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(Review Article)

Exploring physiotherapy strategies in arthrogenic muscle inhibition: A scoping review

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Abstract

Arthrogenic muscular inhibition (AMI) is the presynaptic continual reflex inhibition of the surrounding muscles. It is a defensive reaction that lowers motor neuron activity to prevent further damage; however, if it persists, it can cause muscle atrophy and weakness, which can cause functional limitations. It usually involves quadriceps muscle post knee injuries and surgeries. Though it can be appreciated at any joint post injury or surgery like shoulder , elbow and ankle.

Recent studies shows that post injury or surgery, tissues respond by reflex inhibition mechanism and is unnoticed by many therapists. The aim of this review is to analyse the various approaches available in the physiotherapy rehabilitation for treating AMI of any joint and to know the best treatment approach to be used for optimising the effects of AMI. Total of 37 articles were considered to identify the different outcomes and interventions used in treating AMI.

In conclusion, Effective physiotherapy interventions are necessary to address AMI and enhance joint function and muscle activation. NMES, cryotherapy, and certain strengthening exercises are a few examples of interventions that can help get past the neural inhibition limiting muscle activation surrounding an injured joint.

The implementation of early physiotherapy interventions is essential for preventing

muscle atrophy and regaining normal movement patterns. In order to advance patient rehabilitation and maximize healing and functional outcomes, a customized protocol with particular demands is required.

Keywords: Arthrogenic muscle inhibition (AMI); Knee injury; ACL reconstruction; Musculoskeletal rehabilitation; Functional outcome

1. Introduction

A presynaptic continuous reflex inhibition of the muscles surrounding a joint upon distension or damage to the joint is known as arthrogenetic muscle inhibition (AMI)[1]. While AMI is a natural, protective response meant to lower motor neuron activity in order to stop additional joint damage, prolong AMI can result in atrophy and weakening of the muscles, which can lead to functional deficits [2]. Patients with musculoskeletal problems are significantly impacted, especially by pain-associated AMI [3].

After a knee injury, arthrogenous muscular activation in the quadriceps has been extensively documented[4,5]. Few research, meanwhile, have looked into the possibility of AMI in the musculature surrounding the ankle, elbow, and shoulder joints. In their 2005 study, Eric D. McVey et al. established the presence of AMI in the leg musculature of

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participants who had functional ankle stability[9]. Patients recuperating from ACL injuries frequently experience AMI in their quadriceps, and it has been linked to the development of altered biomechanics[10,11], patient disability[12,13], and post-traumatic osteoarthritis[14,15]. Years following total knee arthroplasty, lower limb muscular weakness continues, with persistent strength losses reaching 42%[16].

The ramifications of this are severe, particularly for elderly individuals, since weakening in the quadriceps muscles is linked to reduced gait, speed, balance, and the capacity to ascend stairs and get out of a chair, as well as an increased risk of falls[17-23]. When acute knee surgery is performed, such as patellar dislocations, anterior cruciate ligament repairs, or Tibial spine avulsion fixation, post-operative stiffness is frequently the consequence of failing to take AMI into mind prior to surgery[24].

It is widely acknowledged that AMI results from a modification in the way articular sensory receptors from the injured joint discharge, which modifies the excitability of several spinal and supraspinal pathways in the central nervous system. Reduced quadriceps muscular activation is the cumulative effect, and this affects knee extension strength[25].In the near term, pain, edema, inflammation, and damage to mechanoreceptors that change afferent signals from the joint to the central nervous system are the main effects of these neurological changes. Longer term, there is compelling evidence linking AMI to a degenerative cycle of weakening, atrophy, and wasting of the muscles, which consequently reduces the efficacy of rehabilitation regimens[26].

