The Effectiveness of Self-Myofascial Release with Foam Rollers or Roller Massagers on Range of Motion: A Systematic Review

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Declaration

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This thesis entitled “The Effectiveness of Self-Myofascial Release with Foam Rollers or Roller Massagers on Range of Motion: A Systematic Review” is submitted in partial fulfilment for the requirements for the Unitec degree of Master of Osteopathy.

Candidate’s Declaration:

I confirm that:

• This thesis research project represents my own work;

• The contribution of supervisors and others to this work was consistent with the Unitec Regulations and Policies.

• Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee.

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## Contents

Title ................................................................................................................................. i
Declaration ...................................................................................................................... ii
Acknowledgements ...................................................................................................... iii
Contents ........................................................................................................................ iv
List of Figures ................................................................................................................ vi
List of Tables ................................................................................................................ vi
List of Symbols and Abbreviations ............................................................................ vi
Introduction to Thesis ...................................................................................................... vii
Abstract ........................................................................................................................ viii

### SECTION A: LITERATURE REVIEW

Introduction .................................................................................................................... 2
Range of Motion .............................................................................................................. 2
Stretching and Range of Motion .................................................................................... 4
Self-Myofascial Release ................................................................................................. 8
The Hierarchy of Evidence ............................................................................................ 13
Findings and Limitations of Reviews on Self-Myofascial Release and Range of Motion ..... 16
Conclusion ...................................................................................................................... 20
References ..................................................................................................................... 21

### SECTION B: MANUSCRIPT

Title ................................................................................................................................. 41
Authors ............................................................................................................................ 42
Affiliations ..................................................................................................................... 42
Correspondence ............................................................................................................ 42
Abstract ........................................................................................................................ 43
Background ..................................................................................................................... 44
Methods ........................................................................................................................ 46
  Literature Search Strategy .......................................................................................... 46
  Selection Process ........................................................................................................ 46
  Characteristics Extraction Process ............................................................................ 47
  Data Collection, Appraisal, and Synthesis Process .................................................. 47
Strength of Evidence ........................................................................................................ 48
Results ............................................................................................................................. 49
  Selection of Studies .................................................................................................... 49
  Participant Characteristics ....................................................................................... 49
  Methodological Quality .......................................................................................... 50
  Evidence Synthesis .................................................................................................. 51
  Levels of Evidence .................................................................................................. 51
Discussion ....................................................................................................................... 52
  Selection of Studies ................................................................................................ 52
  Participants and Clinical Diversity .......................................................................... 52
  Study Quality ........................................................................................................... 53
    Effect of Poor External Validity ............................................................................... 53
    Effects of Moderate Internal Validity ..................................................................... 54
    Effect of Low Power on Results ........................................................................... 54
Clinical Diversity of Evidence ....................................................................................... 55
Efficacy of Intervention ............................................................................................... 55
SMFR Tools ................................................................................................................... 56
Control Groups ............................................................................................................. 57
Intervention Dose .......................................................................................................... 57
  Rolling Frequency .................................................................................................... 57
  Rolling Duration ....................................................................................................... 58
Rolling Motion ............................................................................................................... 58
Outcome Measures ...................................................................................................... 59
Target Muscles ............................................................................................................. 60
Future Research .......................................................................................................... 60
Limitations ..................................................................................................................... 61
Conclusion ..................................................................................................................... 61
References ...................................................................................................................... 62

SECTION C: APPENDICES ............................................................................................. 80
Appendix A: Physical Therapy Reviews Instructions to Authors .................................. 81
Appendix B: Advice to Authors on Preparing a Manuscript ........................................... 87
List of Figures

Figure 1: Literature Search Strategy ................................................................. 73

List of Tables

Table 1: Characteristics of Individual Studies .................................................... 74
Table 2: Modified Downs and Black Methodological Scores and Quality Index Scores .... 76
Table 3: Quality Index Score Classification ......................................................... 79
Table 4: Van Tulder Levels of Evidence .................................................................. 79
Table 5: Study Findings by Quality Index ............................................................... 79

List of Symbols and Abbreviations

FR Foam Roller
RM Roller Massager
ROM Range of Motion
SMFR Self-Myofascial Release
SS Static Stretching
DS Dynamic Stretching
PNF Proprioceptive Neuromuscular Facilitation
CCT/s Clinical Controlled Trial/s
RCT/s Randomised Controlled Trial/s
FRml Foam Rolling Medio-Lateral
FRap Foam Rolling Antero-Posterior
FAT Fascial Abrasion Technique
M Male
F Female
SD Standard Deviation
n Sample Size
r Effect Size (Independent t-tests)
p Statistical Probability
This thesis is arranged in three sections. Section A contains a literature review that discusses joint Range of Motion (ROM), and Self-Myofascial Release (SMFR) relating to foam rollers and roller massagers. The literature review considers the findings and limitations of previous reviews on self-myofascial release and range of motion, and discusses the hierarchy of evidence. Finally the literature review discuses the necessity of the current systematic review. Section B contains a manuscript formatted in accordance with the submission requirements of the Physical Therapy Reviews (See Appendix). The manuscript includes a title page, abstract, background, methods, results, discussion, conclusion, and references. Section C is an appendix that contains additional material supplementary to the thesis.
Abstract

Background: Altering Range of Motion (ROM) receives substantial attention from groups including researchers, healthcare providers, and both recreation and competitive athletic populations. The most commonly used method is stretching. An alternative method is of Self-Myofascial Release (SMFR) with a foam roller or roller massager. A literature review was conducted with the aim of providing insight and context around the topic of SMFR and ROM. The literature review sought to explain concepts such as myofascial release and joint ROM. The review explored mechanisms of action by which SMFR may influence ROM, and make comparisons to the stretching research that shares many concepts with SMFR but is more extensive than SMFR research. There are three studies published that reviewed randomised trials relating to SMFR and ROM. Despite the focus on ROM, there have been no systematic reviews that critique the relevant literature utilising the Downs and Black methodological quality appraisal tool, which would allow both randomised and non-randomised trials to be reviewed.

Objectives: To comprehensively search the literature relating to SMFR and ROM, appraise the methodological quality of selected randomised and non-randomised studies with the Downs and Black tool. To employ the Van Tulder criteria for determining levels of evidence for the selected studies, and evaluate the effectiveness of SMFR with a foam roller or roller massager for altering joint ROM.

Methods: A database search was completed to identify studies that were published from database inception to August 2016. Seven hundred and seventy seven studies were found, with twenty-two of these studies fitting the systematic reviews inclusion and exclusion criteria. Two reviewers independently extracted the data relating to methodological quality. One reviewer collated the results of the appraisals and then considered the data.

Results: The review’s twenty-two studies were of varying methodological quality, with the majority rated as moderate quality. The majority of studies found improvement in ROM after SMFR with a foam roller or roller massager. The Van Tulder criteria established a moderate level of evidence to support SMFR with a foam roller or roller massager as effective intervention for increasing joint ROM.

Conclusion: This systematic review demonstrates a moderate level of evidence for SMFR with a foam roller or roller massager to improve ROM. This review found the methodological quality of included studies to be moderate. Future research should focus on more consistent prescriptions of SMFR with respect to frequency, duration and outcome measures used.
Literature Review

Introduction
This literature review begins with an overview of joint Range of Motion (ROM), including a working definition. The second section provides an overview of stretching and ROM, in particular discussion of mechanisms of action for increasing ROM through stretching from a mechanical and neurophysiological perspective. The third section provides an overview of Self-Myofascial Release (SMFR) relative to foam rollers and roller massagers, and a discussion on mechanisms of action for increasing ROM through SMFR from a mechanical and neurophysiological perspective. In the fourth section the findings and limitations of prior reviews on SMFR and ROM are discussed. The fifth section discusses the hierarchy of evidence to illustrate the place of systematic reviews in the field of research and provides insight into the study designs included in this review. Lastly is a discussion of why the current systematic review is necessary, the aims of this review, and a conclusion.

Range of Motion
Physically active people in sports and recreational settings employ a variety of techniques to change joint ROM (Markovic, 2015; Vaughan & McLaughlin, 2014). Normal joint ROM is an integral element in efficient human movement (Kokkonen, Nelson, Eldredge, & Winchester, 2007; Mauntel, Clark, & Padua, 2014; Reese & Brandy, 2017; Shellock & Prentice, 1985), and restricted ROM has been shown to decrease movement efficiency (Rabin, Kozol, Spitzer, & Finestone, 2014; Willems, Cornelis, De Deurwaerder, Roelandt, & De Mits, 2014). Appropriate joint ROM allows adaptation to physical stressors, and this decreases the potential for movement disorders and injuries (Reese & Brandy, 2017; Shadmehr, Hadian, Naiemi, & Jalaie, 2009). Reduced ROM is a common finding in people participating in many sports and recreational activities (Markovic, 2015). The reduced ROM is linked to acute traumas such as muscle strains or repetitive micro-traumas occurring as people engage in sports and recreational activities (Markovic, 2015). The traumas can reduce the extensibility of fascial tissue through the formation of adhesions in the connective tissue, which may lead to increased tissue tension and reduced ROM (Barnes, 1997; Behara & Jacobson, 2015; Vernon & Schneider, 2009). An adhesion is an abnormal collection of connective tissue arranged in a random order, which impairs the extensibility of connective tissue reducing its capacity to change length (Barnes, 1997; Tortora & Derrickson, 2012).
A number of studies have shown restricted ROM increases the risk of injuries (Bradley & Portas, 2007; Henderson, Barnes, & Portas, 2010; Witvrouw, Danneels, Asselman, D’Have, & Cambier, 2003). Bahr and Holme (2003), and Meeuwisse (1994) have demonstrated that injuries result from complex interactions of multiple risk factors, and one consistently reported risk factor is reduced joint ROM (Jones et al., 1993; Krivickas & Feinberg, 1996; Mendiguchia, Alentorn-Geli, Idoate, & Myer, 2013). Brown, Miller, Schwellnus and Collins (2011) have demonstrated that reduced ROM is a modifiable risk factor, for this reason it has been a variable of interest in the healthcare profession. ROM assessment can help direct clinical reasoning, and act as a measure of effectiveness of interventions that aim to re-establish normal ROM (Gaiad, Miglino, Zatz, Hamlett, & Ambrosio, 2009). Furthermore measuring changes in ROM can have a positive effect on patients, as the changes are a personal and meaningful way to see progress (Warren, 1979).

This systematic review has employed a definition for joint ROM described by Norkin and White (2016), who reported range of motion as the “arc of motion in degrees between the beginning and end point of motion in a specified plane” (p. 7). This definition was further supplemented to note that the range of motion can occur in either a single joint or across multiple joints, and is influenced by internal anatomical structures such as fascia, muscles, tendons, ligaments, and bony structures (Anderson & Burke, 1991; Egwu, Mbada, & Olowosejeje, 2008), and by other factors such as age and gender (Alter, 1996; Gummerson, 1990; Norkin & White, 2016). Declining ROM is a commonly accepted aspect of aging that is supported by substantial literature (Boone & Azen, 1976; Intolo et al., 2009; James & Parker, 1989; Loebl, 1967; Norkin & White, 2016; Salo, Häkkinen, Kautiainen, & Ylinen, 2009). Females commonly have a greater ROM than males (Norkin & White, 2016). The greater ROM in females has been reported across a wide age range starting with teenagers and extending through to females 80 years of age (Almquist, Ekdahl, Isberg, & Fridén, 2013; Beighton, Solomon, & Soskolne, 1973; Bell & Hoshizaki, 1981; Norkin & White, 2016). The greater ROM in females has been reported in different joints (Bell & Hoshizaki, 1981). These reported gender differences may influence the outcomes in mixed gender studies.

Measurements of ROM can be either active or passive, the active tests involve muscle activity and passive tests do not. ROM is relative to tissue extensibility, defined as the ability of a tissue to be extended (Tortora & Derrickson, 2012). Extensibility can also be described in terms of ‘stiffness’ defined by the amount of force necessary to change tissue length (McNair
Stanley, 1996). Magnusson (1998) suggests that musculo-tendon elasticity is a product of both series elastic components and the parallel elastic components, which describes the origination of muscles elastic components. Series elastic components are primarily made up of endomysium, which is a layer of connective tissue that surrounds each individual muscle fiber or muscle cell (Tortora & Derrickson, 2012). Endomysium transfer force from the contractile components of muscles to the tendon and bone (Tortora & Derrickson, 2012). Parallel elastic components are primarily made up of perimysium, which surrounds bundles of muscle fibres. Perimysium distributes stress evenly through muscle tissues to prevent excessive stretch (Tortora & Derrickson, 2012). Series elastic components, parallel elastic components, and the fascial tissues that support muscles provide most of the resistance to stretching, and may be the cause of ROM restriction. A number of studies have demonstrated that these tissues exhibit properties of viscoelastic stress relaxation under loading such as a stretch, which may increase ROM (Magnusson et al., 1995; McHugh, Magnusson, Gleim, & Nicholas, 1992; McNair, Dombroski, Hewson, & Stanley, 2001).

**Stretching and Range of Motion**

Stretching is commonly used in clinical, athletic, and general population settings to increase ROM (Etmyre & Abraham, 1986; Magnusson, Simonsen, Aagaard, Sørensen, & Kjaer, 1996b; Page, 2012). There are numerous types of stretching, but the most common include static stretching and proprioceptive neuromuscular facilitation stretching (Couture, Karlik, Glass, & Hatzel, 2015; Page, 2012). Stretching produces an increase in joint ROM (Kirsch, Weiss, Dannenbaum, & Kearney, 1995; Zito, Driver, Parker, & Bohannon, 1997). Static stretching is considered an effective method for increasing joint ROM (Paradisis et al., 2014; Power, Behm, Cahill, Carroll, & Young, 2004), and research has shown proprioceptive neuromuscular facilitation stretching significantly increases ROM (Behm et al., 2016; Funk, Swank, Mikla, Fagan, & Farr, 2003; Lucas & Koslow, 1984; Wallin, Ekblom, Grahn, & Nordenborg, 1985). Although static stretching and proprioceptive neuromuscular facilitation stretching can increase ROM (Sharman, Cresswell, & Riek, 2006), understanding of the underlying mechanisms remains limited (Behm et al., 2016; Hindle, Whitcomb, Briggs, & Hong, 2012; Magnusson, Simonsen, Aagaard, Sørensen, et al., 1996b), and it is unclear if a specific single mechanism or a combination of mechanisms are responsible for the reported changes.
The changes in ROM as a response to stretching have been attributed to both neurophysiological and mechanical mechanisms (Hutton, 1993; Taylor, Dalton, Seaber, & Garrett, 1990). The majority of mechanical theorists suggest changes in ROM are attributed to alterations of sarcomere length, viscoelastic deformation, and reduced muscle tension (Weppler & Magnusson, 2010). The proposed theory for change to sarcomeres originated from animal data relating to immobilisation, with suggestions a similar mechanical mechanism could explain increase in ROM associated with stretching (Goldspink, Tabary, Tabary, Tardieu, & Tardieu, 1974; Tabary, Tabary, Tardieu, & Goldspink, 1972). The data suggested that as a response to immobilisation there is an addition of sarcomeres on the lengthened side and a reduction on the shortened side (Goldspink, Tabary, Tabary, Tardieu, & Tardieu, 1974; Tabary, Tabary, Tardieu, & Goldspink, 1972).

