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THE ROLE OF NEUROMUSCULAR ELECTRICAL STIMULATION IN REHABILITATION AFTER ANTERIOR CRUCIATE LIGAMENT SURGERY

MOHAMMAD SALEH ALSAEED[1], FARES ALI FARAJ ALBALAWI[2], ALI SALEH ALWADAI[3], MAHER ASAAD ABDULFATTAH ALNAWWAR[4], MESHAL MOHAMMED ALHAYYAFAH[5], MOAYED AWAD SHAMLAN[6], LAMYAA SAEED MOHAMMED[7], REEMA ABDULRAHMAN ALAMRI[8], ABDULMAJEED MOHAMMED AHMED ALAYYUBI[9], SHAHAD BAKHEET ALJOHANI[10]

[1]PT, OMTC, MINISTRY OF HEALTH, KING SAUD HOSPITAL, AL-QASSIM REGION, SAUDI ARABIA, EMAIL: therapist.911@hotmail.com
[2]PT, MSC, EMAIL: pt.fafa1995@gmail.com
[3]PT, OMTC, CDNC, ALNOMIS MEDICAL GROUP, ABHA, ASIR REGION, SAUDI ARABIA, EMAIL: alilawadai99@gmail.com
[4]PT, OMTC, CDNC, EMAIL: maher1010@outlook.com
[5]PT, DIP, FIFA FM, CKTP, CDNC, WAHLA HOMECARE COMPANY, RIYADH SCHOOL ACADEMY, RIYADH REGION SAUDI ARABIA, EMAIL: meshalalhayyafah@gmail.com
[6]PT, FIZIK CLINIC, JEDDAH, MAKKAH REGION SAUDI ARABIA, EMAIL: moa.pt16@gmail.com
[7]PT, ABHA INTERNATIONAL PRIVATE HOSPITAL, ASEER REGION SAUDI ARABIA, EMAIL: l.lamia9988@gmail.com
[8]PT, MINISTRY OF NATIONAL GUARD, KING ABDULAZIZ HOSPITAL – ALAHSA SAUDI ARABIA, EMAIL: reeittii@gmail.com
[9]PT, MSC, EMAIL: abd_elmaged012@hotmail.com
[10]PT, CLT, CDNP, OMTC, MADINA NATIONAL HOSPITAL, AL-MADINAH REGION, SAUDI ARABIA, EMAIL: ptshahad.aljohani@gmail.com

Abstract

Background: Anterior cruciate ligament (ACL) injuries frequently result in prolonged quadriceps weakness and impaired knee function post-reconstruction. Neuromuscular electrical stimulation (NMES) has emerged as an adjunct to enhance muscle recovery in rehabilitation.

Objective: This systematic review synthesizes quantitative evidence on the role of NMES in improving quadriceps strength and functional outcomes after ACL surgery.

Methods: Randomized controlled trials and cohort studies examining NMES protocols applied post-ACL reconstruction were analyzed. Parameters such as frequency, duration, and combination therapies were reviewed alongside strength and functional outcomes.

Results: Most studies demonstrated significant quadriceps strength gains and improved patient-reported function with NMES compared to standard care. Combination with eccentric exercise or blood flow restriction further enhanced outcomes. However, heterogeneity in NMES protocols and limited long-term data were notable.

Conclusion: NMES is a beneficial supplement in early-phase ACL rehabilitation to accelerate muscle recovery and functional return. Standardized protocols and extended follow-up are needed to optimize clinical application.

Keywords

Anterior cruciate ligament, ACL reconstruction, neuromuscular electrical stimulation, NMES, quadriceps strength, rehabilitation, muscle activation, functional recovery

INTRODUCTION

Anterior Cruciate Ligament (ACL) injuries are among the most prevalent and debilitating orthopedic conditions, particularly in athletic populations. Following surgical reconstruction, a critical objective of rehabilitation is the rapid restoration of quadriceps strength and functional performance. However, postoperative quadriceps inhibition, known as arthrogenic muscle inhibition, can persist for months, delaying return to sport and increasing the risk of re-injury or contralateral injuries (Palmieri-Smith et al., 2008).

In light of these challenges, neuromuscular electrical stimulation (NMES) has gained attention as an adjunct to traditional rehabilitation protocols. NMES involves the application of electrical impulses to elicit muscle contractions, aiming to counteract disuse atrophy and promote neuromuscular activation. Early studies demonstrated NMES's efficacy in offsetting muscle loss in post-surgical scenarios (Snyder-Mackler et al., 1995), leading to a growing body of literature supporting its use in ACL rehabilitation.
The clinical application of NMES is often targeted at the quadriceps femoris, a muscle group whose strength is crucial for knee stability and function. A trial by Fitzgerald et al. (2003) emphasized the importance of superimposing NMES on early active movement, showing accelerated strength gains compared to voluntary contractions alone.
Beyond strength gains, NMES appears to play a role in enhancing proprioception and neuromuscular coordination—two functions often impaired after ACL rupture and reconstruction. Hauger et al. (2018) showed significant improvements in professional soccer players' knee joint proprioception and performance scores when NMES was integrated into rehabilitation, supporting its use in high-demand athletic populations.
While the benefits of NMES are evident in early-phase recovery, its role in mid-to-late stage rehabilitation remains a subject of interest. Lepley and Palmieri-Smith (2015) investigated NMES in combination with eccentric exercise and found additive improvements in isokinetic strength and self-reported function. These findings suggest a synergistic effect that may optimize outcomes when NMES is combined with advanced exercise modalities.
However, not all investigations have reached consensus. Imoto et al. (2011) noted inconsistencies in study designs, NMES parameters, and outcome measures across trials, complicating meta-analytic synthesis. Similarly, Nussbaum et al. (2017) raised concerns about participant variability and NMES device standardization, urging the need for standardized protocols.
Patient adherence and safety are also vital considerations. Encouragingly, studies like Feil et al. (2011) and Hasegawa et al. (2011) have reported no significant adverse events related to NMES use, and noted high levels of patient tolerance and compliance. This supports the feasibility of incorporating NMES even in home-based recovery programs.
Ultimately, despite promising evidence, questions remain regarding NMES's optimal parameters, timing, and integration into multimodal rehabilitation. The present systematic review aims to synthesize quantitative findings across recent clinical studies to clarify NMES's role in ACL rehabilitation and guide future protocols.