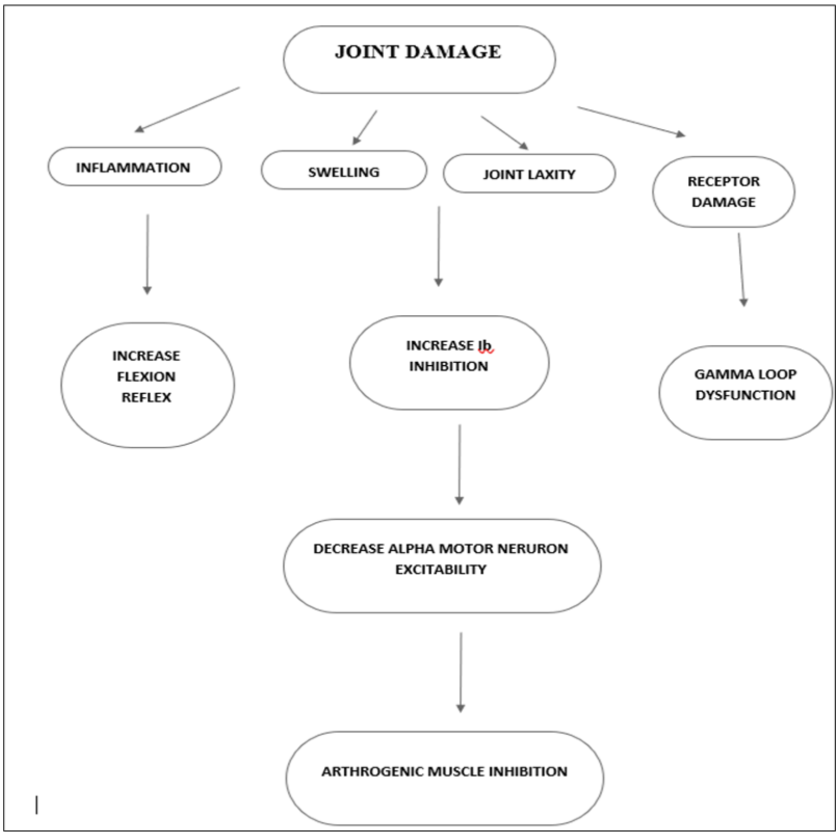

Figure 1 Pathophysiology of Arthrogenic muscle inhibition

In order to prevent difficulties, it is imperative to remove motor inhibition prior to considering any surgical procedures. AMI after a knee injury can appear in a number of ways. Although the knee often appears normal, there may be occasionally a significant effusion or hemarthrosis linked to the inhibition of the Vastus medialis oblique muscle. Because of hamstring contracture and quadriceps deactivation, the patient may exhibit an Extension deficit[24].

In their research, Bertrand Sonnery Cottet et al.[24] divided the AMI into grades based on the VMO Activation and the patient's reaction to the therapeutic intervention.

1.1. Classification of AMI

Table 1 AMI grading based on vmo activation and patient response to intervention

Grade	Presentation
Grade 0	Normal VMO Contraction
Grade 1	VMO contraction inhibited without knee extension deficit
1a	Activation failure reversible within few minutes of commencing simple active assisted extension exercises
1b	Refractory to simple active assisted extension exercises, requiring longer and specific rehabilitation programs.
Grade 2	VMO Contraction Inhibited with associated knee extension deficit due to hamstring contracture
2a	Activation failure and loss of motion reversible within few minutes of fatiguing the hamstrings and commencing simple active assisted extension exercises
2b	Refractory to fatiguing the hamstrings and/or simple active assisted extension exercises therefore longer and specific rehabilitation programs required
Grade 3	Passive chronic extension deficit due to posterior capsule retraction
	Extensive posterior arthrolysis mandatory with specific preoperative and postoperative rehabilitation protocols

Hoffman reflex testing is a widely used method to determine if an arthrogen-induced muscular reaction is present or absent. (Reflex H) [27]. The maximum reflex activation is represented by the peak value of the H reflex, which serves as an indicator of alpha motor neuron excitability[28]. A smaller or decreased maximal H reflex would be indicative of arthrogenous inhibition[29].

Central activation ratio(CAR), Maximal volutary control(MVC) and Maximal voluntary isometric contraction (MVIC) are the other additional metrics that are commonly employed to evaluate AMI. Although most therapeutic exercises aim to strengthen the muscles, they frequently don't work well for people with AMI. Using disinhibition mechanisms, a number of interventional techniques have been proposed recently to modify motor excitability. During a brief rehabilitation session (30 to 90 minutes), some of these treatments—including cryotherapy, transcutaneous neuromuscular stimulation (TENS), electromyography, biofeedback, transcranial magnetic stimulation (TMS), and neuromuscular stimulation—may be helpful to offset the adverse effects of AMI[30-35]. Persistent impairments have been detected despite increases in quadriceps function (knee extension strength, quadriceps activation, and EMG activity). Thus, it is probable that the present therapeutic approaches are failing[24,36-38].

In order to lessen the burden of AMI on rehabilitation, the goal of this review is to assess the effectiveness of various physiotherapeutic therapies in patients with AMI.

2. Methodology

The PubMed search engine was employed in this investigation. Using the keywords "arthrogenic inhibition, knee injury, physiotherapy intervention," 230 publications were first examined. Thirty seven articles were chosen using the search engine above.

Figure 2 Data synthesis

Table 2 Evidence of different outcomes and interventions approaches used by investigators for AMI

Name of Author	Study Design	Year of Publication	Outcome Measures	Intervention
Typhanie Dos Anjos et al[26]	Case series	2024	VMO activation	Neuromotor reprogramming
M Zarrin et al[42]	RCT	2023	EMG, H:M Ratio International Knee Documentation Committee subjective knee form questionnaire score	Dry Needling
Juan Pablo et al[70]	Experimental study	2023		VR
Jeslin T et al[71]	RCT	2022	EMG	Pressure Biofeedback
Grant Norte et al[69]	Review	2021		

