyographic (EMG) investigation of human forearm flexor muscles are commonly undertaken to explore the use of targeted muscle activation for hand prosthetics [Birdwell et al., 2013, Birdwell et al., 2015, Cipriani et al., 2014] and to investigate changes in motor control between those with and without pathology [Heales et al., 2016, Heales et al., 2015, Kelley et al., 1994]. These investigations of human forearm muscles using EMG are challenging given their relatively small cross sectional area, their close proximity to one another, and their proximity to adjacent neurovascular structures. Surface EMG electrodes avoid risk to neurovascular structures but are limited in their capacity to monitor individual forearm muscle activity because of cross talk [Mogk et al., 2003, Kong et al., 2010]. Fine-wire intramuscular EMG electrodes can reduce cross talk because of their small recording area and location within the target muscle.

Two techniques are used to insert fine wire EMG into FDP: (1) insertion via the anterior aspect of the forearm [Burgar et al., 1997], and (2) insertion via the medial aspect of the forearm [Preston et al., 2005, Perotto 2011] (Fig. 1). An anterior approach for FDP intramuscular insertion involves some risk as this muscle lies deep to the median and ulnar nerves and ulnar artery [Saladin 2011]. In addition, there are several muscles that lie superficial to FDP (e.g. flexor digitorum superficialis, palmaris longus) and it is possible that

EMG electrodes could be inaccurately placed in these muscles if the needle is inserted to an insufficient depth (Fig. 1). The medial approach reduces the potential for neurovascular damage and allows access to the majority of the FDP muscle belly with a potentially shorter insertion depth, although the lateral fascicles (digits II and III) are proposed to be deeper and harder to accurately place electrodes. This study aimed to compare the insertion depths required for each technique, provide an overview of the advantages and limitations of each technique, and discuss the safety implications of FDP fine-wire EMG using each technique.

METHODS

Participants

Ten healthy participants were included (Table 1). Participants were excluded if they had: musculoskeletal pain/injury within the preceding 12 months (e.g. elbow pain); upper limb surgery; major trauma within 5 years (e.g. fractures); and/or metabolic disorders (e.g. diabetes). The Institutional Human Research Ethics Committee approved the study and written informed consent was obtained prior to participation.

Protocol

B-mode ultrasound was used to measure FDP depth from skin to the middle of the muscle belly (4-15 MHz linear array transducer, Aixplorer® SuperSonic Imaging, Aix-en-Provence, France). Insertion depth was measured to the: 1) middle of the muscle belly and 2) the index finger fascicle of FDP. The left and right arms of each individual were measured. To determine the FDP depth (mid muscle belly and index finger) using the anterior approach, participants sat with their forearm fully supported in full supination (Fig. 2A)[Burgar et al., 1997]. To determine the FDP depth (mid muscle belly and index finger) using the medial approach, participants sat with their elbow flexed, forearm supinated and the hand resting on the shoulder of the same side (Fig. 2B) [Preston et al., 2005, Perotto 2011]. This position allows FDP to be viewed medial to the ulna. Power Doppler was used to visualise neurovascular structures and their location was considered with respect to the path for insertion of the EMG electrode into FDP. To investigate the variability associated with the location of the ulnar artery with respect to FDP, the distance from the FDP lateral border to the middle of the ulnar artery was measured using the image made from the anterior aspect of the right forearm of all individuals. Finally, forearm circumference was measured as a method to normalize the insertion depth for each individual. Aligned with published methods [Preston et al., 2005], all measures were made at the junction of the middle and proximal third of the forearm, which is approximately four finger breadths distal to the olecranon.

Statistical analysis

Statistical analysis was completed using Statistica (StatSoft Inc., Tulsa, Oklahoma, USA). Two separate repeated measures analysis of variance (ANOVA) were used to compare depth measures for; (1) the mid muscle belly, and (2) the targeted fascicle of the index finger (digit II). For each analysis, Technique (anterior versus medial) and Arm (right versus left) were both included as within-subject effects. The difference between approaches for each ANOVA are presented as mean differences (MD) and 95% confidence interval (95%CI). Alpha was set at $P<0.05$. Variation in ulnar artery location is presented as a range of distances from the lateral FDP muscle border. The estimated insertion depth, as a percentage of forearm circumference, is reported as a range for the anterior and medial approach.