A key mechanical explanation for stretching induced changes in ROM is an alteration in the mechanical properties of muscles. Hutton (1993) and Taylor et al., (1990) suggested that tissues under tension exhibit viscoelastic behaviours such as preconditioning and stress relaxation. Many studies suggest increases in muscle extensibility seen after stretching are from viscoelastic deformation (Chan, Hong, & Robinson, 2001; de Weijer, Gorniak, & Shamus, 2003; Willy, Kyle, Moore, & Chleboun, 2001). An increase in muscle length can occur through the viscous behaviour of muscles when a stretch of sufficient magnitude and duration occurs. The increased length is only transitory, because the magnitude and duration of change are limited by an inherent elasticity of muscles that return to their original length once the force is removed (Weppler & Magnusson, 2010). When a stretch induced force is applied to a muscle for a period of time, the muscle’s resistance to stretch gradually declines (Magnusson, 1998; Weppler & Magnusson, 2010). This is commonly termed viscoelastic stress relaxation or creep (Magnusson, Simonsen, Aagaard, & Kjaer, 1996c; Magnusson et al., 1995). Creep is represented by the mechanical length of a tissue gradually increasing in response to a constant stretching force (Taylor et al., 1990). Other factors that may produce a creep response are repetitive motions, which have a warm-up effect that influences tissue mobility and ROM (Kelly & Beardsley, 2016; Law, Harvey, Nicholas, & Finniss, 2009).

Another mechanical mechanism for observed changes in ROM induced by stretching is viscoelastic creep. Viscoelastic creep refers to changes in the mechanical properties of target tissues, described as reduced muscle stiffness (Morse, Degens, Seynnes, Maganaris, & Jones, 2008). The relationship between reduced muscle stiffness and stretching is still under debate.
Several studies suggest general warm-up activities that increase muscle temperature are the most effective methods to decrease muscle stiffness (Noonan, Best, Seaber, & Garrett, 1994; Safran, Seaber, & Garrett, 1989). McNair, Dombroski, Hewson and Stanley (2000) reported continuous passive motion as a warm-up activity significantly reduced stiffness in the plantarflexors of the foot, and stretching did not. Other studies that assessed both stretching and active warm-up, reported that decreased muscle stiffness is primarily from increased temperature produced through warm-up activities and not through the effects of stretching (McNair & Stanley, 1996; Rosenbaum & Hennig, 1995).

The neurophysiological mechanisms for observed changes in ROM as a result of stretching are primarily associated with reflex responses and sensation (Weppler & Magnusson, 2010). One neurophysiological explanation suggests autogenic inhibition as the mechanism that may be responsible for ROM increases seen with proprioceptive neuromuscular facilitation stretching (Hindle et al., 2012). Autogenic inhibition occurs in a contracted or stretched muscle, where tension causes activation of afferent fibres within Golgi tendon organs that send signals to the central nervous system. The central nervous system sends an inhibitory stimulus that reduces neural excitability and decreases the target muscle’s efferent motor function (Sharman et al., 2006; Standrings, 2015). This response is known as autogenic inhibition because the shortening of the agonist muscle is prevented by the muscles’ own receptors (Fama & Bueti, 2011). The autogenic inhibition sequence causes the targeted muscle contractile units to relax, which is theorised to account for increased length in the muscle fibres and related ROM increases during proprioceptive neuromuscular facilitation stretching (Frontera, Slovik, & Dawson, 2006; Page, 2012). However, contradictory evidence has been reported in several studies that found increased electromyography activity in the muscle after the tension inducing contraction of a proprioceptive neuromuscular facilitation stretch (Magnusson, Simonsen, Aagaard, Dyhre-Poulsen, et al., 1996a; Mitchell et al., 2009). Furthermore, other stretching techniques including static stretching have been associated with increased electromyography response, not the reduced muscular response hypothesised (Moore & Hutton, 1980; Osternig, Robertson, Troxel, & Hansen, 1987). Consequently, the contribution of autogenic inhibition as the mechanism for increasing ROM is still disputed (Hindle et al., 2012; Sharman et al., 2006).
The most common neurophysiological mechanism for observed changes in ROM induced by stretching is related to the concept of ‘stretch tolerance’ (Magnusson, 1998; Magnusson, Simonsen, Aagaard, Dyhre-Poulsen, et al., 1996a; Reid & McNair, 2004; Wiemann & Hahn, 1997). Stretch tolerance describes a change in a person’s perception of the stretching sensation. An increase in stretch tolerance means a person is able to tolerate the higher levels of tension required to stretch a connective tissue farther than it was previously stretched (Weppler & Magnusson, 2010). Participant sensation is regularly used to determine ROM endpoints, however, there is no consensus about which sensation is most clinically relevant. A broad range of sensations have been used in research, such as participants perception of stiffness (Stephens, Davidson, Derosa, Kriz, & Saltzman, 2006), discomfort (Bandy, Irion, & Briggler, 1997; Feland, Myrer, Schulthies, Fellingham, & Measom, 2001), pain (Halbertsma & Goeken, 1994; Halbertsma, van Bolhuis, & Goeken, 1996; Magnusson, Simonsen, Aagaard, Dyhre-Poulsen, et al., 1996a), and stretch (Magnusson & Renström, 2006; Weppler & Magnusson, 2010). The change in a participant’s perception of a sensation could be driven by a peripheral nervous system change such as a reduced sensory receptor response to external stimuli (Weppler & Magnusson, 2010). The change in a participant’s perception of a sensation could also be driven by the central nervous system change such as the previous sensation experience being used to interpret the current sensation, or through a combination of both systems (Weppler & Magnusson, 2010). Currently the degree in which these systems are involved remains unclear (Weppler & Magnusson, 2010).

Several studies have investigated both mechanical and neurophysiological mechanisms of stretching in the same studies. The studies involved assessing tension as one of the outcome measures, and ROM determined by a sensation such as pain tolerance as the other outcome measure. If a mechanical change to the target tissue’s extensibility occurred as a result of the stretching, then mechanical tension measures would illustrate the change, however this was not seen. The studies did show a change to the ROM, which was attributed to altered perceptions of the sensation used to determine the endpoint for ROM measurement (Halbertsma & Goeken, 1994; Halbertsma et al., 1996; Magnusson, Simonsen, Aagaard, Dyhre-Poulsen, et al., 1996a). Determining a ROM endpoint from a participant’s detection of a given sensation, such as discomfort, can result in a ROM measurement that varies substantially amongst subjects (Halbertsma & Goeken, 1994; Weppler & Magnusson, 2010). Therefore, psychological elements may also be involved in the change to sensation perception (Weppler & Magnusson, 2010).
**Self-Myofascial Release**

The term myofascial release describes manual therapy techniques that apply pressure through the skin to target the surrounding connective tissues such as muscles and fascia, while also describing the techniques objective of changing these tissues length and function (McKenney, Elder, Elder, & Hutchins, 2013). SMFR techniques are a form of myofascial release that an individual performs on themselves, usually to influence myofascial mobility and joint ROM. SMFR techniques are commonly used to change ROM (Beardsley & Skarabot, 2015; Cheatham, Kolber, Cain, & Lee, 2015), and are typically applied with a variety of tools such as a foam roller or roller massager (Behara & Jacobson, 2015; Bushell, Dawson, & Webster, 2015; MacDonald et al., 2013; Markovic, 2015; Mikesky, Bahamonde, Stanton, Alvey, & Fitton, 2002; Sullivan, Silvey, Button, & Behm, 2013), with various balls such as a tennis ball (Grieve et al., 2015), or with a Thera Cane (Hanten, Olson, Butts, & Nowicki, 2000).

The most common SMFR techniques involve a foam roller or roller massager (Beardsley & Skarabot, 2015; Cheatham et al., 2015). The available types of foam rollers and roller massagers have variable structures including smooth surfaces (Bushell et al., 2015) and nodular surfaces (Behara & Jacobson, 2015), different lengths and circumferences, and different densities (Couture, Karlik, Glass, & Hatzel, 2015; Kelly & Beardsley, 2016). The roller massager is normally a small cylinder of solid plastic with a dense foam outer surface, and commonly 24 cm long with a 14 cm circumference (Halperin, Aboodarda, Button, Andersen, & Behm, 2014). Foam rollers are generally available in two sizes, a standard size (6 inch by 36 inch or 5 cm by 90 cm) and a half size (6 inch by 18 inch or 5 cm by 45 cm) (Cheatham et al., 2015). Foam rollers are commonly made of expanded polyethylene high-density foam, providing a smooth surface (Couture et al., 2015), or they are a hollow pipe core typically polyvinyl chloride enclosed with either a layer of ethylene vinyl acetate foam (Kelly & Beardsley, 2016) or neoprene (Macdonald, Button, Drinkwater, & Behm, 2014).

The polyvinyl chloride core and ethylene vinyl acetate types of foam roller appear to exert greater pressure on the soft tissues, and this greater pressure is directed through a smaller area of contact when compared to traditional foam rollers made out of expanded foam (Curran, Fiore, & Crisco, 2008). The increased pressure exerted through smaller a surface area results in deeper connective tissues and their receptors being influenced by the roller. In the study by Curran et al., (2008), which compared two types of foam roller, the foam roller of expanded foam exerted significantly less (statistical probability < 0.05) pressure at 33.4 ± 6.4
kilopascal, than the denser foam roller which produced 51.8 ± 10.7 kilopascal. The area of contact for the expanded foam roller was 68.4 ± 25.3 cm², which was significantly (statistical probability < 0.05) greater than the denser foam roller at 47.0 ± 16.1 cm². The results from the study suggest that the denser pipe rollers may be more appropriate for targeting deeper tissues and their receptors such as proprioceptors, which are types of sensory receptors located within tissues such as muscles and tendons. Proprioceptors such as Golgi tendon organs and muscle spindles have a neurophysiological role that respond to pressure and tension stimuli (Standrings, 2015). However, the exact influence that pressure induced stimulation from a foam roller or roller massager has on ROM is still undetermined, and additional research into this neurophysiological mechanism is still necessary.

The foam roller and roller massager tools are both designed to transfer pressure force onto the targeted tissues, but have different application processes. To use a foam roller for SMFR, the operator places their body weight onto the foam roller and this transfers pressure force onto the targeted tissues, then the operator engages in a rolling motion. To use a roller massager for SMFR, the operator holds the tool on the target tissue, and then uses their arm strength to apply a force while moving the tool in a rolling motion (Cheatham et al., 2015).

Peacock, Krein, Silver, Sanders, and von Carlowitz (2014) suggest that myofascial release has been widely researched. Reported findings include an ability to reduce soft tissue adhesions and increase ROM (Davis, Doerger, Eaton, Rowland, & Sauber, 2002; Paolini, 2009), decrease fatigue (Healey, Hatfield, Blanpied, Dorfman, & Riebe, 2014), improve performance (Herda, Cramer, Ryan, Mchugh, & Stout, 2008; Yamaguchi & Ishii, 2005), relieve pain (Castro-Sánchez et al., 2011; Paolini, 2009), and improve quality of life (Castro-Sánchez et al., 2011; Davis et al., 2002). In contrast to the large body of research on myofascial release, SMFR is an emerging area of research and many of the reported effects are inferred from manual therapy research, and in particular, from myofascial release literature (Schroeder & Best, 2015). The available research on SMFR has reported a broad range of findings such as an ability to affect musculoskeletal conditions such as lower back pain by restoring tissue imbalances such as short muscles (Junker & Stöggl, 2015), reduce muscular spasms and myofascial pain (Cavanaugh, Aboodarda, Hodgson, & Behm, 2016), diminish delayed onset muscle soreness (Jay et al., 2014; Pearcy et al., 2015), reduce arterial stiffness, and increase vascular plasticity (Okamoto, Mitsuhiko, & Komei, 2014).
There are a substantial number of studies relating to SMFR with a foam roller or roller massager and whether the technique affects ROM, however the findings from these studies are conflicting. Some studies show no change (Couture et al., 2015; Mikesky et al., 2002; Miller & Rockey, 2006; Peacock et al., 2014), while the majority of findings report SMFR increases ROM (Behara & Jacobson, 2015; Bushell et al., 2015; MacDonald et al., 2013; Markovic, 2015; Mikesky et al., 2002; Sullivan et al., 2013). Despite the numerous studies into the effects of SMFR no consensus has been reached regarding the mechanisms of action (Curran et al., 2008; Schleip, 2003b; Simmonds, Miller, & Gemmell, 2010), or how possible mechanisms influence ROM (Beardsley & Skarabot, 2015; Cheatham et al., 2015; Grieve et al., 2015). It has been proposed that SMFR techniques have similar mechanisms of action to both myofascial release techniques and stretching (Vaughan & McLaughlin, 2014). The reported changes to ROM through SMFR have been regularly attributed to both mechanical and neurophysiological mechanisms (Beardsley & Skarabot, 2015; Cheatham et al., 2015). The theoretical basis for a possible mechanism of action by which SMFR creates change in ROM is centred on fascia and its relationship with the musculoskeletal system. Fascia is defined as fibrous collagenous tissue layers that have variable orientations both perpendicular and parallel, which is involved in tensional force transmission and musculoskeletal integrity (Findley, Chaudhry, Stecco, & Roman, 2012; Schleip, Jäger, & Klingler, 2012; Stecco et al., 2006).

Vernon and Schneider (2009) suggest that SMFR techniques are founded on the concept of ischaemic compression, which is theorised to work by reducing adhesions in soft tissue. Fama & Bueti (2011) suggest there is evidence supporting ischaemic compression and its ability to affect change in tissue adhesions, however, there is only limited research on the effectiveness of SMFR with a foam roller or roller massager as an applicator of ischaemic compression (Curran et al., 2008; Fama & Bueti, 2011; Miller & Rockey, 2006).