Sonnerry Cottet et al[24]	Review	2019		
Lowe and Dong[44]	Case control	2018	CAR	Hamstring fatigue induced by squats
Kuenze et al[45]	Case series	2017	MVIC, CAR	Cryotherapy, lower extremity muscle stretching, progressive strengthening exercises and balance training.
Konishi et al[46]	RCT, Cross over	2017	MVIC	TENS
Kim KM et al[47]	RCT	2016	H reflex, CAR, MVIC	Kinesio taping
Son et al[48]	RCT	2016	MVIC	TENS, Infusion of hypertonic saline
Pamukoff et al[49]	RCT	2016	Active Motor threshold (AMT)- WBV, LMV CAR - WBV, LMV,MVIC	WBV, LMV
Pamukoff et al[50]	RCT	2016	Quadriceps active motor threshold (AMT), motor-evoked potential (MEP) amplitude, Hoffmann reflex (H-reflex) amplitude, peak torque (PT), rate of torque development (RTD), Electromyographic amplitude, and central activation ratio (CAR)	WBV, LMV
Oliveira et al[51]	RCT	2016	Postural balance analysis, Ecentric and concentric isokinetic assessment	Kinesio taping
Callaghan MJ et al[43]	Secondary analysis RCT	2016	Quadriceps MVC measured isometrically and Quadriceps AMI measured by twitch interpolation	Knee braces
Lepley LK et al[32]	Prospective cohort	2015	Limb symmetry	NMES, Eccentric exercises
Lepley et al[52]	Prospective cohort	2015	MVIC	NMES, Eccentric exercises
Norte et al[53]	RCT	2015	H reflex	Ultrasound
Blackburn JT et al[39]	RCT	2014	voluntary peak torque (VPT) and the central activation ratio (CAR)	Whole body vibration, Local muscle vibration
Harkey MS et al[54]	Systematic review	2014		Manual therapy, Transcutaneous electrical nerve stimulation, Cryotherapy, Neuromuscular electrical stimulation and Transcranial magnetic stimulation
Hart et al[3]	RCT	2014	MVIC	Cryotherapy, Rehabilitation exercises

Glaviano et al[55]	RCT	2014	MVIC	Electrical neuromuscular stimulation to Quadriceps and hamstrings
Joseph M Hart et al[36]	Cross sectional study	2014	H reflex, MVIC, CAR	Cryotherapy, Rehabilitation exercises
Warner et al[56]	RCT	2013	CAR, MVIT	Moist Heat Pack
Fu CL et al[57]	RCT	2013	Biodex dynamometer, Biodex Stability System, and Cybex NORM, respectively. Knee range of motion (ROM), stability (manual testing and KT-1000 arthrometer), and functional ability	WBVT
Ageberg et al[58]	RCT	2012		Local cutaneous application of Anesthetic cream
Grindstaff et al[59]	RCT	2012	Quadriceps force activation, Isometric knee extension	Lumbopelvic manipulations, PROM, Passive extension
Davis et al[60]	Cross over	2011		Brace sleeve
Gibbsons et al[61]	RCT	2010	CAR, MVIC	TMS
Palmieri et al[62]	RCT	2010	Western Ontoria and Mc master osteoarthritis index, 40 minute walk test	NMES
Rice et al[63]	RCT	2009	MVIC	Cryotherapy
Grindstaff et al[64]	RCT	2009	Quadriceps force activation, Isometric knee extension	Lumbopelvic manipulations, PROM, Passive extension
Pietrosimone et al[65]	RCT	2009	CAR	TENS, Focal knee joint cooling
Urbach et al[66]	RCT Cross over study	2005	MVC, Voluntary Activation	TMS
Drover JM et al[67]	Case Series	2004	MVIT	Active release technique
Hopkins et al[68]	RCT	2002	H Reflex	Cryotherapy, TENS

The above table shows the evidence of different approaches used with different outcome measures for testing the approaches used till date in treating arthrogenic muscle inhibition.

3. Discussion

In cases of post-knee injuries and post-operative knee injuries when quadriceps performance declines as a result of inactivity and reflex inhibition, this study highlights the important impacts of AMI. AMI is known to result from joint insult, which also causes inflammation, edema, laxity in the joint, and damage to the receptors, which lowers the excitability of alpha motor neurons in the joint.

AMI is a frequent consequence of knee pathology that causes quadriceps dysfunction and raises the likelihood of post-traumatic osteoarthritis, according to a study by Blackburn JT et al [39]. According to the findings of Dutaillis B et al.[40] and

Lepley AS et al.[41], quadriceps AMI has been linked to post-traumatic knee injury deficiencies, such as a deficit in muscle growth and extension, which restricts the capacity to advance throughout rehabilitation.

AMI is not particularly noteworthy by many therapists in physiotherapy practices where enhancing the functional outcome is the primary goal.The efficacy of various treatment approaches in reducing the consequences of AMI has been compiled in a number of studies, but the best and most efficient approach to treatment has not yet been determined. Thus, this study's primary goal is to provide an evidence-based strategy to produce important guidelines for the care of AMI patients.