RESULTS

Mid muscle belly of flexor digitorum profundus

There was no significant difference in FDP muscle depth between an individual's arms (Interaction: Arm x Technique $p=0.17$; Main Effect: Arm $p=0.73$). The FDP muscle belly was deeper (Main effect: Technique $p>0.001$) when approached from the anterior aspect of the forearm (3.1±0.4cm, Fig. 2A) than the medial aspect (1.5±0.2cm, Fig. 2B) (MD 1.5cm

[95%CI 1.4-1.7], $p<0.001$). When participants were considered individually, the shortest distance to the mid FDP muscle belly with an anterior approach was 2.7cm, and 1.2cm using the medial approach (Table 1). The greatest distances were 4.0 and 2.0cm for the anterior and medial approach, respectively (Table 1). Viewed anteriorly, the ulnar artery was always observed immediately superficial to the FDP muscle with substantial variation in medial-lateral location. The location of the artery ranged between 2.2 and 3.8cm from the lateral border of the muscle (Table 1). The insertion depth as a percentage of forearm circumference ranged between 10.4 and 12.8% (mean11.6 ±0.6%) for the anterior approach and between 5.0 and 6.5% (mean 5.9 ±0.5%) for the medial approach.

Targeted selection of the index finger fascicle of flexor digitorum profundus

There was no significant difference in FDP muscle depth between an individual's arms (Interaction: Arm x Technique $p=0.17$; Main Effect: Arm $p=0.34$). The index finger fascicle of FDP was deeper (Main effect: Technique $p>0.001$) when approached from the anterior aspect of the forearm (3.0±0.3cm, Fig. 2A) than the medial aspect (2.4±0.3cm, Fig. 2B) (MD 0.6cm [95%CI 0.4-0.7], $p<0.001$). When participants were considered individually, the shortest distance to the index finger fascicle (digit II) of FDP with an anterior approach was 2.6cm, and 2.0cm using the medial approach (Table 1). The greatest distances were 3.8cm and 3.1cm for the anterior and medial approach, respectively (Table 1). Viewed medially, the ulnar artery is located beyond the furthest border of the index finger fascicle.

DISCUSSION

The novelty of this study is that it provides objective data regarding the insertion depth, demographic descriptors (e.g. age, weight, height, BMI), and forearm circumference to inform both clinicians and researchers of two previously published techniques for the insertion of fine-wire electrodes to record FDP EMG. Regardless of the intended target, the medial approach requires a lesser insertion depth to insert fine-wire electrodes into FDP.

Previous work by Burgar et al., [1997] suggests an insertion depth of 3.0cm for all individuals using the anterior approach to target the index finger fascicle. Although this is identical to the average insertion depth identified in the present study (3.0 ±0.3cm), it would not ensure placement in FDP for participants with greater muscle depth (i.e. up to 3.8cm in our study) with potential to remain in more superficial muscles and not record FDP EMG. The variation in ulnar artery location highlights the potential risk if the insertion is performed without US guidance. Using the medial technique, no muscles or vessels overly FDP. This ensures that even if a standardised depth of insertion was used, electrodes would be placed in FDP without potential trauma to the ulnar artery, despite variation in forearm size. For either technique, standardised insertion depth would cause variation in recording location within the muscle between individuals with large and small forearms. Even when a specific fascicle is not targeted, the accuracy of both techniques could be improved by using 11.6% and 5.9% of the forearm circumference for the anterior and medial approach, respectively, or ultrasound guidance.