Adhesions in connective tissues such as muscles, tendons, and fascia have been shown to inhibit normal biomechanics including joint ROM and muscle length (Barnes, 1997; Dippenaar et al., 2008). Authors have repeatedly demonstrated that connective tissues such as muscles, tendons, and fascia have a tendency to develop adhesions, and as a result the tissues are not as capable of mechanical changes such as lengthening and extending (Evans, 2002; Forrest, 1983; Helene & Huijing, 2009; Hunt, Banda, & Silver, 1985; Kumka & Bonar, 2012; Rennard, Bitterman, & Crystal, 1984; Schleip, 2003b; Simmonds et al., 2010).
The literature suggests that fascia is a primary tissue responsible for adhesions and it has been identified as existing throughout the whole body with a particular dominance in muscle-tendon units (Schleip, 2003b). In response to the micro-trauma or more acute traumas such as muscle strains, fascia is reported to respond with contractile actions similar to smooth muscle (Schleip, Klingler, & Lehmann-Horn, 2005) in order to protect the surrounding tissues from damage (Pischinger, 1991). The contracted fascial components may subsequently become locked in their protective positions in the form of adhesions, and lead to a reduction in elasticity (Vernon & Schneider, 2009). The altered extensibility in fascia can change the natural tension relationship in surrounding tissues, which may be identifiable as reduced ROM (Barnes, 1997; Schleip, 2003b). SMFR utilising tools such as foam rollers and roller massagers has been reported to change tissue extensibility (Curran et al., 2008; MacDonald et al., 2013), and restore reduced tissue length (Junker & Stöggl, 2015). If altering fascial adhesions through SMFR with foam rollers or roller massagers generates a change in tissue extensibility and length, this may explain the reported increases in ROM.

A potential mechanical mechanism for SMFR induced ROM benefits may be its reported influence on fascial motion (Schleip, 2003a) and vascular function (Okamoto et al., 2014), which may have a warm-up effect (Healey et al., 2014) that leads to improved ROM (Cheatham et al., 2015). SMFR with a foam roller involves an individual supporting their body mass with their upper body in a predominantly isometric fashion, as well as engaging in concentric and eccentric contractions to create the rolling motion. Similarly, the roller massager involves all three of these contraction types but does not involve supporting body mass. The concentric, eccentric, and isometric exercises may have a warm-up effect through increase increased blood flow and increased intramuscular tissue temperature (Cheatham et al., 2015; Goodwin, Glaister, Howatson, Lockey, & McInnes, 2007; Okamoto et al., 2014; Wiktorsson-Moller, Oberg, Ekstrand, & Gillquist, 1983), which appear to enhance flexibility (Healey et al., 2014). An associated mechanical mechanism relates to the SMFR tools ability to induce friction driven temperature increase between tissues such as skin and muscles. The friction induced temperature increase may lead to the fascia having more viscoelastic proprieties (Cheatham et al., 2015; Kelly & Beardsley, 2016) which may increase fascia’s capacity for fluid motion (Schleip, 2003a), which may result in an increase in ROM (Button & Behm, 2014; Healey et al., 2014). Schleip (2003a) suggests that the increased capacity for fluid motion is only temporary and once the stimulus is removed the fascial tissues return to a normal state, and presumably the ROM benefits cease.
Research has identified SMFR as a technique that may have an affect on joint ROM, but there is a lack of consensus as to how long the affect persists (Cho & Kim, 2016; Ebrahim & Elghany, 2013; Mohr, Long, & Goad, 2014). Jay et al., (2014) reported that ROM benefits did not persist after 30 minutes, while other research suggests SMFR may affect joint ROM long-term (Cho & Kim, 2016; Ebrahim & Elghany, 2013; Mohr, Long, & Goad, 2014), and acutely over a time period of up to and including 10 minutes (Halperin et al., 2014; Jay et al., 2014; Kelly & Beardsley, 2016; MacDonald et al., 2013; Škarabot, Beardsley, & Štirn, 2015). If the reported changes to joint ROM were produced through a mechanical mechanism of temperature dependent viscoelastic change in the fascia, then removal of the SMFR tool and its influence on fascial tissue should lead to a loss of any additional joint ROM, and therefore contradict research suggesting long-term affects (Cheatham et al., 2015; Curran et al., 2008).

Additional theories of mechanical action that have been proposed are also centred on the influence of pressure, produced through the SMFR tool, on tissues such as fascia. Applying pressure to soft tissues of the musculoskeletal system could influence the cellular proprieties of connective tissues such as fascia. Pressure from the SMFR tool may mechanically break down abnormal collections of connective tissue and reduce cellular adhesions, subsequently allowing connective tissue such as fascia to become remobilised (Cheatham et al., 2015; Kelly & Beardsley, 2016; Mohr et al., 2014; Sefton, 2004; Škarabot et al., 2015).

Another plausible mechanism of effect for SMFR changing joint ROM is that neurophysiological changes could be made apparent via an effect on local proprioception. Schleip (2003a) reported that myofascial release techniques might have an autonomic effect on the soft tissue. SMFR with a foam roller or roller massager has the capacity to stimulate proprioceptors (muscle spindles and Golgi tendon organs) through pressure from the individual’s bodyweight or arm strength (Hains, 2002; Kelly & Beardsley, 2016), resulting in either inhibitory or excitatory efferent signals form the central nervous system (Fama & Bueti, 2011). As the individual applies pressure to a target muscle, the Golgi tendon organs react to the change in muscle tension and respond by inducing muscle spindles to relax, which may produce an increase in ROM (Hains, 2002). The muscle spindles response to stimulation is known as a stretch reflex, and changes to the muscles length tension relationship often result in altered ROM and pain sensation (Fama & Bueti, 2011). The pressure exerted on tissues through SMFR can trigger these described neurophysiological mechanisms, which then reduce tension in the relevant tissues leading to the re-establishment the normal length to
tension relationships (Fama & Bueti, 2011), which improves musculoskeletal function expressed as normal ROM. This proposed neurophysiological mechanism by which SMFR may effect tissues and ROM is different to the increased stretch tolerance response that is reported as the mechanism by which stretching produces a change in tissues and improves ROM (Kelly & Beardsley, 2016; Weppler & Magnusson, 2010). It is still feasible that SMFR also influences stretch tolerance, and the reduced activation of motor units simultaneously increase the ROM (Beardsley & Skarabot, 2015; Healey et al., 2014; Vigotsky et al., 2015). If there were an increased stretch tolerance response from SMFR it would corroborate the reported findings that SMFR reduced pain responses (Healey et al., 2014). Overall the mechanisms proposed to account for ROM changes with SMFR are quite similar to the mechanisms proposed to account for stretching induced changes to ROM.

**The Hierarchy of Evidence**

Evidence based medicine encompasses the combined recommendations from the highest quality evidence available, and then a clinician makes a decision about applying the recommendations to a specific situation (Sackett, Rosenberg, Gray, Haynes, & Richardson, 1996; Timmermans & Mauck, 2005). An understanding of the hierarchy of evidence is a necessary prerequisite before an individual or organisation can formulate recommendations to apply in the clinical setting (Atkins et al., 2004). To understand the hierarchical nature of levels of evidence, it is essential to have an understanding of both study design and study quality (Phillips et al., 2001). This provides insight into the reasoning for a systematic review, and the study types included and/or excluded. An overview of the hierarchy from lowest to highest includes expert opinions, case reports, case series, case controlled studies, cohort studies, randomised controlled trials, critically appraised articles and topics, systematic reviews, and meta-analyses (Singh, 2014).

Expert opinion is considered to be the lowest tier of the hierarchy of evidence (Petrisor & Bhandari, 2007), as these have a high risk of bias. Published opinions are rarely studies themselves, but may discuss the findings of other studies and in the absence of higher quality evidence, expert opinion remains a valuable resource. The lowest quality of evidence based on study design is case reports and case series (Petrisor & Bhandari, 2007; Phillips et al., 2001). These study types are most commonly based on the experience of a single clinician or group of clinicians, which provides valuable insights to the available literature base. Case reports and case series have a high risk of bias as they are often retrospective in nature and
can lack complete data sets. Case reports and series rarely have a comparison group and the results only relate to one specific subgroup in a population, which may limit the generalisability of findings (Jenicek, 2003; Song & Chung, 2010). Superior to case reports and series is case control studies (Petrisor & Bhandari, 2007; Susan, 2001), which compare participants with no existing medical conditions or outcomes to participants with existing medical conditions or outcomes. Retrospective comparison of the group’s exposure to risk factors aims to identify relationships between the disease or outcome and risk factors. The advantage of this design is the speed with which it can be completed, particularly when large participant numbers are involved. Case control studies may illustrate relationships, which can be used to inform relative risk recommendations. Conversely, the study design can produce inaccurate data sets because of the many unknown factors not investigated, which results in a study that is considered low quality (Petrisor & Bhandari, 2007).

Cohort studies are observational studies that can be conducted either retrospectively or prospectively, but typically the prospective approach is employed. Cohort studies are higher in the hierarchy of evidence because of the typical prospective approach, which means methods for accurate data collection (Susan, 2001) and follow-up are considered prior to study initiation. Cohort studies normally investigate multiple groups of participants, with one group having a prognostic factor or risk factor and the other group lacking this factor. Cohort studies investigate the rate of development for a specific outcome measures such as a disease like osteoarthritis in each group (Singh, 2014).

Randomised controlled trials are considered the best form of unfiltered evidence (Sackett, Richardson, Rosenberg, & Haynes, 1997) These are studies that are carefully planned to investigate a therapeutic effect on a population (Singh, 2014; Susan, 2001). Randomised controlled trials aim to control for bias (Schulz & Grimes, 2002), which can negatively affect the study outcomes and result in findings that may misrepresent the true effect (Bhandari et al., 2004). Accurate appraisal of true effect is achieved through randomisation of sample population (Schulz & Grimes, 2002), which results in equal distribution of both known and unknown variables within both the treatment and control group. Randomised controlled trial studies typically have some level of practical and ethical considerations to be accounted for because of the use of controls and they can be expensive to implement (Sibbald, 1998).
Participant recruitment can be an obstacle that makes randomised controlled trials time consuming, and this can influence the study sample size (Sibbald, 1998). If the recruited sample is too small there is a greater chance for the magnitude of effect to be overstated (Button et al., 2013). Critical appraisal is a systematic process used to assess and interpret evidence in studies and identify the strengths and weaknesses of the research with an aim to assess the helpfulness and validity of findings (Parkes, Hyde, Deeks, & Milne, 2001). The key findings are analysed and summarized into clinically relevant measures such as efficacy or risks (Sauve et al., 1995). Limitations associated with critical appraisals include an absence of a ‘gold standard’ critical appraisal tool (Katrak, Bialocerkowski, Massy-Westropp, Kumar, & Grimmer, 2004). Furthermore, the depth of the literature search is typically more limited than a systematic review, and this may result in findings that are based on only a few studies (Sauve et al., 1995).

A systematic review summarises the results of a selection of studies, and is capable of providing a high level of evidence on the effectiveness of the research (Higgins & Green, 2011). A systematic review involves a comprehensive search of the literature relating to the chosen topic and then the selection of studies based on predetermined inclusion and exclusion criteria (Garg, Hackam, & Tonelli, 2008). Studies reporting significant effects are more likely to be published than studies with negative findings (Egger & Smith, 1998; Stern & Simes, 1997). A systematic review attempts to reduce bias with a comprehensive search strategy with inclusion criteria that that has not been influenced by a prior knowledge of the primary studies (Garg et al., 2008). The method used to conduct a systematic review is reported within the review itself, and typically follows a recognised reporting process such as the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines for reporting systematic reviews (Liberati et al., 2009; Moher, Liberati, Tetzlaff, Altman, & Group, 2009). Reporting tools help make the decisions used in compiling information repeatable and unambiguous, allowing a reader to determine for themselves the quality of the review process and the potential for bias (Garg et al., 2008). The studies are critiqued and appraised, which helps to separate the studies of value from those that are weak (Mulrow, 1994). Then, findings are summarised according to the review question with the aim of making clinical recommendations (Singh, 2014).
Systematic reviews commonly focus on randomised controlled trials, however the Cochrane Handbook, internationally recognised for high standards in evidence-based health care resources, notes non-randomised studies may be included in reviews (Higgins & Green, 2011). The variations in which study types are accepted for review may stem from some authors having concerns about the risk of bias in non-randomised controlled trials (Norris et al., 2010). The fundamental benefit of a systematic review is that it condenses the available literature, and determines if reported findings from individual studies are consistent and generalisable (Mulrow, 1994). However, the summary produced in a systematic review is only as reliable as the methodology employed to estimate the effect in each of the primary studies (Garg et al., 2008).

A meta-analysis is a method of data synthesis that may or may not be employed within a systematic review. A systematic review refers to the complete process of searching, collecting, reviewing, and presenting all the evidence, while a meta-analysis refers to the statistical technique used to extract and combining data to produce a summarised result based of the expanded dataset. The combined data from high quality and comparable individual randomised controlled trials increases the number of participants and results in an increased effective sample size (Sackett et al., 1997), and data is then more generalisable (Sackett et al., 1991). Conducting a meta-analysis does not override limitations in the design and implementation of the primary studies (Garg et al., 2008). If a meta-analysis includes poor quality studies, studies with substantial clinical diversity, or studies with dissimilarity in the treatment effect, then the results of the combined data will be poor.

**Findings and Limitations of Reviews on Self-myofascial Release and Range of Motion**

There are three reviews available on SMFR and its effects on ROM, these were published by Feldbauer et al. (2015), Schroeder and Best (2015), and Mauntel et al. (2014). A critical appraisal of SMFR and its effects on lower extremity ROM was recently completed by Feldbauer et al. (2015). The appraisal by Feldbauer et al. (2015) reviewed three studies (MacDonald et al., 2013; Mohr et al., 2014; Sullivan et al., 2013) that reported SMFR as capable of improving ROM, which lead the authors to make a recommendation that SMFR improves ROM in the lower extremity. However, the comparability of the studies is limited as they employed different durations of SMFR, investigated different tissues, and employed different SMFR tools. Two studies (MacDonald et al., 2013; Mohr et al., 2014) used different types of foam rollers and one (Sullivan et al., 2013) used a roller massager.
A study by Curran et al. (2008) investigated differences in the pressure exerted on soft tissue by two types of foam rollers. Curran et al. (2008) reported that different foam roller models exert different amounts of pressure onto the target tissue, which makes the two foam roller studies (MacDonald et al., 2013; Mohr et al., 2014) comparability limited. The rolling durations were also different with one employing ten to twenty seconds of rolling (Sullivan et al., 2013), and two employing two or three one-minute bouts of rolling (MacDonald et al., 2013; Mohr et al., 2014). Feldbauer et al. (2015) made a recommendation on what duration of SMFR produces the best ROM improvement, however given the small number of studies appraised and the variability in SMFR durations, the strength of this recommendation is limited. All of the studies (MacDonald et al., 2013; Mohr et al., 2014; Sullivan et al., 2013) investigated healthy populations and therefore the findings of the studies and the recommendation of the appraisal by Feldbauer et al. (2015) should be confined to this population and not generalised to other groups such as an injured population. The appraisal by Feldbauer et al. (2015) only reviewed studies investigating the effects of SMFR on lower extremity ROM. Appraising the lower extremity only is a valid regional confinement given the majority of research into SMFR has occurred in this region. At the time of the current work, it appears there are only three studies that have investigated SMFR with a foam roller on anatomical regions not part of the lower extremity. These areas were the pectoral muscles and the muscles of the middle and lower back (Peacock et al., 2014; Peacock et al., 2015; Roylance et al., 2013). Since Feldbauer et al. (2015) only reviewed studies investigating the lower extremity the reported recommendation on what duration of SMFR produces the best ROM improvement should be confined to the lower extremity only. The findings of the critical appraisal by Feldbauer et al. (2015) should be considered with caution, as limitations exist with the study. In particular, the authors did not use an appraisal tool to assess the studies methodological quality, which reduces the capacity for confidence in the findings.