The texts included in this review were published between 2002 and 2024. According to available data, the following treatment modalities are used for AMI: cryotherapy; transcranial magnetic stimulation (TENS); whole body vibration therapy (WBVT); local muscle vibration therapy (LMV); transcranial magnetic stimulation; manual therapy; therapeutic exercises; eccentric exercises; kinesio taping; knee braces; sleeves; active release technique; ultrasound; local cutaneous application of anesthetic cream; focal knee joint cooling; infusion of hypertonic solution; moist heat pack.

The features, design, year of publication, outcome measures, and therapeutic approaches of the numerous AMI studies are compiled in Table 2.

Cryotherapy: The effects of cryotherapy on AMI patients were assessed in six studies. Three RCTs, a systematic review, a cross-sectional study, and a case study were all included in this. A notable increase in the recruitment of the quadriceps motor pool was shown by Hopkins et al.

Transcutaneous electrical nerve stimulation (TENS): The efficacy of TENS was demonstrated in five investigations, including four RCTs and one systematic review. TENS has been found in three randomised trials to have some effect on improving AMI in a lab environment. The quadriceps muscular strength (MVIC) improved significantly in two trials as compared to controls, and the quadriceps motor neuron pool (measured by H-reflex) was effectively disinhibited in the third trial.

Four studies—one RCT, one comprehensive review, and two chort studies—showed how neuromuscular electrical nerve stimulation (NMES) affected acute myocardial infarction (AMI). In the prospective cohort study, Lepley et al. found that biomechanical limb symmetry was restored in the group receiving both neuromuscular electrical stimulation (NMES) and eccentric exercise.

Four RCTs assessed the effectiveness of vibration therapy. Patients with total ankle arthroscopy were randomly assigned to three groups: control, local muscle vibration (LMV), and whole body vibration (WBV). After WBV and LMV (+2.7%), there was a statistically significant increase in CAR (+4.9%). Additionally, after WBV (−3.1%) and LMV (−2.9%), there was a decrease in the quadriceps active motor threshold, indicating that the therapies raise corticomotor excitability.

Therapeutic activity: Hart et al. and Kuenze et al., who also used exercise as an adjuvant to cryotherapy, showed that all of the included studies showed that exercise therapy was linked with a significant improvement in quadriceps activation (MVIC and CAR).Three of the workout regimens included progressive closed-chain strengthening activities for the hamstring and quadriceps muscles as well as standard open-chain exercises with resistance.[15–17]

Quadriceps sets, straight leg lifts with hip abduction/adduction, and a progression to wall squats, free-standing quarter squats, hamstring curls, hip flexion/extension, and leg presses were among the resistance exercises. Stretching exercises for the quadriceps, hamstrings, and calf were used to increase flexibility. In the fourth trial, a case-control analysis was conducted to determine how a hamstring fatigue workout regimen affected AMI patients after ACLR. After hamstring fatigue activities, the ACLR group's quadriceps CAR was considerably greater (mean 96.0%, SD 7.6%) compared to pre-fatigue.

One RCT and one systematic review on transcranial magnetic stimulation were included.There was just one experiment found, an RCT (n=20) assessing transcranial magnetic stimulation (TMS) in individuals with persistent quadriceps weakness (CAR<85%) following a partial meniscectomy.When comparing the CAR and MVIC of the treated group to that of the control group, no discernible difference was found. There is no evidence to support the use of TMS in the treatment of AMI, according to this systematic review.

Taping and bracing: The effects of taping on quadriceps muscle performance were evaluated in two randomized controlled trials and one cross-sectional investigation.There were no differences found between the brace and no brace conditions.

Others: The active release technique is a soft tissue manipulation system that aims to reduce adhesions and fibrosis to release tension in the tissue. Both strengthening and decreasing quadriceps inhibition were unaffected. In a different study, it was discovered that applying local anesthetic cream had no impact on quadriceps function or on the sensorimotor function of the knee in individuals with ACL injuries.