Burgar et al., [1997] cautioned that incorrect insertion via an anterior approach could perforate the radial nerve or artery, median nerve, and interosseous nerve or artery, but did not mention the ulnar nerve or artery despite their location superficial to FDP (Fig. 2A). It is likely this was not mentioned because they intended to target the FDP fascicle responsible for index finger flexion and those fascicles are located further laterally, away from the ulnar nerve and artery [Burgar et al., 1997]. Given the position of the ulnar artery over the midline of the muscle belly, an anterior approach might be better suited to target the lateral FDP fascicles (i.e. the index finger), despite the greater insertion depth required with the anterior approach. When a medial approach is used, the ulnar nerve could be potentially perforated by the needle is the deeper fascicles of FDP (i.e. index finger fascicles) are targeted [Preston et al., 2012]. To avoid the ulnar nerve and target the lateral fascicles, Preston et al., [2012] suggest the needle be inserted further to the medial edge of the forearm in the frontal plane (i.e. medial to lateral) rather than from a posterior angle (Fig. 1). Given that the medial approach ensures that no neurovascular structures lie superficial to FDP and that insertion requires less depth to reach the mid muscle belly (i.e. 1.5 ± 0.2 mm) and lateral fascicles (i.e. 2.4 ± 0.3 cm), the associated risk of the medial approach is likely less than the anterior approach, particularly when targeting the medial muscle fascicles.

Advantages and limitations of each insertion approach

The medial approach for FDP electrode insertion has several advantages. These include a reduced likelihood of neurovascular damage (as no vessels lie in the path of electrode insertion), a lesser insertion depth required to reach FDP (both medial and lateral fascicles), and less potential for the electrode to be inaccurately placed in more superficial muscles, because no muscles overly FDP medially. Several limitations require consideration. Although insertion into the lateral fascicles via the medial approach results in a lesser insertion depth, the medial approach might make it more difficult to target the lateral FDP fascicles (i.e. the index finger) as this fascicle is in close proximity to the antero-lateral ulna. In addition, the ulnar artery lies just beyond the distant border of the index finger muscle fascicles when inserting via a medial approach (Fig. 2B). Using ultrasound imaging to visualise the depth of the ulnar artery would provide a safer technique and ensure accurate placement of the fine-wire EMG electrode. Depending on task and limb position, medial FDP intramuscular electrode insertion might increase the potential to induce to movement artifact if the forearm contacts a support surface. A foam pad under the forearm and firm electrode fixation to the skin could minimise such artifacts. It is important to note that tape fixation should not be too close to the insertion point or obstruct the sliding of the fine wire during muscle contraction, as this may result in the potential extraction of the electrode. Finally, superficial veins (e.g. basilic vein) may be more difficult to visualise on the medial than anterior forearm due to darker skin complexion and the presence of hair (especially in males).

Technical considerations for intramuscular electrode insertion

Intramuscular EMG electrode insertion requires training and experience. Aseptic technique is recommended to protect the participant and operator. Ultrasound imaging with Power Doppler capabilities permits visual confirmation of electrode insertion into the target muscle, identification of neurovascular structures so they can be avoided, and individualizes the electrode insertion depth to match the participant's size. We recommend the use of ultrasound imaging for accurate insertion of intramuscular electrode into FDP, but argue that if this is not available, the medial approach is more likely to achieve placement in the muscle with least risk.

CONCLUSION

This study offers an unbiased comparison of the advantages and disadvantages of two different techniques to insert fine-wire electrodes into FDP. Although ultrasound guidance of electrode insertion is recommended, we propose that the medial technique offers a potentially safer approach with lower risk of injury to neurovascular structures, to investigate behavior of the FDP muscle with fine wire intramuscular EMG electrodes.

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Table 1. Demographic characteristics and individual participant data.