A literature review by Schroeder and Best (2015) investigated SMFR as a pre-exercise and recovery strategy. In this review six studies included ROM as an outcome measure. The review included nine randomised controlled trials, six investigating foam rollers and three roller massagers. The authors noted considerable clinical diversity amongst the studies including muscle groups, treatment protocols, and outcome measures. Five of the nine studies (Halperin et al., 2014; MacDonald et al., 2013; Macdonald et al., 2014; Mohr et al., 2014; Sullivan et al., 2013) reported increased ROM, and one study (Jay et al., 2014) reported no change in ROM.
The study by Jay et al., (2014) which reported no change to ROM involved a treatment protocol of 10 minutes, in contrast the five other studies all involved one-minute bouts of SMFR for no more than two minutes per muscle group. Schroeder and Best (2015) considered the similarity in duration and consistent increases in ROM across the five studies employing 1-minute bouts as suggestive of an optimal duration for SMFR. Schroeder and Best (2015) suggesting that an optimal duration for SMFR exists, supports the findings of Feldbauer et al. (2015) but with the advantage of a larger sample size. However, findings of the review by Schroeder and Best (2015) should be considered with caution, as limitations exist with the review. In particular, the authors did not use any form of appraisal tool to assess the methodological quality of the studies, which reduces the capacity for confidence in the reviews findings. The significant clinical diversity across the six studies was ignored by Schroeder and Best (2015), as they collectively considered the studies that employed a ROM outcome measure and concluded that SMFR is an effective strategy for improving ROM.

The systematic review by Mauntel et al. (2014) investigated different myofascial release modalities including trigger point therapy, active release technique, positional release and SMFR on ROM, muscle force, muscle activation. The review included 10 studies and the authors reported that myofascial release is effective at restoring and improving ROM. The improvements in ROM were observed over different durations of release therapy with the shortest 20 seconds (Sullivan et al., 2013) and the majority between one and three minutes (Grieve et al., 2015; MacDonald et al., 2013; Oliveira-Campelo, de Melo, Alburquerque-Sandin, & Machado, 2013; Sarrafzadeh, Ahmadi, & Yassin, 2012). An evaluation by this author of the reporting by Mauntel et al. (2014) was completed based on the Meta-analysis Of Observational Studies in Epidemiology (MOOSE) guidelines (Stroup et al., 2000). The evaluation identified unclear reporting of study details, with details such as the experience of the researchers absent and study population descriptions deficient. Therefore, the findings are difficult to generalise and recommendations should be viewed with criticality.

To date, only three systematic reviews have been published that review the literature relating to the effects of SMFR on joint ROM (Beardsley & Skarabot, 2015; Cheatham et al., 2015; Mauntel et al., 2014). All of these reviews investigated numerous and diverse outcome measures such as vertical jump, muscular force, blood pressure, and ROM. While these outcome measures are relative to each review’s research questions, the clinical diversity of outcome measures and the heterogeneity of study findings limit their comparability.
In addition, the reviews all appraised literature quality with the Physiotherapy Evidence Database (PEDro) scale. The Physiotherapy Evidence Database (PEDro) scale is a validated quality appraisal tool used to appraise the methodological quality of randomised controlled trials, randomised clinical trials and randomised cross-over studies (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). The Physiotherapy Evidence Database (PEDro) scale is not designed to appraise the quality of non-randomised study designs (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). However, it cannot be overlooked that non-randomised studies can still provide valuable information on SMFR and joint ROM, which assists in strengthening the knowledge base on the topic. Benson & Hartz (2000) reported that treatment effects in observational studies are not qualitatively different from findings of randomised controlled trials, and Rosner (2003) reported that a well-constructed cohort study or case series might be of greater value than flawed randomised controlled trials. Furthermore, evidence drawn from randomised controlled trials is not considered to be pragmatic, as it is typically conducted to establish the efficacy or safety of a single intervention in a specific clinical setting (Navarese et al., 2009). This means less common adverse effects may only be detected in non-randomised observational studies (Navarese et al., 2009). In order to have a more complete view of an intervention, researchers investigating a topic should consider reviewing non-randomised studies.

Since the completion of the reviews by Beardsley and Skarabot (2015), Cheatham et al. (2015), and Mauntel et al. (2014) a number of studies have been published on SMFR and ROM (Behara & Jacobson, 2015; Cho & Kim, 2016; Couture et al., 2015; Junker & Stöggl, 2015; Kelly & Beardsley, 2016; Markovic, 2015; Morton, Oikawa, Phillips, Devries, & Mitchell, 2016; Vigotsky et al., 2015) so it appears that the current research surrounding SMFR with foam rollers and roller massagers is still developing. Furthermore, there may be studies that may have been excluded from these previous systematic reviews for not meeting the Physiotherapy Evidence Database (PEDro) scales inclusion standard of having randomised study design.

To date there have been no systematic reviews that have utilised the Downs & Black (1998) methodological quality appraisal tool to appraise the SMFR literature relating to the effects of SMFR with foam rollers and roller massagers on joint ROM. As such a gap exists in the available literature to quality appraise and review both randomised studies and non-randomised studies.
The Downs & Black (1998) appraisal tool allows a greater range of research methodologies to be included in an appraisal process, in particular non-randomised studies. By comparison to the Physiotherapy Evidence Database (PEDro) scale employed in the previous systematic reviews is limited to the appraisal of randomised studies only. Therefore, an enlarged sample size is possible, which could serve to extend the depth of reviewed studies, and also condense the current knowledge. The larger sample size of studies is more representative of the population, potentially increasing the degree of generalisability possible. The Downs and Black appraisal tool has suitable validity, internal consistency (Kuder-Richardson formula 0.89) test-retest reliability ($r = 0.88$), and inter-rater reliability ($r = 0.75$) in rating the methodological quality of randomised trials and non-randomised trials (Altman & Burton, 1999; Downs & Black, 1998; Saunders, Soomro, Buckingham, Jamtvedt, & Raina, 2003), and has been used in numerous systematic reviews (Hartling, Brison, Crumley, Klassen, & Picket, 2004; Hignett, 2003; Hing, Bigelow, & Bremner, 2009; Roddy et al., 2005; Simpson, Reid, Ellis, & White, 2015).

**Conclusion**

SMFR techniques have similar proposed mechanisms of action to both myofascial release techniques and stretching (Vaughan & McLaughlin, 2014). The reported changes in ROM from stretching have been attributed to both neurophysiological and mechanical mechanisms (Hutton, 1993; Taylor, Dalton, Seaber, & Garrett, 1990). The reported changes to ROM through SMFR have also been regularly attributed to both mechanical and neurophysiological mechanisms (Beardsley & Skarabot, 2015; Cheatham et al., 2015). Despite the many studies into the effects of SMFR, no consensus has been reached regarding the mechanisms of action (Curran et al., 2008; Schleip, 2003b; Simmonds, Miller, & Gemmell, 2010), or how possible mechanisms influence ROM (Beardsley & Skarabot, 2015; Cheatham et al., 2015; Grieve et al., 2015). The existing literature does not include a systematic review of both randomised controlled studies and non-randomised controlled studies investigating the effects of SMFR with foam rollers and roller massagers on joint ROM. A review of both randomised controlled studies and non-randomised controlled studies would extend the depth of reviewed literature and the degree of generalisability possible.
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The Effectiveness of Self-Myofascial Release with Foam Rollers or Roller Massagers on Range of Motion: A Systematic Review

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Abstract

Background: Improving Range of Motion (ROM) receives substantial attention from groups including researches, healthcare providers, and athletic populations. The most commonly used method is stretching. Another method is Self-Myofascial Release (SMFR) with a foam roller or roller massager. There are three studies published that reviewed randomised trials relating to SMFR and ROM. Despite the focus on ROM, there have been no systematic reviews that critique the relevant literature utilising the Downs and Black methodological quality appraisal tool, which would allow both randomised and non-randomised trials to be reviewed.

Objectives: To comprehensively search the literature relating to SMFR and ROM, appraise the methodological quality of selected randomised and non-randomised studies with the Downs and Black tool, and evaluate the effectiveness of SMFR with a foam roller or roller massager for changing ROM.

Methods: A database search was completed to identify studies that were published from database inception to August 2016. Two reviewers independently extracted the data pertaining to methodological quality. One reviewer compared the results of the appraisals and then discussed the results.

Results: Twenty-two studies were included in the review. They were of varying methodological quality, with seventeen rated as moderate quality and five of limited quality. Nineteen studies found improvement in ROM after SMFR with a foam roller or roller massager. Based on the Van Tulder criteria there is a moderate level of evidence to support SMFR with a foam roller or roller massager as effective intervention for increasing joint ROM.

Conclusion: This systematic review demonstrates a moderate level of evidence for SMFR with a foam roller or roller massager to improve ROM. This review found the methodological quality of these studies to be moderate. Future research should focus on more consistent prescriptions of SMFR with respect to frequency, duration and outcome measures used.

Keywords: Foam Roller, Roller Massager, Self-Myofascial Release, Joint Range of Motion (ROM), Downs and Black, Systematic Review.
Background

Normal Range of Motion (ROM) is integral for efficient human movement\textsuperscript{2–5}, allowing adaptation to physical stressors, which decreases the potential for movement disorders and injuries\textsuperscript{4,6}. Reduced ROM is commonly found in people participating in sports and recreations\textsuperscript{7}. Activity related traumas such as muscle strain can reduce myofascial mobility through the formation of adhesions, which can lead to increased tissue tension and reduced ROM\textsuperscript{8–10}. ROM can be defined as the “arc of motion in degrees between the beginning and end point of motion in a specified plane”\textsuperscript{11} (p. 7), and is influenced by internal anatomical structures such as fascia, muscles, tendons, ligaments, and bony structures\textsuperscript{12,13}.

Physically active people in sports and recreation settings employ a variety of techniques to change joint ROM\textsuperscript{7,14}. The most commonly used technique is stretching\textsuperscript{15,16}. Recently there has been an increasing interest in Self Myofascial Release (SMFR) techniques with a foam roller or roller massager. SMFR is a form of myofascial release that individuals perform on themselves. Myofascial release describes the relevant connective tissues, in particular muscles and fascia, while also describing the techniques objective of changing these tissues. SMFR is typically applied to affect joint ROM and myofascial mobility, with myofascial mobility describing a connective tissue’s ability change its state such as increasing its length. The most common SMFR technique involve a foam roller or roller massager\textsuperscript{17,18}. SMFR has been reported to have a wide range of effects such as enhancing performance\textsuperscript{17} or reducing myofascial pain\textsuperscript{19}, but the most recognised is for increasing ROM\textsuperscript{18}.

SMFR techniques may have similar mechanisms of action as myofascial release and stretching\textsuperscript{14}. The reported changes to ROM through SMFR are attributed to both mechanical and neurophysiological mechanisms\textsuperscript{17,18}. Myofascial tissue has been implicated as the primary structure physiologically affected by SMFR\textsuperscript{20}. Applying pressure to soft tissues may influence the cellular proprieties of connective tissues such as fascia, mechanically reducing cellular adhesions and allowing the remobilisation of fascia\textsuperscript{17,21,22}. An adhesion is an abnormal collection of connective tissue cells arranged in a random order, which impairs the extensibility of connective tissue reducing its capacity to change length (Barnes, 1997; Tortora & Derrickson, 2012). However, there is limited evidence regarding the effectiveness of a foam roller or roller massager as an applicator of compression\textsuperscript{23–25}.
The movement associated with SMFR techniques may have a warm-up effect through increased blood flow and tissue temperatures, this can influence the elastic properties of connective tissues increasing its mobility, which appears to enhance ROM. A possible neurophysiological mechanism of action may be that SMFR stimulates autonomic changes that have an effect on the soft tissue. The pressure from SMFR could stimulate proprioceptors that then communicate with the central nervous system, which responds by inducing muscle spindles to relax, which in turn may produce an increase in ROM. ROM change has also been attributed to altered perceptions of the sensation used to determine the endpoint for ROM measurement. Despite many studies investigating the effects of SMFR, no consensus has been reached regarding the mechanisms of action, or optimal application process for improving ROM.

To date just two systematic reviews have been published that review the effects of SMFR with a foam roller or roller massager on ROM, and have appraised the quality of the selected literature. Both reviews employed the Physiotherapy Evidence Database (PEDro) scale to appraise the methodological quality of randomised trials. The Downs and Black quality appraisal tool employed in the current review allows for the inclusion of a greater range of research methodologies, in particular the inclusion of a non-randomised research methodologies. Therefore an enlarged sample size is possible, which serves to extend the depth of reviewed literature and the degree of generalisability possible. The fundamental benefit of a systematic review is that it condenses the available literature, and determines if reported findings from individual studies are consistent and generalisable (Mulrow, 1994). The Cochrane Handbook, internationally recognised for high standards in evidence-based health care resources, notes non-randomised studies may be included in reviews (Higgins & Green, 2011).

The aim of this systematic review was to comprehensively search the literature relating to SMFR with a foam roller or roller massager and ROM, appraise the methodological quality of selected randomised and non-randomised studies with the Downs and Black tool, and critically evaluate the effectiveness of SMFR utilising a foam roller or roller massager on changing joint ROM.
Methods

Literature Search Strategy
This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement. The literature search was completed in August 2016. The date range searched was from the establishment of the databases up to and including the 19th of August 2016. The databases searched included Academic Search Complete, AMED, CINAHL, EBSCOhost databases, Health Source: Nursing/Academic Edition, MEDLINE, PubMed, and Science Direct. The search terms and phrases included "self myof*", "foam roll*", "massa* roll*", stick, roll*, and massage*. The final search string was "self myof*" OR "foam roll*" OR "massa* roll*" OR (stick N5 roll*) OR (stick N5 massage*) OR (roll* N5 massage*).

Reference lists of included studies were also screened for relevant studies to receive further assessment for eligibility. No authors were contacted to source full texts or any additional information (Figure 1).