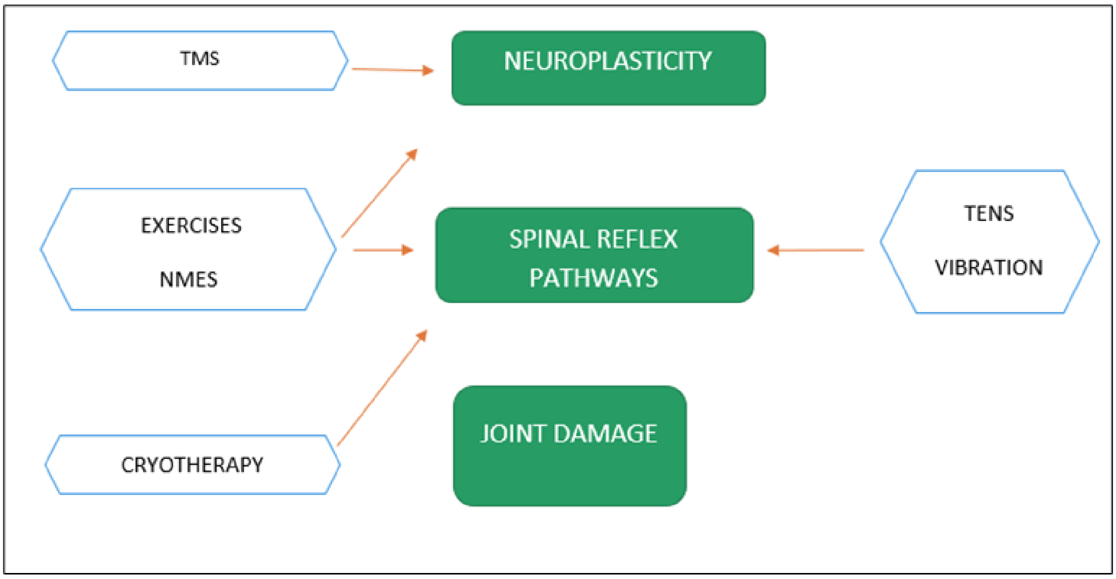

Figure 3 Effects of Various Interventions at Different Levels

4. Conclusion

Physiotherapy interventions are essential for effectively addressing AMI to improve muscle activation and joint function. Interventions such as NMES , cryotherapy and specific strengthening exercises can help overcome the neural inhibition that limits muscle activation around affected joint .

Early physiotherapy intervention application plays a crucial role to prevent muscle atrophy and to restore normal movement patterns. Tailored protocol with specific needs is necessary to progress patient rehab to optimize recovery and functional outcomes.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Hopkins JT, Ingersoll CD, Arthrgenic muscle inhibition: a limiting factor in knee joint rehabilitation. J Sport Rehabil.2000;9:135-159.

[2] O'Reilly S, Jones A, Muir KR, Doherty M. Quadriceps weakness in knee osteoarthritis: the effect on pain and disability. Ann Rheum Dis.1998;57(10):588-594. doi:10.1136/ard.57.1.0.588.

[3] Hart JM, Kuenze CM, Diduch DR, Ingersoll CD. Quadriceps muscle function after rehabilitation with cryotherapy in patients with anterior cruciate ligament reconstruction. Journal of athletic training. 2014 Dec 1;49(6):733-9.

[4] Docherti, C; Gansneder, B; Arnold, B; Hurwitz' S: Reliability and validity of an ankle instability instrument' J' Athl' Train38(2):S12,2003

[5] Hurley MV, Jones DW, Newham DJ. Arthrogenic quadriceps inhibition and rehabilitation of patients with extensive traumatic knee injuries. Clinical Science (London, England: 1979). 1994 Mar 1;86(3):305-10.

[6] DJ M. Effects of strength training and immobilization on human muscle fibers. Eur J Appl Physiol. 1980;43:25-34.

[7] MacDougall JD, Ward GR, Sale DG, Sutton JR. Biochemical adaptation of human skeletal muscle to heavy resistance training and immobilization. Journal of Applied Physiology. 1977 Oct 1;43(4):700-3.

[8] Hall RC, Nyland J, Nitz AJ, Pinerola J, Johnson DL. Relationship between ankle invertor H-reflexes and acute swelling induced by inversion ankle sprain. Journal of Orthopaedic & Sports Physical Therapy. 1999 Jun;29(6):339-44.

[9] McVey ED, Palmieri RM, Docherty CL, Zinder SM, Ingersoll CD. Arthrogenic muscle inhibition in the leg muscles of subjects exhibiting functional ankle instability. Foot & ankle international. 2005 Dec;26(12):1055-61.

[10] Torry MR, Decker MJ, Viola RW, D O'Connor D, Steadman JR. Intra-articular knee joint effusion induces quadriceps avoidance gait patterns. Clinical Biomechanics. 2000 Mar 1;15(3):147-59.

[11] Pietrosimone B, Lepley AS, Murray AM, Thomas AC, Bahhur NO, Schwartz TA. Changes in voluntary quadriceps activation predict changes in muscle strength and gait biomechanics following knee joint effusion. Clinical Biomechanics. 2014 Sep 1;29(8):923-9.

[12] Pietrosimone B, Lepley AS, Harkey MS, Luc-Harkey BA, Blackburn JT, Gribble PA, Spang JT, Sohn DH. Quadriceps Strength Predicts Self-reported Function Post-ACL Reconstruction. Medicine and science in sports and exercise. 2016 Sep 1;48(9):1671-7.

[13] Palmieri-Smith RM, Kreinbrink J, Ashton-Miller JA, Wojtys EM. Quadriceps inhibition induced by an experimental knee joint effusion affects knee joint mechanics during a single-legged drop landing. The American journal of sports medicine. 2007 Aug;35(8):1269-75.

[14] Pietrosimone B, Pfeiffer SJ, Harkey MS, Wallace K, Hunt C, Blackburn JT, Schmitz R, Lalush D, Nissman D, Spang JT. Quadriceps weakness associates with greater T1ρ relaxation time in the medial femoral articular cartilage 6 months following anterior cruciate ligament reconstruction. Knee Surgery, Sports Traumatology, Arthroscopy. 2019 Aug 1;27:2632-42.