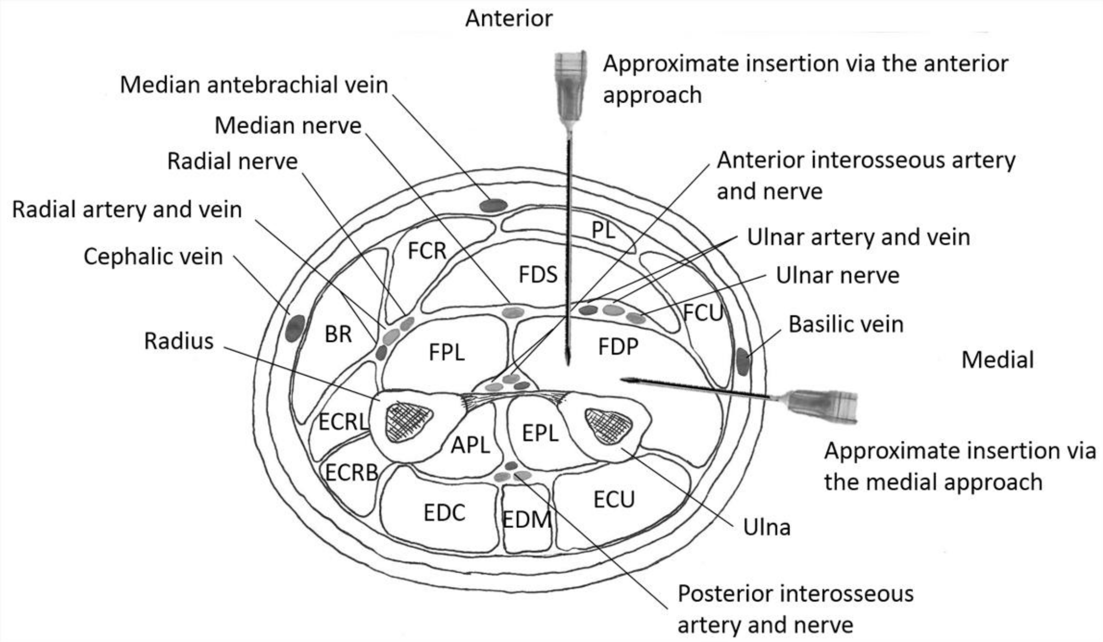
Subject	Age (yrs)	Sex	Dominant arm	Height (m)	Mass (kg)	BMI (kg/m^2)	Right forearm circumference (cm)	Left forearm circumference (cm)	Right ANT mid (cm)	Left ANT mid (cm)	Right MED mid (cm)	Left MED mid (cm)	Right ANT digit II (cm)	Left ANT digit II (cm)	Right MED digit II (cm)	Left MED digit II (cm)	Distance from ulnar artery to lateral border of FDP (Right arm only) (cm)
1	22	F	Right	1.61	60.6	23.5	24.2	24.5	2.8	2.9	1.4	1.4	2.6†	2.7	2.2	2.1	2.2†
2	31	F	Right	1.77	76.8	24.6	25.5	24.5	2.9	2.8	1.2†	1.3†	2.8	2.7	2.0†	2.1	2.2
3	28	F	Left	1.70	69.8	24.2	25.2	24.7	2.9	2.9	1.4	1.4	3.0	2.8	2.1	2.0	2.6
4	36	F	Right	1.60	66.2	25.7	24.4	24.2	2.8†	2.7†	1.4	1.4	2.6	2.7	2.3	2.2	2.3
5	31	M	Right	1.78	94.0	29.7	29.4	29.7	3.3	3.3	1.6	1.8	3.3	3.2	2.6	2.6	3.2
6	23	F	Right	1.68	61.8	21.9	24.0†	23.3†	2.9	3.0	1.5	1.5	2.7	2.8	2.4	2.2	2.6
7	20	M	Right	1.86	74.2	21.4	25.8	25.0	2.9	3.0	1.7	1.6	2.8	2.7	2.5	2.4	3.8†
8	51	M	Right	1.87	104.0	29.7	31.5†	31.9†	4.0†	3.9†	2.0†	1.7	3.7	3.8†	3.1	2.6	2.8
9	28	M	Right	1.67	82.0	27.4	27.5	27.4	2.9	3.2	1.7	1.7†	3.0	3.0	2.6	2.8†	3.6
10	57	M	Right	1.83	85.6	25.6	28.9	28.4	3.4	3.4	1.6	1.7	3.2	3.4	2.6	2.6	3.3
Mean (SD)	32.7 (12.3)			1.74 (0.10)	77.5 (14.1)	25.6 (3.1)	26.6 (2.6)	26.4 (2.8)	3.1 (0.4)	3.1 (0.4)	1.6 (0.2)	1.5 (0.2)	3.0 (0.4)	3.0 (0.4)	2.4 (0.3)	2.4 (0.3)	2.9 (0.6)

† - minimum and maximum values for each measure. FDP – flexor digitorum profundus, ANT – anterior, MED – medial, mid – middle of the muscle belly, digit II – index finger (lateral fascicle).