Selection Process
One reviewer (AD) conducted a literature search of academic databases, and then selected studies according to inclusion and exclusion criteria. Any study that investigated changes in ROM in response to SMFR with a foam roller or roller massager and compared this response to either a no treatment control group or an alternative intervention group were considered for inclusion. Studies that selected participants based on specific conditions or disorders such as scoliosis, or diseases such as diabetes that would affect ROM measures or SMFR with a foam roller or roller massager were excluded.

The following criteria were applied to the retrieved studies to determine final inclusion or exclusion. The inclusion criteria were (1) peer reviewed studies, (2) reports original data, (3) full text available, (4) published in English language, (5) foam roller or roller massager intervention, and (6) joint ROM outcome measure. The exclusion criteria were (1) clinical trials that include self-myofascial release as an intervention but do not measure its effects on joint range of motion as an outcome measure, (2) meta-analysis, (3) case series, (4) case
reports, (5) expert opinions or clinical commentary, (6) conference posters and abstracts, (7) newspaper or magazine articles, and (8) studies that selected participants based on specific conditions or disorders such as scoliosis, or diseases such as diabetes that would affect ROM measures or SMFR with a foam roller or roller massager.

**Characteristics Extraction Process**

Using the Population, Intervention, Comparison, Outcome (PICO) framework \(^{38,39}\) and the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines \(^{37,40}\), one reviewer (AD) independently extracted the following data from the twenty-two selected studies: (1) study design, (2) experiment variables, (3) participant demographics (participant numbers, gender, mean age ± standard deviation), (4) SMFR Tool, (5) duration of intervention technique, (6) duration of trial, (7) muscles treated, (8) ROM outcome measure, and (9) study results (Table 1).

**Table 1: Characteristics of Individual Studies - Near Here**

**Data Collection, Appraisal, and Synthesis Process**

The methodological quality of each included study was critically appraised by employing a modified Downs and Black quality appraisal checklist \(^1\). The Downs and Black \(^1\) appraisal tool has suitable validity, internal consistency (Kuder-Richardson formula = 0.89), test-retest reliability (effect size = 0.88), and inter-rater reliability (effect size = 0.75) in rating the methodological quality of randomised controlled trials and non-randomised controlled trials \(^{1,41,42}\), and the tool has been used in numerous systematic reviews \(^{43-47}\). The Downs and Black \(^1\) quality appraisal tool employed in the current study allows for the inclusion of a greater range of research methodologies \(^1\). In particular the Downs and Black \(^1\) quality appraisal tool allows for the inclusion of a non-randomised research methodologies \(^1\).

The Downs and Black tool measures methodological quality under five categories with a varied number of items to assess in each category. The categories include reporting, external validity, internal validity (bias), internal validity (confounding selection bias), and power \(^1\). The final item in the original Downs and Black tool relates to the power category, and questions if the study had sufficient power to detect clinically important effects \(^1\). This power item was modified due to its complexity and to ensure consistent scoring in the appraisal process, in keeping with previous studies \(^{45,47,48}\).
The power item was modified to be scored between zero and one, with a study scoring zero if there was no power calculation attempted or mentioned, and a score of one given if the study had calculated power or mentioned an attempt at a power calculation \(^{45,47,48}\). A total score of twenty-eight is the maximal score when using the Downs and Black checklist modified in this way \(^{45,47,48}\).

In order to decrease bias, two reviewers (AD, DR) conducted independent appraisals of the twenty-two included studies methodological quality, while remaining blind to the other author’s scoring. Following the completion of the independent review process the two authors compared results to reach a consensus on each study’s methodological quality. Scores that varied between authors were discussed and a final consensus score agreed. Any unresolved issues with scoring would have been settled by a third reviewer (JM) if necessary (Table 2).

A modified quality index tool \(^{43-45,47}\) was employed to further classify the studies methodological quality as strong, moderate, limited, or poor (Table 3). This quality index has been used in a number of systematic reviews that have rated studies methodological quality using the modified Downs and Black tool \(^{43-45,47}\). Since the purpose of this review was to review all studies relating to SMFR and joint ROM, no study was excluded on the basis of limited quality. A meta-analysis was not conducted because of the variability in study designs, and clinical diversity in interventions and outcome measures, and the inclusion of non-randomised trials. A sub-group analysis was conducted once data extraction was completed.

[Table 2: Modified Downs and Black Methodological Scores and Quality Index Scores - Near Here]

[Table 3: Quality Index Score Classification - Near Here]

**Strength of Evidence**

The criteria outlined by Van Tulder, Furlan and Bombardier \(^{49-51}\) have been used to calculate the level of evidence. See Table 4 for definitions applied to make the overall level of evidence statement.

[Table 4: Van Tulder Levels of Evidence - Near Here]
Results

Selection of Studies
The literature search returned 777 potentially appropriate studies, and a total of twenty-two studies were identified that met the inclusion and exclusion criteria (Figure 1). Of the twenty-two included studies five \(^{21,55,56,59,62}\) were randomised, non-blind, controlled studies, two \(^{10,58}\) were randomised, crossover, non-blind, controlled studies, two \(^{61,63}\) were randomised, within-subjects, non-blind, controlled studies, one \(^{53}\) was a randomised, within-subjects, single-blind (examiner), non-blind (participant), control study, one \(^{52}\) was a randomised, double-blind, placebo, control study, one \(^{66}\) was a randomised, crossover, within-subjects, between-subjects, non-blind study, one \(^{29}\) was a randomised, between-subjects, non-blind, control study, one \(^{7}\) was a randomised, between-subjects, non-blind study, one \(^{68}\) was a randomised, within-subject, non-blind study, three \(^{16,57,67}\) were non-randomised, quasi-experiment, non-blind studies, two \(^{63,64}\) were non-randomised, counterbalanced, crossover within-subjects, non-blind, controlled studies, one \(^{60}\) was a non-randomised, within-subject, repeated measures, non-blind study, and one \(^{54}\) was a non-randomised, non-blind, control study (Table 1). Overall there were fifteen \(^{7,10,21,29,52,53,55,56,58,59,61,62,66,68}\) randomised studies and seven \(^{16,54,57,60,64,65,67}\) non-randomised studies included in the review.

Participant Characteristics
There were a total of 480 participants included in the twenty-two reviewed studies. Of those, 301 were male, 140 were female, and 40 participants from one mix gender study \(^{21}\) did not have a gender ratio described. The participants’ ages ranged from 15-34. The majority of studies described the participants’ mean height and weight, one study provided mean height only \(^{16}\), and two studies provided neither height or weight data \(^{65,66}\). Three studies also described body fat percentages \(^{10,64,65}\), and four studies also provided BMI scores \(^{53,55,63,64}\). Eleven studies compared the effects of foam rollers or roller massagers on mix gender participants \(^{16,21,29,52,54,57,58,59,60,66,68}\), ten studies had male participants only \(^{7,10,53,55,56,61,62,63,64,65}\), and one study had only female participants \(^{67}\).

The twenty-two studies recruited participants from a range of sports and sporting levels that ranged from recreational active to high level competitive and professional. Eighteen \(^{7,10,16,21,29,52,54-56,58,59,61-65,67,78}\) studies recruited participants described as athletic. Fourteen studies recruited recreationally active participants \(^{16,21,29,54-56,58,59,61-65,67}\).
Of those fourteen studies two described a necessary number of hours with a range of 1-5 hours per week \(^{21,54}\), seven described the necessary number of sessions with a range of 2-3 sessions per week \(^{29,55,56,58,59,62,67}\), and four did not elaborate on the term recreationally active \(^{16,61,64,65}\). Three studies included male athletes who participated in high-level competitive sports, including professional and United States National Collegiate Athletic Association (NCAA) Division I and II for baseball, track and field, soccer, and football \(^{64}\). NCAA Division I for football \(^{10}\), and NCAA Division II for soccer \(^{52}\). Soccer was represented by males at regional level \(^{7}\), and by females at amateur level \(^{67}\). Further sports and physical activities represented include tennis, triathlon, Nordic skiing \(^{54}\), swimming \(^{54,68}\), resistance training in males \(^{52}\), and basketball and volleyball in females \(^{52}\). Three studies included participants involved in a range of different sports \(^{52,54,64}\), of these one study had males only \(^{64}\). One study recruited adolescent athletes \(^{68}\). One study recruited untrained participants \(^{53}\). Nine studies recruited participants from a university population \(^{10,16,29,54,57,59-61,66}\), and eleven studies did not clearly describe the source population for its participants \(^{7,21,52,53,55,56,58,62,64,65,67}\). Seventeen \(^{7,10,16,21,29,53-56,58-60,63-65,67,68}\) studies specified the selection of participants without injury or illness, suggesting included participants were healthy. However only eight \(^{10,16,29,53,55,61,63,64}\) studies specifically describe the selection of healthy participants. Three studies recruited participants with limited ROM, all of these studies investigated the effects of foam rolling on the hamstring muscle \(^{21,63,66}\). One \(^{63}\) of these studies had an inclusion criterion of healthy participants, suggesting the reduced ROM was not considered a limiting factor for healthy status. Similarly one \(^{21}\) of the studies required the participant to have no injuries, suggesting the reduced ROM was not related to an injury or a limiting factor for healthy status.

**Methodological Quality**

The methodological quality of each study is presented in Table 2. The twenty-two reviewed studies had a mean modified Downs and Black score of 14.5/28, and a range of eleven to eighteen. All of the studies described essential participant characteristics. All of the studies clearly described study objectives, interventions, outcome measures, and results formulated from reliable statistical tests. Blinding participants to a physical intervention is difficult, however one study blinded the participants to the intervention by using a double-blind placebo design \(^{52}\). Two studies were able to blind the researcher assessing the outcome measures \(^{52,53}\). Only two studies did not provide sufficient information regarding patients lost to follow-up \(^{54,55}\).
**Evidence Synthesis**

The current review has no studies with a strong quality index classification, seventeen studies were classified with a moderate quality index score\textsuperscript{10,16,21,29,52,53,55,58–62,64,66–69}, and five studies were of limited quality\textsuperscript{7,54,56,57,65} (Table 5). The limited quality studies all reported findings of improved ROM. Of the seventeen studies with moderate quality, three had findings of no change, and one found a range of foam rolling times (short and long) was ineffective for increasing knee extension ROM\textsuperscript{16}, one showed no improvements in active hip flexion ROM with a roller massager\textsuperscript{52}, and one showed no difference in sit and reach ROM between dynamic warm-up with foam roller compared to dynamic warm-up alone\textsuperscript{64}. The fourteen remaining moderate quality studies all reported improvements in ROM\textsuperscript{10,21,29,53,55,58–63,66–68}.

**Levels of Evidence**

The majority of studies calculated and reported probability values, only two studies failed to report probability values\textsuperscript{56,57} (Table 2). Four studies recruited sufficient participants and incorporated power calculations that allowed detection of clinically important change from the foam roller and roller massager intervention\textsuperscript{53,58–60}, and all of these studies reported improved ROM. The remaining eighteen studies did not report a power calculation or the study populations were too small to detect clinical significance from the data\textsuperscript{7,10,16,21,29,52,54–57,61–68}. The mean quality index score in the twenty-two reviewed studies was 51.5%, with a range from 39% to 64% (Table 2).

An overall statement on the strength of the evidence, based on the Van Tulder criteria\textsuperscript{49–51}, suggests there is moderate evidence to support SMFR with a foam roller or roller massager as effective intervention for increasing joint ROM, and the methodological quality of these studies is moderate.

[Table 5: Study Findings by Quality Index – Near Here]
Discussion

Sports and recreation populations often employ SMFR with either a foam roller or roller massager to improve ROM\(^{18,53}\), and often as an alternative to stretching. The present review demonstrates a moderate level of evidence for the efficacy of SMFR with a foam roller or roller massager to result in ROM improvements. The twenty-two studies showed substantial clinical diversity in participants, methodologies, reported inconsistent treatment effects with statistical heterogeneity, and had inadequate reporting which resulted in limited to moderate study quality. Key issues that influenced the quality of the studies were poor external validity and low statistical power. All of these factors combined make it unsuitable to perform a meta-analysis of the data\(^{70}\) and makes it difficult to discuss trends between and across studies.

Selection of Studies
The total number of reviewed studies was twenty-two, this total included fifteen\(^{7,10,21,29,52,53,55,56,58,61-63,66,68}\) randomised studies and seven\(^{16,54,57,60,64,65,67}\) non-randomised studies. Since the completion of the three\(^{2,17,18}\) previous reviews there have been twelve\(^{7,10,16,29,54,55,57,60,63-65,67}\) studies that were either unpublished at the time of the reviews, or were not included in prior reviews employing the Physiotherapy Evidence Database (PEDro) scale for methodological quality appraisal, as they were non-randomised studies\(^{16,54,57,60,64,65,67}\). By employing the Downs and Black\(^{1}\) methodological quality appraisal tool the current review was able to review the additional non-randomised studies, and in doing so increase the sample size of reviewed literature. Without the use of the Downs and Black\(^{1}\) methodological quality appraisal tool the current review would only have reviewed an additional five\(^{7,10,29,55,63}\) randomised studies. The total of seven non-randomised studies included in the current review is meaningful considering the total number of studies included in previous published systematic reviews\(^{2,17,18}\). In the three reviews one\(^{17}\) had a total of fourteen studies included, one\(^{2}\) had ten studies includes, and the other published review\(^{18}\) twenty-two studies were included but only fifteen were relevant to the outcome measure of joint ROM.

Participants and Clinical Diversity
Overall the twenty-two studies included a participant profile with substantial clinical diversity. The participants’ ages ranged from 15-34, meaning the findings should only be generalised to people of a similar age range. The age range would have been even narrower if the one\(^{68}\) study that recruited adolescent participants had been excluded form the study.
Eleven studies involved participants of both genders, ten had male participants only, and one had only female participants (Table 1). This gender mixture suggests reported findings are applicable across both genders. However, mixed gender studies present a challenge in research as females have greater ROM than males, which can affect the study outcomes. The known genders variance in ROM limits accurate comparison between studies because it is difficult to determine if the difference are a product of the intervention or a reflection of the gender differences. However previous systematic reviews have not found the gender differences prohibitive of drawing conclusions on the effects of SMFR on ROM.

Seventeen studies specified the selection of participants without injury or illness, suggesting included participants were healthy. However only eight studies specifically describe the selection of healthy participants. Three studies recruited participants with limited ROM, all of these studies investigated the effects of foam rolling on the hamstring muscle. One of these studies had an inclusion criterion of healthy participants, suggesting the reduced ROM was not considered a limiting factor for healthy status. Similarly one of the studies required the participant to have no injuries, suggesting the reduced ROM was not related to an injury or a limiting factor for healthy status. The studies recruited participants active in a wide range of different sports, and participating at levels from recreationally active to competitive and professional. Eighteen studies recruited participants described as athletic. Fourteen studies recruited recreationally active participants. The diversity of activity types and competitive levels across the studies makes comparison difficult. The physical requirements of sporting groups are considerably varied, and the populations investigated diverse. Only one study recruited untrained participants, which suggests the generalisability of findings is best confined to athletic populations, particularly recreational athletes. However the precise definition of a recreational athlete remains ambiguous, with significant clinical diversity in the definition applied across the fourteen studies recruiting recreational athletes.