[15] Palmieri-Smith RM, Thomas AC. A neuromuscular mechanism of posttraumatic osteoarthritis associated with ACL injury. Exercise and sport sciences reviews. 2009 Jul 1;37(3):147-53.

[16] Huang CH, Cheng CK, Lee YT, Lee KS. Muscle strength after successful total knee replacement: a 6-to 13-year followup. Clinical Orthopaedics and Related Research®. 1996 Jul 1;328:147-54.

[17] Mizner RL, Petterson SC, Snyder-Mackler L. Quadriceps strength and the time course of functional recovery after total knee arthroplasty. Journal of Orthopaedic & Sports Physical Therapy. 2005 Jul;35(7):424-36.

[18] Connelly DM, Vandervoort AA. Effects of detraining on knee extensor strength and functional mobility in a group of elderly women. Journal of Orthopaedic & Sports Physical Therapy. 1997 Dec;26(6):340-6.

[19] Scarborough DM, Krebs DE, Harris BA. Quadriceps muscle strength and dynamic stability in elderly persons. Gait & posture. 1999 Sep 1;10(1):10-20.

[20] Fukagawa NK, Brown M, Sinacore DR, Host HH. The relationship of strength to function in the older adult. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 1995 Nov 1;50(Special_Issue):55-9.

[21] Rantanen T, Guralnik JM, Izmirlian G, Williamson JD, Simonsick EM, Ferrucci L, Fried LP. Association of muscle strength with maximum walking speed in disabled older women1. American journal of physical medicine & rehabilitation. 1998 Jul 1;77(4):299-305.

[22] Skelton DA, Greig CA, Davies JM, Young A. Strength, power and related functional ability of healthy people aged 65–89 years. Age and ageing. 1994 Sep 1;23(5):371-7.

[23] Moreland JD, Richardson JA, Goldsmith CH, Clase CM. Muscle weakness and falls in older adults: a systematic review and meta-analysis. Journal of the american Geriatrics Society. 2004 Jul;52(7):1121-9.

[24] Sonnery-Cottet B, Hopper GP, Gousopoulos L, Vieira TD, Thaunat M, Fayard JM, Freychet B, Ouanezar H, Cavaignac E, Saithna A. Arthrogenic muscle inhibition following knee injury or surgery: pathophysiology, classification, and treatment. Video Journal of Sports Medicine. 2022 Apr;2(3):26350254221086295.

[25] Rice DA, McNair PJ. Quadriceps arthrogenic muscle inhibition: neural mechanisms and treatment perspectives. InSeminars in arthritis and rheumatism 2010 Dec 1 (Vol. 40, No. 3, pp. 250-266). WB Saunders.

[26] Dos Anjos T, Gabriel F, Vieira TD, Hopper GP, Sonnery-Cottet B. Neuromotor treatment of arthrogenic muscle inhibition after knee injury or surgery. Sports Health. 2024 May;16(3):383-9.

[27] Palmieri RM, Ingersoll CD, Hoffman MA. The Hoffmann reflex: methodologic considerations and applications for use in sports medicine and athletic training research. Journal of athletic training. 2004 Jul;39(3):268.

[28] Zehr PE. Considerations for use of the Hoffmann reflex in exercise studies. European journal of applied physiology. 2002 Apr;86:455-68.

[29] Angel RW, Hofmann WW. The H reflex in normal, spastic, and rigid subjects: studies. Archives of Neurology. 1963 Jun 1;8(6):591-6.

[30] Bremner CB, Holcomb WR, Brown CD, Perreault ME. The effectiveness of neuromuscular electrical stimulation in improving voluntary activation of the quadriceps: A critically appraised topic. Journal of Sport Rehabilitation. 2017 Jul 1;26(4):316-23.

[31] Kuenze CM, Kelly AR, Jun HP, Eltoukhy M. Unilateral quadriceps strengthening with disinhibitory cryotherapy and quadriceps symmetry after anterior cruciate ligament reconstruction. Journal of athletic training. 2017 Nov 1;52(11):1010-8.

[32] Lepley LK, Wojtys EM, Palmieri-Smith RM. Combination of eccentric exercise and neuromuscular electrical stimulation to improve biomechanical limb symmetry after anterior cruciate ligament reconstruction. Clinical biomechanics. 2015 Aug 1;30(7):738-47.

[33] Pietrosimone BG, McLeod MM, Lepley AS. A theoretical framework for understanding neuromuscular response to lower extremity joint injury. Sports health. 2012 Jan;4(1):31-5.

[34] Pietrosimone BG, Saliba SA, Hart JM, Hertel J, Ingersoll CD. Contralateral effects of disinhibitory TENS on quadriceps function in people with knee osteoarthritis following unilateral treatment. North American journal of sports physical therapy: NAJSPT. 2010 Sep;5(3):111.