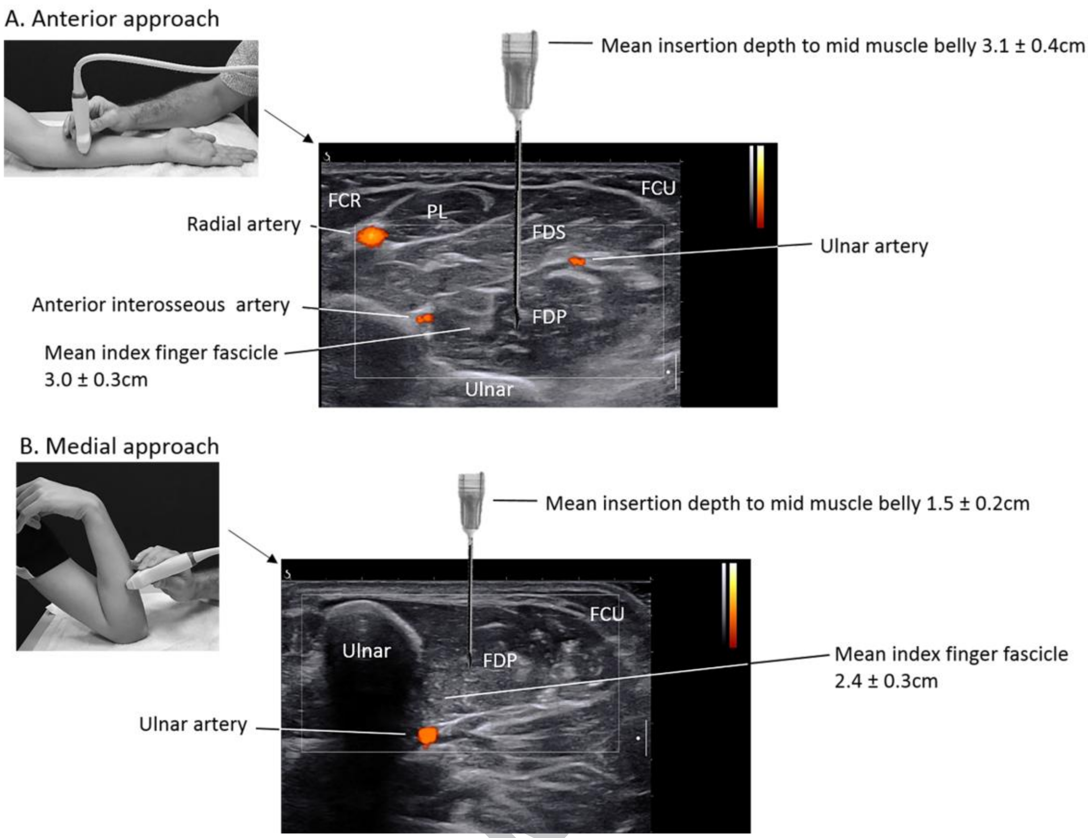
FIGURE LEGENDS

Figure 1. Schematic cross sectional representation of the right forearm at the junction of the middle and proximal third (viewed from distal end). It should be noted that the lateral FDP fascicles might be difficult to reach with the medial insertion approach and if that is the target for investigation the anterior insertion approach under US guidance may be required. BR – brachioradialis, FCR – flexor carpi radialis, PL – palmaris longus, FCU – flexor carpi ulnaris, FDS – flexor digitorum superficialis, FDP – flexor digitorum profundus, FPL – flexor pollicis longus, ECRL – extensor carpi radialis longus, ECRB – extensor carpi radialis brevis, EDC – extensor digitorum comminus, EDM – extensor digiti minimi, ECU – extensor carpi ulnaris, APL – abductor pollicis longus, EPL – extensor pollicis longus.

Figure 2. Representation of the needle path, insertion depth and ulnar artery location associated with the A) anterior, and B) medial approach. FCR – flexor carpi radialis, FCU – flexor carpi ulnaris, FDP – flexor digitorum profundus, FDS – flexor digitorum superficialis, PL – palmaris longus



Anterior
Approximate insertion via the anterior approach
Median antebrachial vein
Median nerve
Radial nerve
Anterior interosseous artery and nerve
Radial artery and vein
Ulnar artery and vein
Cephalic vein
Ulnar nerve
Basilic vein
Radius
Medial
PL
FCR
FDS
FCU
BR
FPL
FDP
ECRL
APL
EPL
ECRB
EDC
EDM
ECU
Approximate insertion via the medial approach
Ulna
Posterior interosseous artery and nerve