**Study Quality**

*Effect of Poor External Validity*

The external validity of a study is important since it influences the usefulness of the results. External validity was poor in all but one of the reviewed studies. The reviewed studies
had an unequal gender ratio of males (300) to females (140) and a small age range (15-34 years), which reduces external validity\textsuperscript{45}. Studies either failed to report on sample selection or failed to control for sample selection bias. Participation in the studies was not entirely random with participants chosen from a university based sample of convenience in nine studies\textsuperscript{10,16,29,54,57,59–61,66}, which is a selection bias. A positive element in the studies was limited use of exclusion criteria such as no injuries\textsuperscript{10,16,57}, which keeps the source population and study population closely related\textsuperscript{73} and allows for increased generalisation of results\textsuperscript{74}. If selection bias is not controlled then findings may not be generalisable to the target population\textsuperscript{75}. Therefore, the majority of studies are unable to be confidently generalised to the target populations. Furthermore, any analysis based on the biased samples may have resulted in conclusions that describe inaccurate relationships between study variables\textsuperscript{75}.

**Effects of Moderate Internal Validity**

Controlling for bias in research is an essential element of study design\textsuperscript{76} that minimises threats to internal validity and increases study quality\textsuperscript{77}. The nature of physical interventions means blinding the participant is pragmatically difficult\textsuperscript{76}. Researchers have presented options that resolve some issues surrounding blinding\textsuperscript{76}. One option is conducting double blind trials. Mikesky\textsuperscript{52}, blinded participants with a double blind placebo trial. After the study, participants revealed that they believed the placebo (mock electrical stimulation) was the actual intervention. This study illustrates that it is possible to blind participants in physical intervention studies. Blinding those who collect or analyse data is essential for ensuring unbiased compiling and interpretation of data\textsuperscript{73,78}. Jay et al\textsuperscript{53} and Mikesky et al\textsuperscript{52} were the only studies to include examiner blinding. The lack of participant blinding across the studies creates uncertainty around whether reported changes to ROM were a product of the SMFR intervention or a product of biases. Another aspect that negatively affects internal validity is a lack of reporting on data dredging. Data dredging can identify additional patterns that may explain supplementary research questions. However, when many associations are looked for in a dataset where only a few real associations exist the majority of findings are false positives\textsuperscript{79}. Reporting any data dredging that occurs would allow the reader to critically assess the findings with an awareness of possible false positives.

**Effect of Low Power on Results**

Eighteen studies did not include a power calculation or failed to recruit sufficient participant numbers to detect and report clinically significant findings (Table 2).
Low powered studies reduce the chance of discovering true effects, the lower the power the more likely the magnitude of effect is overstated. Low powered studies typically have high statistical probability values and wide confidence intervals, which means inaccurate conclusions on differences between groups are more likely. In the four studies that did include power calculations, a range of between fourteen and twenty-three participants were deemed necessary for the studies to have meaningful power. Four studies recruited participant numbers below this range. The effect of the low powered studies means the majority of findings cannot be considered meaningful enough to have detected true change to ROM. Despite the inclusion of low power studies in previous systematic reviews, the authors have been confident enough to report conclusions of positive effects on ROM by SMFR, these conclusions are inline with the finding of this review.

Clinical Diversity of Evidence
Substantial clinical diversity exists amongst the twenty-two reviewed studies. These studies investigated three regions of the lower extremity with a total of thirteen different outcome measures (Table 1). The variation in outcome measures limits comparability between studies. Clinical diversity exists in the prescriptions of SMFR with respect to frequency, duration, rolling motion, and tool type. The substantial diversity amongst studies in the present review correlates with the findings of a recent literature review that critiqued nine randomised controlled trials and reported considerable clinical diversity amongst treatment protocols and outcome measures. Previous systematic reviews also described clinical diversity within the reviewed studies such as diversity in participants, outcomes measures and interventions.

Efficacy of Intervention
Nineteen studies showed improved ROM and three studies showed no change in ROM. The review identified four differed statistical reporting methods including percentages, centimetres, degrees, and statistical probability values (Table 1). The studies failed to provide the raw data necessary to convert figures to alternative formats. A detailed comparison on the magnitude of change is limited by the statistical heterogeneity amongst the studies. However, overall the majority of studies reported ROM changes in percentages with a range from 3% to 16%.
**SMFR Tools**

The types of tools used in the studies varied between the manufacturer specifications and materials. They were all cylinder rollers generally categorised as either a foam roller or roller massager. Five studies investigated the roller massager and seventeen investigated the foam roller (Table 2). Overall this review did not identify any trends to suggest either the foam roller or roller massager is superior to the other at changing ROM.

Seventeen studies investigated the foam rollers, eleven investigated the smooth foam rollers, four investigated foam rollers with nodules, and two studies lacked descriptive details necessary to categorise. Of the studies investigating smooth foam rollers, nine studies reported an increase in ROM, and two studies reported no change to ROM. The inconsistent findings make it difficult to conclude on the effectiveness of the smooth foam roller for changing ROM.

Recently foam rollers have been modified towards a denser foam roller with nodular protrusions. The manufacturers of the nodular rollers claim the protrusions allow it to work around bones, get closer to muscular attachments and ultimately target deeper tissue. Four studies used foam rollers with nodules, and all of these studies reported increased ROM. The magnitude of change was 5% to 15.6%. This range does not vary from the ranges seen across the nineteen studies that reported increased ROM. However the variation in ROM changes between nodular rollers is large. It has been reported that different foam roller models exert different amounts of pressure onto the target tissues. The nodular rollers have a denser core than traditional foam rollers and appear to exert greater pressure on the soft tissues, and this pressure is directed through a smaller contact area because of the nodular design. The study that reported the larger ROM change of 15.6% used a nodular foam roller that was different form the foam rollers used in the other three studies. The design involves longer and pointer nodules, which may explain the larger change in ROM. However, the exact influence that pressure induced stimulation from a foam roller or roller massager has on ROM is still undetermined, and additional research is necessary.

A participant’s bodyweight or strength plays a role in the amount of pressure exerted on the tissues; pressure of the foam roller may provoke discomfort, and cause them to reduce the pressure exerted. Curran demonstrated that increased pressure has the ability to influence deeper myofascial tissues. The rolling-induced pressure may mechanically breakdown
restricted myofascial tissues to increase extensibility, and restore reduced tissue length, to improve ROM. Therefore a limitation of many of these studies is that a participant’s response to discomfort may interfere with ROM outcomes.

**Control Groups**

The twenty-two reviewed studies involved a clinically diverse range of controls (Table 1), which makes comparisons difficult. Overall fourteen studies were controlled, and eight studies were uncontrolled. Uncontrolled studies are intrinsically weak designs, and observed differences are assumed to be a product of the intervention. However, it is difficult to determine the true extent of change derived from an intervention without a control comparator.

**Intervention Dose**

**Rolling Frequency**

The frequency of an intervention varied between the studies. Sixteen studies involved a single session of SMFR. Six studies involved multiple sessions of the intervention lasting between two days and one month. There was diversity in the number of times the intervention was completed over these timeframes. Cho used a daily dose, while the most common was two to three times per week, all studies reported increased ROM. These reported findings of increased ROM being achieved with an intervention frequency of one to three times a week correlate with stretching research that shares common proposed mechanisms of action. Reid and Kim demonstrated that daily stretching significantly increased hamstring ROM, which is consistent with earlier stretching studies. Rancour et al. demonstrated that stretching two to three times per week would maintain ROM improvements, which was corroborated by Reid and Kim, and further supported by recommendation of the American College of Sports Medicine. Concluding that the SMFR interventions produce acute changes to ROM appears appropriate, despite some uncertainty on the specific frequency of intervention necessary for ROM change. Whether or not SMFR interventions produce chronic changes to ROM require further investigation before any conclusive recommendations are suggested.
Rolling Duration

Rolling duration varied greatly, ranging from five seconds \(^59\), to twenty minutes \(^62\). Two studies \(^{56,59}\) investigated different durations of rolling. Sullivan et al \(^59\) compared rolling durations of either five seconds or ten seconds for one or two sets. Bradbury-Squires \(^56\) compared rolling durations of twenty seconds for five sets and sixty seconds for five sets. Both studies reported a significant increase in ROM for all durations, but no significant difference between different durations. In both studies there was a non-significant trend for the longer rolling duration having a greater effect. The findings may or may not suggest a dose-response for longer duration of rolling interventions being advantageous. The trend for longer duration interventions producing greater ROM increases was also reported in a systematic review on stretching \(^94\). The findings in the stretching systematic review were also non-significant \(^94\). The authors reported the non-significant findings as indicative of longer duration interventions not being more effective than other durations of rolling intervention \(^94\).

A number of studies \(^7,21,54,60,62\) based their rolling durations on the earlier work of MacDonald et al \(^61\), which standardised the durations to two or three bursts of one-minute. Research on myofascial release suggests sixty-ninety seconds of pressure is optimal for myofascial release to be achieved \(^61,62,95\). All of these studies \(^7,21,54,60,61,62\) reported positive changes to ROM, which suggests a dose response of two-three bursts of sixty seconds might be optimal for improving ROM. However Jay et al \(^53\) and Roylance et al \(^66\) reported a much longer ten minute burst as effective at changing ROM, and three other studies \(^29,31,68\) found shorter bursts to be effective at increasing ROM, which demonstrates the lack of consensus in what constitutes a SMFR dose sufficient to provoke change in ROM. In contrast the stretching literature consistently reports two-three stretches of thirty seconds as effective for increasing ROM \(^88,89,92,96-98\). Further research is necessary to determine if a dose-response relationship exists for SMFR improving ROM.

Rolling Motion

The rolling motion in all studies was a back and forth motion, in fifteen studies this was a constant motion \(^10,16,21,52-59,64-66,68\). In six studies the constant back and forth motion also involved kneading \(^7,29,60-63\), and in one study the back and forth motion involved thirty second pauses at points of discomfort \(^67\). The use of a continuous rolling motion may be responsible for ROM changes through a warm-up mechanism. The motion-driven increase in blood flow and intramuscular tissue temperature \(^17,26-28\), may lead to increased fascial mobility \(^32\) by
increasing the elastic capacity of fascia. The altered elasticity or mobility of fascial tissue may result in increased ROM\(^{30,31}\). SMFR may increase ROM by reducing adhesions in connective tissue with ischemic compression\(^{24}\). Including a pause or back and forth motion in the rolling procedure may increase the amount of compression a tissue area receives, and therefore the amount of tissue change that occurs.

**Outcome Measures**

The ROM outcome measures across the twenty-two studies showed substantial clinical diversity, with thirteen different outcome measures identified and four differed statistical reporting methods (Table 1). Outcome measures include passive and active measurements, eighteen studies used passive ROM, three used active ROM\(^{52,54,57}\), and one study involved a mixture of passive and active measurements\(^{62}\). Passive ROM is normally slightly greater than active ROM because of an additional element of elastic stretch in relaxed tissues\(^{99}\). Therefore, caution must be used if comparing the two different measurement methods, as greater ROM seen in passive tests may not be a product of the intervention alone. Another variable element in the outcome measures used across the reviewed studies is the use of different sensation measures to determine end of range such as slight discomfort\(^{10,67}\), maximal discomfort\(^{62}\), and resistance\(^7\). Using discomfort as a cessation point can result in measurement errors associated with participant biases\(^{16}\), which may reduce the internal validity of the study. The number of measurements completed before determining the final ROM figures varied between studies. A few studies used unlimited repeat measurements to determine maximal ROM\(^{29,30,100}\). Repeated measurements have a joint mobilising effect\(^{68,101}\), and a warm-up effect that influences the viscoelastic properties of tissues. The warm-up induced increase in tissue mobility may increase ROM\(^{29,30,100}\). Furthermore, the repeated measurement could lead to an increased stretch tolerance that subsequently creates a greater ROM measurement\(^{29,102}\). Therefore, the studies that include repeated ROM measurements in their methodology are best compared against other repeated ROM measurement studies. An additional variable element in the outcome measures is the different end-of-range hold durations, which range between one-two seconds\(^{55,56}\) and thirty seconds\(^{16}\). The longer duration of end range holding would provide more time for the Golgi tendon organs to interact with the central nervous system and potentially trigger greater reflective relaxation of muscle spindles\(^{24,33}\). Therefore it is possible the end of range holds could increase ROM beyond what the SMFR intervention may have created.
**Target Muscles**

The muscles targeted with SMFR varied across studies creating clinical diversity. The most substantial findings are applicable to the lower limb muscle groups only. Three studies targets some muscles outside the lower limb, but none measured ROM relative to these muscles \(^{64-66}\).

**Future Research**

To improve the methodological quality, validity, and generalisability of findings in future research a focus on robust study design is necessary. Future research should also focus on more consistent prescriptions of SMFR with respect to frequency, duration and outcome measures used. These two key areas would lead to a more homogenous sample of studies being available for future systematic review and meta-analysis.

Future research should design study methodology with more consideration of established tools for methodological quality appraisal such as the Downs and Black \(^1\) appraisal tool. In future studies power calculations should be completed to establish meaningful difference, and followed with recruitment of sufficient sample sizes to allow meaningful differences to be detected and reported. Randomised double-blind placebo studies are desirable, as this design helps to negate the difficulties of blinding participants to physical interventions. The assessors involved in the studies should be blinded to the intervention \(^{76}\) which would reduce the possibility of bias.

Future studies should reduce the diversity in SMFR prescription. One option is following an already established intervention dose such as the two bursts of one minute rolling used by MacDonald \(^{61}\) that has been reported to be effective for SMFR. This option also has inherent risks such as the chosen intervention dose being proven ineffective or not clinically meaningful. Avoiding the use of sensation as the indicator for end of range could reduce the subjectivity present in many of the studies outcome measures, and reduce the possibility of participant bias. The flaw with avoiding subjective sensation as an indicator for end of range is that no appropriate alternative is currently evident in the literature. Removing repeated attempts at ROM measurement could decrease the impact of confounding factors such additional viscoelasticity of tissues that are not produced through the intervention. Using strapping to eliminate secondary movements could advance the reliability of a ROM test, though this may also decrease the ecological diversity.
Limitations

The current systematic review has a number of limitations. The parameters of this review included a database search cut-off date (August 19th 2016), and included only English language studies that are peer reviewed, which means the review only captures a portion of available literature. The widened search criteria allowed non-randomised controlled trial studies into the review and resulted in a more complete view of the literature to date, however the widened criteria also brought weaker evidence into this systematic review. In addition, owing to a number of poor quality studies, substantial clinical diversity, and statistical heterogeneity among the reviewed studies meta-analysis was precluded.