[35] Ranganathan VK, Siemionow V, Liu JZ, Sahgal V, Yue GH. From mental power to muscle power—gaining strength by using the mind. Neuropsychologia. 2004 Jan 1;42(7):944-56.

[36] Hart JM, Kuenze CM, Diduch DR, Ingersoll CD. Quadriceps muscle function after rehabilitation with cryotherapy in patients with anterior cruciate ligament reconstruction. Journal of athletic training. 2014 Dec 1;49(6):733-9.

[37] Loro WA, Thelen MD, Rosenthal MD, Stoneman PD, Ross MD. The effects of cryotherapy on quadriceps electromyographic activity and isometric strength in patient in the early phases following knee surgery. Journal of Orthopaedic Surgery. 2019 Feb 25;27(1):2309499019831454.

[38] Tayfur B, Charuphongsa C, Morrissey D, Miller SC. Neuromuscular function of the knee joint following knee injuries: does it ever get back to normal? A systematic review with meta-analyses. Sports medicine. 2021 Feb;51:321-38.

[39] Blackburn JT, Pamukoff DN, Sakr M, Vaughan AJ, Berkoff DJ. Whole body and local muscle vibration reduce artificially induced quadriceps arthrogenic inhibition. Archives of physical medicine and rehabilitation. 2014 Nov 1;95(11):2021-8.

[40] Dutaillis B, Maniar N, Opar DA, Hickey JT, Timmins RG. Lower limb muscle size after anterior cruciate ligament injury: a systematic review and meta-analysis. Sports Medicine. 2021 Jun;51:1209-26.

[41] Lepley AS, Grooms DR, Burland JP, Davi SM, Kinsella-Shaw JM, Lepley LK. Quadriceps muscle function following anterior cruciate ligament reconstruction: systemic differences in neural and morphological characteristics. Experimental brain research. 2019 May 7;237:1267-78.

[42] Zarrin M, Naghdi S, Hasson S, Forogh B, Rezaee M. Dry Needling for Arthrogenic Muscle Inhibition of Quadriceps Femoris in Patients after Reconstruction of Anterior Cruciate Ligament: a Protocol for a Randomized Controlled Trial. Journal of Acupuncture and Meridian Studies. 2023 Oct 1;16(5):193-202.

[43] Callaghan MJ, Parkes MJ, Felson DT. The effect of knee braces on quadriceps strength and inhibition in subjects with patellofemoral osteoarthritis. journal of orthopaedic & sports physical therapy. 2016 Jan;46(1):19-25.

[44] Lowe T, Dong XN. The use of hamstring fatigue to reduce quadriceps inhibition after anterior cruciate ligament reconstruction. Perceptual and motor skills. 2018 Feb;125(1):81-92.

[45] Kuenze C, Eltoukhy M, Kelly A, Kim CY. Impact of quadriceps strengthening on response to fatiguing exercise following ACL reconstruction. Journal of science and medicine in sport. 2017 Jan 1;20(1):6-11.

[46] Konishi Y, McNair PJ, Rice DA. TENS Alleviates muscle weakness attributable to attenuation of ia afferents. International Journal of Sports Medicine. 2017 Mar;38(03):253-7.

[47] Kim KM, Davis B, Hertel J, Hart J. Effects of Kinesio taping in patients with quadriceps inhibition: A randomized, single-blinded study. Physical Therapy in Sport. 2017 Mar 1;24:67-73.

[48] Son SJ, Kim H, Seeley MK, Feland JB, Hopkins JT. Effects of transcutaneous electrical nerve stimulation on quadriceps function in individuals with experimental knee pain. Scandinavian journal of medicine & science in sports. 2016 Sep;26(9):1080-90.

[49] Pamukoff DN, Pietrosimone B, Lewek MD, Ryan ED, Weinhold PS, Lee DR, Blackburn JT. Whole-body and local muscle vibration immediately improve quadriceps function in individuals with anterior cruciate ligament reconstruction. Archives of physical medicine and rehabilitation. 2016 Jul 1;97(7):1121-9.

[50] Pamukoff DN, Pietrosimone B, Lewek MD, Ryan ED, Weinhold PS, Lee DR, Blackburn JT. Immediate effect of vibratory stimuli on quadriceps function in healthy adults. Muscle & nerve. 2016 Sep;54(3):469-78.

[51] Oliveira AK, Borges DT, Lins CA, Cavalcanti RL, Macedo LB, Brasileiro JS. Immediate effects of Kinesio Taping® on neuromuscular performance of quadriceps and balance in individuals submitted to anterior cruciate ligament reconstruction: a randomized clinical trial. Journal of science and medicine in sport. 2016 Jan 1;19(1):2-6.

[52] Lepley LK, Wojtys EM, Palmieri-Smith RM. Combination of eccentric exercise and neuromuscular electrical stimulation to improve quadriceps function post-ACL reconstruction. The Knee. 2015 Jun 1;22(3):270-7.