A. Anterior approach
Mean insertion depth to mid muscle belly 3.1 ± 0.4cm
FCR
PL
FCU
FDS
Radial artery
Ulnar artery
Anterior interosseous artery
FDP
Mean index finger fascicle
3.0 ± 0.3cm
Ulnar
B. Medial approach
Mean insertion depth to mid muscle belly 1.5 ± 0.2cm
FCU
Ulnar
FDP
Mean index finger fascicle
2.4 ± 0.3cm
Ulnar artery

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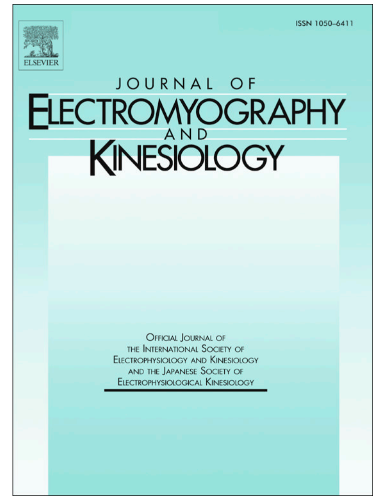
Kylie Tucker [PhD, BSc(Hons), BA] has worked at the University of Queensland (UQ) as a NHMRC project funded postdoctoral Research Fellow (2006-2011) and NHMRC CD Fellow (2011-2015) during which time she was mentored by Professor Paul Hodges within the clinically focused NHMRC CCRE-SPINE, UQ. Kylie established the Laboratory for Movement Control and Pain Research in 2014, and was appointed as Senior Lecturer in the School of Biomedical Sciences in 2016. She has published > 66 papers and book chapters, and has received 2 international research awards for her work including the KP Granata Award from the International Society of Electromyography & Kinesiology, which is presented to a ''researcher who demonstrates a distinguished accomplishment during the first 5 years after PhD."

Bill Vicenzino [PhD, MSc, GradDipSportsPhty, BPhty] is a Professor in Sports Physiotherapy at the University of Queensland, Australia. He is the Director of the Master of Physiotherapy programs in Musculoskeletal & Sports Physiotherapy and of the Sports Injury Rehabilitation and Prevention for Health research unit. Bill's focus is on musculoskeletal health, pain and injury (focusing on conditions such as tendinopathy, patellofemoral pain, ankle sprain). He has received over $25 million in research funds (from NHMRC, ARC and industry) and conducts clinical trials on treatments such as exercise, manual therapy, injections, advice/education, and orthoses/taping. One trial on physiotherapy versus steroid injections for tennis elbow was rated as a top 15 /29,000 (PEDro-indexed) '…ground breaking trials that changed the way people are treated…' and '…mark important milestones in the evolution of physiotherapy treatment…' He has communicated his research in over 240 peer-reviewed journal publications, 2 books, 35 chapters, and in over 300 podium/workshop presentations.

Paul W. Hodges [PhD, MedDr, DSc, BPhty(Hons), FACP] is an NHMRC Senior Principal Research Fellow and Directs the NHMRC Centre for Clinical Research Excellence in Spinal Pain, Injury and Health. Paul has 3 doctorates; one in Physiotherapy and two in Neuroscience. His research blends these skills to understand pain, control of movement, and the multiple functions of trunk muscles including spine control, continence, respiration and balance. His large multidisciplinary Research Centre bridges the gap between basic science and clinical practice. He has received numerous international research awards (including 2006/2011 ISSLS Prize), published > 370 papers and book chapters and presented > 220 keynote lectures in > 35 countries. He is the past president of the International Society for Electrophysiology and Kinesiology (ISEK) and chaired the 2012 conference of ISEK in Brisbane, Australia.

David MacDonald [PhD, BSc(PT)] is a Senior Lecturer in Physiotherapy at Griffith University and an Honorary Lecturer in the Division of Physiotherapy at the University of

Queensland. He has published 15 papers and his research has been presented at 21 national and international conferences. His previous research advanced our understanding of trunk muscle behaviour in people with recurrent low back pain. His current research focuses on the use of exercise in the management of people with chronic low back pain.



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