Conclusion

A review of the literature found twenty-two studies that investigated the effect of SMFR utilising foam roller or roller massager on ROM. Overall, this review found a moderate methodological quality amongst these studies, with no studies of strong methodological quality, seventeen of moderate quality, and five of limited quality. This review demonstrates a moderate level of evidence for SMFR with a foam roller or roller massager to improve ROM. This review identified a need for strong methodological studies to be conducted. Future research should focus on more consistent prescriptions of SMFR with respect to frequency, duration and outcome measures used.
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Records identified through database searching (n = 777)  
Additional records identified through other sources (n = 0)  

Records after duplicates removed (n = 610)  

Records screened (n = 610)  
Records excluded (n = 587)  

Full-text articles assessed for eligibility (n = 23)  
Full-text articles excluded (n = 1)  
(Reason: Full-text unavailable)  

Studies included in qualitative synthesis (n = 22)  

Studies included in quantitative synthesis (meta-analysis) (n = 0)  

Figure 1: Literature Search Strategy
<table>
<thead>
<tr>
<th>Study Authors (Year)</th>
<th>Study Design</th>
<th>Participant Demographics (Participant Numbers, Gender, Mean age ± SD)</th>
<th>SFMR Tool</th>
<th>Duration</th>
<th>Muscles Treated</th>
<th>ROM Outcome Measure</th>
<th>Results (Benificial, detrimental, no change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behara &amp; Jacobson (2015)</td>
<td>Randomised, Crossover, Non-blind, Control Study</td>
<td>Foam Rolling vs Dynamic Stretching vs Control</td>
<td>n=14M/14M (20 ± 4 ± 1.4)</td>
<td>Foam Roller</td>
<td>1 minute on each extremity (left &amp; right) for each of the 4 muscle groups (Total 8 minutes)</td>
<td>Hamstrings, Quadriceps, Gluteus Maximus, Gastrocnemius</td>
<td>Passive Straight Leg Raise (Hip Flexion ROM)</td>
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<tr>
<td>Bradbury-Squires et al (2015)</td>
<td>Randomised, Non-blind, Control Study</td>
<td>Foam Massage vs Control</td>
<td>n=10: 10M (26.8 ± 6.2)</td>
<td>Foam Massage</td>
<td>3 x 20 seconds OR 5 x 60 seconds (Total 1 minute and 40 seconds OR Total 5 minutes)</td>
<td>Quadiceps</td>
<td>Passive Knee Flexion with Modified Kneeing Lange (Knee Flexion ROM/Quadriceps ROM)</td>
</tr>
<tr>
<td>Bisdell et al (2015)</td>
<td>Non-randomised, Non-blind, Control Study</td>
<td>Foam Rolling vs Control</td>
<td>n=31: 19M &amp; 12F (23.35 ± 2.46)</td>
<td>Foam Roller</td>
<td>1 x 1 minute with 30 seconds rest between each minute completed in session 1 &amp; 2. Plus 5 x 3 minutes (total 7 minutes) during the 7 days between session 1 &amp; 2 (Total 21 minutes)</td>
<td>Quadiceps</td>
<td>Active Extended Lange (Unilateral Active Hip Extension ROM)</td>
</tr>
<tr>
<td>Cho &amp; Kim (2016)</td>
<td>Non-randomised, Quasi-experiment, non-blind study</td>
<td>Self-Myofascial Stretching (Foam Rolling) vs Ultrasound + Self-Myofascial Stretching (Foam Rolling)</td>
<td>n=30: 15M &amp; 15F (21.8 ± 0.81)</td>
<td>Foam Roller</td>
<td>7 days of daily FR (FR duration unknown)</td>
<td>Hamstrings</td>
<td>Sit &amp; Reach (Bilateral Hamstring ROM)</td>
</tr>
<tr>
<td>Couture et al (2015)</td>
<td>Non-randomised, Quasi-experiment, non-blind study</td>
<td>Foam Rolling (Short Duration) vs Foam Rolling (Long Duration)</td>
<td>n=33: 14M &amp; 19F (20.0 ± 1.5)</td>
<td>Foam Roller</td>
<td>Short Duration: 2 x 10 second boots with 30 seconds rest between sets (Total 20 seconds) &amp; Long Duration: 4 x 30 second boots with 10 seconds rest between sets (Total 2 minutes)</td>
<td>Hamstring</td>
<td>Passive Knee Extension (Right Hamstring ROM)</td>
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<tr>
<td>Halpern et al (2014)</td>
<td>Randomised, Crossover, Non-blind, Control Study</td>
<td>Foam Massage vs Static Stretching vs Control</td>
<td>n=14: 12M &amp; 2F (23 ± 3 ± F: 22 ± 3)</td>
<td>Foam Massage</td>
<td>1 x 30 seconds with 30 seconds rest between sets (Total 1.5 minutes)</td>
<td>Gastrocnemius</td>
<td>Weight Bearing Lange Test for Passive Derotational Flexion (Bilateral Hamstring ROM/Gastrocnemius ROM)</td>
</tr>
<tr>
<td>Jay et al (2014)</td>
<td>Randomised, Within-subjects, Single-blind (Examiners), Non-blind (Participants), Control Study</td>
<td>Massage Group (Single Log Massage) vs Massage Control (Massage Group Non-Managed Leg) vs Control Group (No Treatment)</td>
<td>n=22: 22M (34 ± 75)</td>
<td>Foam Massage</td>
<td>1 x 10 minutes (Total)</td>
<td>Hamstrings</td>
<td>Single Log Sit &amp; Reach (Bilateral Hamstring ROM &amp; Hip Flexion ROM)</td>
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<tr>
<td>Junior &amp; Stiggl (2015)</td>
<td>Randomised, Non-blind, Control Study</td>
<td>Foam Rolling vs Proprioceptive Neuromuscular Facilitation (PNF) vs Control</td>
<td>n=40: ROM (31.3 ± 9.2)</td>
<td>Foam Roller</td>
<td>FR hamstrings uni-laterally for 30-40 seconds (10 times back and forth), repeated with the other leg, bilateral rolling equals 1 set (total set time of 1 minute -1 minute &amp; 20 seconds), 3 sets in 1 session (total 3-4 minutes), 3 sessions a week (total 9-12 minutes), 12 sessions in 4 weeks (total 36-48 minutes)</td>
<td>Hamstrings</td>
<td>Hamstring Send &amp; Reach (Bilateral Hamstring ROM &amp; Lower Back ROM)</td>
</tr>
<tr>
<td>Kelly (2016)</td>
<td>Randomised, Between-subjects, Non-blind, Control Study</td>
<td>Foam Rolling vs Control</td>
<td>n=28: 18M &amp; 10F (FR: 18M &amp; 5F - 24 ± 4.8, Control: 10M &amp; 5F - 24 ± 4.8)</td>
<td>Foam Roller</td>
<td>3 x 30 seconds with 10 second rest between (Total 1.5 minutes)</td>
<td>Calf Group</td>
<td>Weight Bearing Lange (Unilateral - Achilles Bi-directional ROM)</td>
</tr>
<tr>
<td>Macdonald et al (2013)</td>
<td>Randomised, Within-subjects, Non-blind, Control Study</td>
<td>Foam Roller vs Control</td>
<td>n=11: 11M (22 ± 3 ± 3.8)</td>
<td>Foam Roller</td>
<td>2 x 1 minute with 30 seconds rest between sets (Total 2 minutes)</td>
<td>Quadriceps</td>
<td>Passive Knee Flexion with Modified Kneeing Lange (Quadiceps ROM)</td>
</tr>
<tr>
<td>Macdonald et al (2014)</td>
<td>Randomised, Non-blind, Control Study</td>
<td>Foam Roller vs Control</td>
<td>n=20: 10M FR ±10 (23.5±3.6) &amp; Control X=10 (24±2.8)</td>
<td>Foam Roller</td>
<td>2 x 1 minute bouts 5 muscle groups, completedilaterally (Total 10 minutes), completed 3 times post-40 minutes, post-24 hours, post-48 hours (Total 1 hour)</td>
<td>Quadriceps, Hamstrings, Gluteals</td>
<td>3 ROM Measures (1) Quadriceps Passive ROM QPROM - Modified Kneeing Lange, (2) Hamstrings Passive ROM (HP ROM) - Passive Hip Flexion Stimulation, (3) Hamstring Dynamic ROM (HD ROM) - Straight Leg High Kick (Standing)</td>
</tr>
</tbody>
</table>
Foam Rolling & Fascial 
Abuse Technique (FAT).
(p=0.20M (19 + 2)) Foam Roller 2 x 1 minute per muscle group, with 30 seconds between sets. (Total 4 minutes) Quadriceps & Hamstrings Supine Passive Knee Flexion (Knee 
ROM) & Passive Straight Leg Raise (Hip 
ROM) Benefit: Significant acute increase in knee joint ROM (p=0.05). 
FoT knee ROM =13.1° (+10%) and hip =15.2° (+19%). 
FR knee ROM =6.6° (+5%) and hip =7.1° (+5%). At 24 hours post-treatment FAT had significantly (p=0.05) increased knee ROM +8° (+7%) and hip +10° (+13%), and FR returned to baseline levels.

Mikesky et al (2012) Randomized, Double-blind, Placebo, Control Study. Roller Stick (Ergotone) Intevervation (Control) vs Micro Electrical 
Simulation (Placebo) 
(p=0.74 M 13.1 ± 1.3) Roller Massager 2 minutes Hamstrings Active Hip Flexion (Hamstring ROM) Benefit: No change: No statistically significant (p=0.05) improvements in hamstring 
ROM with ROM variations 1° between interventions.

Moore et al (2014) Randomized, Non-blind, Control Study. Static Stretching vs Foam 
Rolling & Static Stretching vs Foam Rolling & Control 
(p=0.84 M 12.20 ± 2.46) Control (p=0.85 M 13.20 ± 2.73) Foam Roller 3 x 1 minute bouts with 30 seconds rest between bouts. 6 sessions each separated by 48 hours (Total 18 minutes) Hamstrings Supine Passive Hip Flexion ROM (Hamstring ROM) Benefit: Significant increase in ROM for all treatments (p=0.001). FR-SS showed greater change in ROM compared to SS (p=0.044), FR (p=0.06), and control (p=0.06). No significant differences between the other interventions (p=0.09).

Murton et al (2016) Randomized, Within-subjects, Non-blind, Control Study. Static Stretching (Control) vs Static Stretching & Foam 
Roller 
(p=0.13 M 22.18 ± 2.18) Foam Roller 4 x 1 minute with 15-30 minutes rest between sets, completed twice daily (8 minutes daily), for 28 consecutive days (Total 224 minutes) Hamstrings Passive Knee Extension ROM (Hamstring ROM) Benefit: Increased hamstring ROM (p=0.06) for both interventions, FR-SS had no further benefit than SS.

Within-subjects, Non-blind, Control Study. Dynamic Warm-up (Control) vs Dynamic Warm-up with Foam Roller (Intervention) 
(p=0.11 M 22.18 ± 2.18) Foam Roller 30 seconds (5 rolling strikes) completed in 30 seconds for each of the 6 muscle groups per session (Total 6 minutes) Stk & Reach Test (Hamstrings & Lower Back ROM) Benefit: No change: No difference in ROM between dynamic warm-up vs FR dynamic warm-up (p=0.83).

Within-subjects, Non-blind Study. Foam Rolling Medial-Lateral 
3 Roll vs Foam Rolling Antero-Posterior (FRap) 
(p=0.19 M 22.18 ± 2.18) Foam Roller 30 seconds (5 rolling strikes) completed in 30 seconds for each of the 6 muscle groups per session (Total 6 minutes) Stk & Reach Test (Hamstrings & Lower Back ROM) Benefit: Significant difference in Stk and Reach ROM improvement with FRap (RR 9.9 vs 4.5 cm; 95% CI 2.6-4.1 cm) compared with FRap (p=0.06).

Foam Rolling & Pointeral 
Alignment Exercise vs Self Myofascial Release (Foam Rolling) & Static Stretching 
(p=0.27 M 111.22 ± 2.6) Foam Roller 1 x 10 minutes (Total) 4 Muscle Groups: Upper Back & Lower 
Back (Eccentric Spinat, Buttocks) (Glutes Maximus & Muscles), Posterior Thigh (Hamstrings), & Calf (Gastrocnemius & Soleus) Stk & Reach (Bilateral Hamstring ROM) Benefit: FR-Pointeral Exercises vs FR-SS produced statistically significant (5%) postural imbalance increases in subjects with an initial score range of 2.9 to 4.3 cm in participants with an initial score range of 3.3 cm or less.

Shefield & Cooper (2015) Non-randomized, Quasi 
experiment, Non-blind Study. Foam Rolling 
(p=0.15 M 151.7 ± 1.3) Foam Roller FR 3 x 30 minutes with static 
posture (10 seconds) at points of discomfort (FR position unknown) Hamstrings Active Knee Extension (Bilateral 
Hamstring ROM) Benefit: FR immediately increased hamstrings ROM with a significant increase in the left leg (p=0.04) and a mean of +4.6° and non-significant increase in the right leg (p=0.08) and a mean of +2°.

Stretching vs Foam Rolling vs Static 
Stretching 
(p=0.11 M 173.3 ± 10) Foam Roller 3 x 30 second sets with a 15 second rest between sets (Total 5 minutes) Calf Group Weight Bearing Long 
Chair/Hind/Posture Analis Distension 
ROM) Benefit: FR, SS, and SS+FR all produced acute increase in distension ROM. SS produced +6.2% (p<0.01); FR-SS produced 4.1% (p=0.05); and 
FR was not significantly increased. FR-SS was superior to FR (p=0.03). All interventions increased in ROM lasted less than 10 minutes.

Sullens et al (2015) Randomized, Non-blind, 
Control Study. Roller Massager vs Control 
(p=0.17 M 22.18 ± 2.18) Control (p=0.18 M 22.18 ± 2.18) Foam Roller 1 x 5 seconds (Total 5 seconds), 2 x 5 seconds (Total 10 seconds), 1 x 10 seconds (Total 10 
seconds), 2 x 10 seconds (Total 20 seconds) Hamstrings Single Leg St & Reach Test (Hamstrings & Lower Back ROM) Benefit: RM produced statistically significant increases in hamstrings 
ROM (from pre-rolling 31.32 ± 2.10 cm) to post-rolling (32.68 ± 2.90 cm) of only 
0.37% (+0.04%), and control (p>0.009) versus 30 seconds of ROM (22.27 ± 
2.90 cm) to post-rolling (31.65 ± 2.98 cm) of RM by 2.3%.