[53] Norte GE, Saliba SA, Hart JM. Immediate effects of therapeutic ultrasound on quadriceps spinal reflex excitability in patients with knee injury. Archives of physical medicine and rehabilitation. 2015 Sep 1;96(9):1591-8.

[54] Harkey MS, Gribble PA, Pietrosimone BG. Disinhibitory interventions and voluntary quadriceps activation: a systematic review. Journal of athletic training. 2014 Jun 1;49(3):411-21.

[55] Glaviano NR, Langston WT, Hart JM, Saliba S. Influence of patterned electrical neuromuscular stimulation on quadriceps activation in individuals with knee joint injury. International journal of sports physical therapy. 2014 Dec;9(7):915.

[56] Warner B, Kim KM, Hart JM, Saliba S. Lack of effect of superficial heat to the knee on quadriceps function in individuals with quadriceps inhibition. Journal of sport rehabilitation. 2013 May 1;22(2):93-9.

[57] Fu CL, Yung SH, Law KY, Leung KH, Lui PY, Siu HK, Chan KM. The effect of early whole-body vibration therapy on neuromuscular control after anterior cruciate ligament reconstruction: a randomized controlled trial. The American journal of sports medicine. 2013 Apr;41(4):804-14.

[58] Ageberg E, Björkman A, Rosén B, Roos EM. Principles of brain plasticity in improving sensorimotor function of the knee and leg in patients with anterior cruciate ligament injury: a double-blind randomized exploratory trial. BMC musculoskeletal disorders. 2012 Dec;13:1-8.

[59] Grindstaff TL, Hertel J, Beazell JR, Magrum EM, Kerrigan DC, Fan X, Ingersoll CD. Lumbopelvic joint manipulation and quadriceps activation of people with patellofemoral pain syndrome. Journal of athletic training. 2012 Jan 1;47(1):24-31.

[60] Davis AG, Pietrosimone BG, Ingersoll CD, Pugh K, Hart JM. Quadriceps function after exercise in patients with anterior cruciate ligament–reconstructed knees wearing knee braces. Journal of athletic training. 2011 Nov 1;46(6):615-20.

[61] Gibbons CE, Pietrosimone BG, Hart JM, Saliba SA, Ingersoll CD. Transcranial magnetic stimulation and volitional quadriceps activation. Journal of athletic training. 2010 Nov 1;45(6):570-9.

[62] Palmieri-Smith RM, Thomas AC, Karvonen-Gutierrez C, Sowers M. A clinical trial of neuromuscular electrical stimulation in improving quadriceps muscle strength and activation among women with mild and moderate osteoarthritis. Physical therapy. 2010 Oct 1;90(10):1441-52.

[63] Rice D, McNair PJ, Dalbeth N. Effects of cryotherapy on arthrogenic muscle inhibition using an experimental model of knee swelling. Arthritis Care & Research. 2009 Jan 15;61(1):78-83.

[64] Grindstaff TL, Hertel J, Beazell JR, Magrum EM, Ingersoll CD. Effects of lumbopelvic joint manipulation on quadriceps activation and strength in healthy individuals. Manual therapy. 2009 Aug 1;14(4):415-20.

[65] Pietrosimone BG, Hart JM, Saliba SA, Hertel J, Ingersoll CD. Immediate effects of transcutaneous electrical nerve stimulation and focal knee joint cooling on quadriceps activation. Medicine and science in sports and exercise. 2009 Jun 1;41(6):1175-81.

[66] Urbach D, Berth A, Awiszus F. Effect of transcranial magnetic stimulation on voluntary activation in patients with quadriceps weakness. Muscle & Nerve: Official Journal of the American Association of Electrodiagnostic Medicine. 2005 Aug;32(2):164-9.

[67] Drover JM, Forand DR, Herzog W. Influence of active release technique on quadriceps inhibition and strength: a pilot study. Journal of manipulative and physiological therapeutics. 2004 Jul 1;27(6):408-13.

[68] Hopkins JT, Ingersoll CD, Edwards J, Klootwyk TE. Cryotherapy and transcutaneous electric neuromuscular stimulation decrease arthrogenic muscle inhibition of the vastus medialis after knee joint effusion. Journal of athletic training. 2002 Jan;37(1):25.

[69] Norte G, Rush J, Sherman D. Arthrogenic muscle inhibition: best evidence, mechanisms, and theory for treating the unseen in clinical rehabilitation. Journal of sport rehabilitation. 2021 Dec 9;31(6):717-35.

[70] Flórez Fonnegra JP, Pino Prestan AC, López LL, Yepes JC, Pérez VZ. Rehabilitation of Patients with Arthrogenic Muscular Inhibition in Pathologies of Knee Using Virtual Reality. Sensors. 2023 Nov 11;23(22):9114.

[71] Achens JT, Victor VS, Joseph JK. Early activation of quadriceps with pressure biofeedback for the Prevention of Arthrogenic muscle inhibition following lower Limb Orthopedic surgeries: a proof of Concept Clinical Trial. Journal of Chiropractic Medicine. 2022 Dec 1;21(4):296-304