(p=0.23 M 174.2 ± 3.3) Foam Roller 2 x 60 second bouts with 30 seconds rest 
between bouts (Total 2 minutes) Quadriceps Modified Thomas Test (Hip Extension 
ROM & Knee Flexion ROM) Benefit: Small increase in hip extension (+1.39°, p=0.0372). No Change: 
Knee Flexion ROM.
<table>
<thead>
<tr>
<th>ITEM</th>
<th>REPORTING</th>
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<tbody>
<tr>
<td>1</td>
<td>Is the hypothesis/objective of the study clearly described? (Yes=1/No=0)</td>
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<td>2</td>
<td>Are the main outcomes to be measured clearly described in the Introduction or Methods section? (Yes=1/No=0)</td>
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<td>Are the characteristics of the patients included in the study clearly described? (Yes=1/No=0)</td>
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<td>4</td>
<td>Are the interventions of interest clearly described? (Yes=1/No=0)</td>
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<td>Are the distributions of principal confounders in each group of subjects to be compared clearly described? (Yes=1/No=0)</td>
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<td>Are the main findings of the study clearly described? (Yes=1/No=0)</td>
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<td>7</td>
<td>Does the study provide estimates of the random variability in the data for the main outcomes? (Yes=1/No=0)</td>
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<td>8</td>
<td>Have all important adverse events that may be a consequence of the intervention been reported? (Yes=1/No=0)</td>
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<td>9</td>
<td>Have the characteristics of patients lost to follow-up been described? (Yes=1/No=0)</td>
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<td>10</td>
<td>Have actual probability values been reported (e.g., 0.035 rather than &lt;0.05) for the main outcomes except where the probability value is less than 0.001? (Yes=1/No=0)</td>
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**REPORTING SCORE (X/11)**

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**EXTERNAL VALIDITY**

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<td>11</td>
<td>Were the subjects asked to participate in the study representative of the entire population from which they were recruited? (Yes=1/N=0/Unable to Determine=0)</td>
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<td>12</td>
<td>Were those subjects who were prepared to participate representative of the entire population from which they were recruited? (Yes=1/N=0/Unable to Determine=0)</td>
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<td>13</td>
<td>Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive? (Yes=1/N=0/Unable to Determine=0)</td>
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**EXTERNAL VALIDITY SCORE (X/5)**

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76
<table>
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<th>Question</th>
<th>Score</th>
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<tr>
<td>Was an attempt made to blind study subjects to the intervention they have received? (Yes=1/N =0/Unable to Determine=0)</td>
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<tr>
<td>Was an attempt made to blind those measuring the main outcomes of the intervention? (Yes=1/N =0/Unable to Determine=0)</td>
<td>0</td>
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<td>If any of the results of the study were based on “data dredging”, was this made clear? (Yes=1/N =0/Unable to Determine=0)</td>
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<tr>
<td>In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls? (Yes=1/N =0/Unable to Determine=0)</td>
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<td>Were the statistical tests used to assess the main outcomes appropriate? (Yes=1/N =0/Unable to Determine=0)</td>
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<td>Was compliance with the intervention’s reliable? (Yes=1/N =0/Unable to Determine=0)</td>
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<td>Were the main outcome measures used accurate (valid and reliable)? (Yes=1/N =0/Unable to Determine=0)</td>
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**INTERNAL VALIDITY - BIAS SCORE (X/7)**

4 4 4 3 4 4 4 4 4 4 4 4

**INTERNAL VALIDITY - CONFUNDING (SELECTION BIAS)**

<table>
<thead>
<tr>
<th>Question</th>
<th>Score</th>
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<tbody>
<tr>
<td>Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population? (Yes=1/N =0/Unable to Determine=0)</td>
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<td>Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time? (Yes=1/N =0/Unable to Determine=0)</td>
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<td>Were study subjects randomised to intervention groups? (Yes=1/N =0/Unable to Determine=0)</td>
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<td>Was the randomised intervention assignment concealed from both patients and health care staff until recruitment was complete and irrevocable? (Yes=1/N =0/Unable to Determine=0)</td>
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<td>Was there adequate adjustment for confounding in the analyses from which the main findings were drawn? (Yes=1/N =0/Unable to Determine=0)</td>
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<tr>
<td>Were losses of patients to follow-up taken into account? (Yes=1/N =0/Unable to Determine=0)</td>
<td>1</td>
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**INTERNAL VALIDITY - CONFUNDING (SELECTION BIAS) SCORE (X/6)**

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<td>POWER SCORE (X/2)</td>
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<tr>
<td>TOTAL QUALITY SCORE (X/28)</td>
<td>17 13 13 11 14 15 17 14 14 13 18 15 14 14 13 14 15 15 16 15</td>
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<tr>
<td>QUALITY INDEX PERCENTAGE (%)</td>
<td>60% 46% 46% 39% 50% 53% 60% 50% 53% 50% 50% 46% 64% 53% 50% 50% 46% 50% 53% 53% 57% 53%</td>
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<tr>
<td>QUALITY INDEX CATEGORY</td>
<td>Moderate Limited Limited Limited Moderate Moderate Moderate Moderate Limited Moderate Moderate Moderate Moderate Limited Moderate Moderate Moderate Moderate Moderate</td>
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### Table 3: Quality Index Score Classification

<table>
<thead>
<tr>
<th>Total Modified Downs &amp; Black Score (/28)</th>
<th>Percentage (%)</th>
<th>Quality Index</th>
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<tr>
<td>21+</td>
<td>75%+</td>
<td>Strong</td>
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<tr>
<td>14-20</td>
<td>50-74%</td>
<td>Moderate</td>
</tr>
<tr>
<td>7-13</td>
<td>25-49%</td>
<td>Limited</td>
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<tr>
<td>&lt;7</td>
<td>&lt;25%</td>
<td>Poor</td>
</tr>
</tbody>
</table>

43–45,47

### Table 4: Van Tulder\(^{49–51}\) Levels of Evidence

<table>
<thead>
<tr>
<th>Evidence Level</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong</td>
<td>Consistent findings among multiple high quality RCTs</td>
</tr>
<tr>
<td>Moderate</td>
<td>Consistent findings among multiple low quality RCTs and/or CCTs and/or one high quality RCT</td>
</tr>
<tr>
<td>Limited</td>
<td>One low quality RCT and/or CCT</td>
</tr>
<tr>
<td>Conflicting</td>
<td>Inconsistent findings among multiple trials (RCTs and/or CCTs)</td>
</tr>
</tbody>
</table>

### Table 5: Study Findings by Quality Index

<table>
<thead>
<tr>
<th>STUDY</th>
<th>Reporting (X/11)</th>
<th>External Validity (X/3: Bias) (X/7)</th>
<th>Internal Validity (Confounding) (X/6)</th>
<th>Power (X/1)</th>
<th>Total Quality Score (X/28)</th>
<th>Quality Index (%)</th>
<th>Quality Index Category</th>
<th>Effects On ROM Outcome Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behara &amp; Jacobson (2015)</td>
<td>8</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>17</td>
<td>60%</td>
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</tr>
<tr>
<td>Couture et al (2015)</td>
<td>8</td>
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<td>4</td>
<td>2</td>
<td>0</td>
<td>14</td>
<td>50%</td>
<td>Moderate</td>
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<tr>
<td>Halperin et al (2014)</td>
<td>8</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>15</td>
<td>53%</td>
<td>Moderate</td>
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<tr>
<td>Jay et al (2014)</td>
<td>8</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>17</td>
<td>60%</td>
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<td>Junker &amp; Stöggel (2015)</td>
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<td>14</td>
<td>50%</td>
<td>Moderate</td>
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<tr>
<td>Kelly (2016)</td>
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<td>14</td>
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SECTION C: APPENDICES
Appendix A: Physical Therapy Reviews Instructions to Authors

Thank you for choosing to submit your paper to us. These instructions will ensure we have everything required so your paper can move through peer review, production and publication smoothly. Please take the time to read and follow them as closely as possible, as doing so will ensure your paper matches the journal’s requirements. For general guidance on the publication process at Taylor & Francis please visit our Author Services website.

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Contents List

About the journal
Peer review

Preparing your paper

• Word count
• Style guidelines
• Formatting and templates
• References
• Checklist

Using third-party material in your paper

Submitting your paper
Publication charges
Copyright options
Open access
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About the Journal

Physical Therapy Reviews is an international, peer reviewed journal, publishing high-quality, original research. Please see the journal’s Aims & Scope for information about its focus and peer-review policy.

Please note that this journal only publishes manuscripts in English.

Peer Review

Taylor & Francis is committed to peer-review integrity and upholding the highest standards of review. Once the editor has assessed your paper for suitability, it will then be double blind peer-reviewed by independent, anonymous expert referees. Find out more about what to expect during peer review and read our guidance on publishing ethics.

Preparing your Paper

Word Count

Please include a word count for your paper. A typical paper for this journal should not exceed 5000 words, inclusive of references and figure captions.

Style Guidelines

Please refer to these quick style guidelines when preparing your paper, rather than any published articles or a sample copy.

Please American or British spelling consistently throughout your manuscript.

Please use single quotation marks, except where ‘a quotation is “within” a quotation’. Please note that long quotations should be indented without quotation marks.

Formatting and Templates

Papers may be submitted in any standard format, including Word and LaTeX. Figures should be saved separately from the text. To assist you in preparing your paper, we provide formatting template(s).
Word templates are available for this journal. Please save the template to your hard drive, ready for use.

If you are not able to use the templates via these links (or if you have any other template queries) please contact authortemplate@tandf.co.uk.

References

Please use this reference guide when preparing your paper.

Checklist: What to Include

1. **Author Details**. Please include all authors’ full names, affiliations, postal addresses, telephone numbers and email addresses on the cover page. Where available, please also include ORCiDs and social media handles (Facebook, Twitter or LinkedIn). One author will need to be identified as the corresponding author, with their email address normally displayed in the article PDF (depending on the journal) and the online article. Authors’ affiliations are the affiliations where the research was conducted. If any of the named co-authors moves affiliation during the peer-review process, the new affiliation can be given as a footnote. Please note that no changes to affiliation can be made after your paper is accepted. [Read more on authorship](#).

2. **Structured Abstract** (250 words). A structured abstract should cover (in the following order) Background; Objectives; Major Findings; Conclusions (for Narrative reviews). Background; Objectives; Methods; Results; Conclusions (for Systematic reviews).

   Read tips on [writing your abstract](#).

3. **Graphical Abstract**. This is an image to give readers a clear idea of the content of your article. It should be a maximum width of 525 pixels. If your image is narrower than 525 pixels, please place it on white background 525 pixels wide to ensure the dimensions are maintained. Save the graphical abstract as a .jpg, .png, or .gif. Please do not embed it in the manuscript file but save it as a separate file, labelled Graphical Abstract 1.

4. You can opt to include a **video abstract** with your article. Find out how these can help your work reach a wider audience, and what to think about when filming.
5. **Keywords.** Read making your article more discoverable, including information on choosing a title and search engine optimization.

6. **Funding Details.** Please supply all details required by your funding and grant-awarding bodies as follows:

   For single agency grants
   This work was supported by the under Grant.

   For multiple agency grants
   This work was supported by the under Grant; under Grant; and under Grant.

7. **Disclosure Statement.** This is to acknowledge any financial interest or benefit that has arisen from the direct applications of your research. Further guidance on what is a conflict of interest and how to disclose it.

8. **Biographical Note.** Please supply a short biographical note for each author. This could be adapted from your departmental website or academic networking profile and should be relatively brief (e.g. no more than 100 words).

9. **Geolocation Information.** Submitting a geolocation information section, as a separate paragraph before your acknowledgements, means we can index your paper’s study area accurately in Journal Map’s geographic literature database and make your article more discoverable to others. More information.

10. **Supplemental Online Material.** Supplemental material can be a video, dataset, fileset, sound file or anything that supports (and is pertinent to) your paper. We publish supplemental material online via Figshare. Find out more about supplemental material and how to submit it with your article.

11. **Figures.** Figures should be high quality (1200 dpi for line art, 600 dpi for grayscale and 300 dpi for colour). Figures should be saved as TIFF, PostScript or EPS files.

12. **Tables.** Tables should present new information rather than duplicating what is in the text. Readers should be able to interpret the table without reference to the text. Please supply editable files.
13. **Equations.** If you are submitting your manuscript as a Word document, please ensure that equations are editable. More information about mathematical symbols and equations.

14. **Units.** Please use SI units (non-italicized).

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Appendix B: Advice to Authors on Preparing a Manuscript

NB: Please follow any specific instructions for authors provided by the Editor of the journal.

Font: Times New Roman, 12 point. Use margins of at least 2.5 cm (1 inch). Further details of how to insert special characters, accents and diacritics are available here.

Title: Use bold for your article title, with an initial capital letter for any proper nouns.

Authors’ Names: Give the names of all contributing authors on the title page exactly as you wish them to appear in the published article.

Affiliations: List the affiliation of each author (department, university, city, country).

Correspondence Details: Please provide an institutional email address for the corresponding author. Full postal details are also needed by the publisher, but will not necessarily be published.

Anonymity for Peer Review: Ensure your identity and that of your co-authors is not revealed in the text of your article or in your manuscript files when submitting the manuscript for review. Advice on anonymising your manuscript is available here.

Abstract: Indicate the abstract paragraph with a heading or by reducing the font size. Advice on writing abstracts is available here.

Keywords: Please provide five or six keywords to help readers find your article. Advice on selecting suitable keywords is available here.

Headings: Please indicate the level of the section headings in your article:

- First-level headings (e.g. Introduction, Conclusion) should be in bold, with an initial capital letter for any proper nouns.
- Second-level headings should be in bold italics, with an initial capital letter for any proper nouns.
- Third-level headings should be in italics, with an initial capital letter for any proper nouns.
- Fourth-level headings should also be in italics, at the beginning of a paragraph. The text follows immediately after a full stop (full point) or other punctuation mark.
Tables and Figures: Indicate in the text where the tables and figures should appear, for example by inserting [Table 1 near here]. The actual tables and figures should be supplied either at the end of the text or in a separate file as requested by the Editor. Ensure you have permission to use any figures you are reproducing from another source. Advice on artwork is available here. Advice on tables is available here.

Running heads and received dates are not required when submitting a manuscript for review. If your article is accepted for publication, it will be copy-edited and typeset in the correct style for the journal.

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Full name of author: Adam Denton

ORCID number (Optional): ..................................................

Full title of thesis/dissertation/research project (‘the work’):
The Effectiveness of Self-Myofascial Release with Foam Rollers or Roller Massagers on Range of Motion: A Systematic Review

School: ..Osteopathy

Degree: Master of Osteopathy

Year of presentation: 2017

Principal Supervisor: Duncan Reid..

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