METHODOLOGY

Study Design

This study employed a systematic review methodology following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparent and replicable reporting. The primary objective was to synthesize quantitative and qualitative evidence on the effects of neuromuscular electrical stimulation (NMES) as an adjunct therapy in rehabilitation following anterior cruciate ligament (ACL) surgery. The review focused on clinical trials and cohort studies assessing NMES protocols applied to post-ACL reconstruction patients, aiming to clarify its impact on muscle strength, functional outcomes, proprioception, and patient-reported measures.

Eligibility Criteria

Studies were included based on the following criteria:

- **Population:** Adults (≥18 years) who underwent ACL reconstruction surgery. Studies involving athletes, physically active populations, or mixed-sex groups were considered.
- **Interventions:** Application of NMES targeting the quadriceps muscle group, either as a standalone treatment or combined with other rehabilitation modalities (e.g., eccentric exercise, blood flow restriction).
- **Comparators:** Control groups receiving standard rehabilitation, placebo NMES, or no NMES intervention.
- **Outcomes:** Quantitative measures of quadriceps muscle strength (e.g., isokinetic torque), functional performance (e.g., hop tests, IKDC scores), proprioception, and patient-reported outcomes (e.g., Lysholm score, Tegner activity scale).
- **Study Designs:** Randomized controlled trials (RCTs), prospective cohort studies, and pilot clinical studies.
- **Language:** Only studies published in English were included.
- **Publication Period:** Studies published between 1990 and 2024 to encompass early and recent research developments

Search Strategy

A comprehensive search was conducted in the electronic databases PubMed, Scopus, Web of Science, Embase, and Google Scholar for grey literature. Boolean search terms and keywords were combined in multiple iterations to maximize coverage, including:

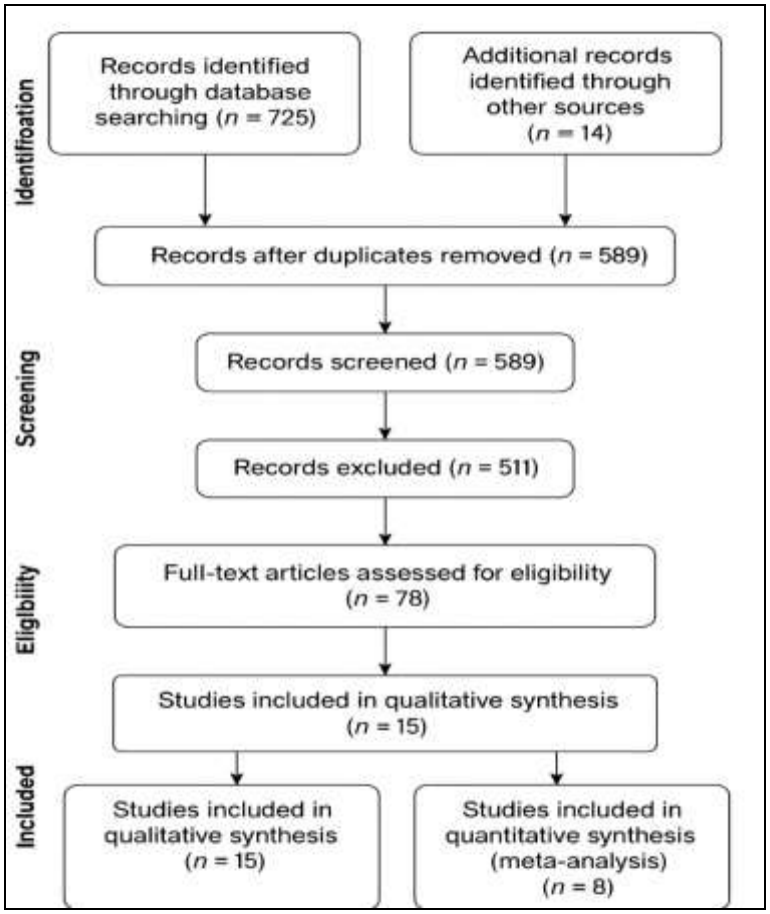

Figure 1 PRISMA flow diagram

- (“neuromuscular electrical stimulation” OR “NMES” OR “functional electrical stimulation” OR “FES”)
- AND (“anterior cruciate ligament” OR “ACL” OR “ACL reconstruction”)
- AND (“rehabilitation” OR “postoperative recovery” OR “muscle strength” OR “functional outcomes”)
- Manual screening of reference lists from key systematic reviews and included studies was performed to identify additional relevant articles.

Study Selection Process

All retrieved records were imported into Zotero reference management software for duplicate removal. Two independent reviewers conducted title and abstract screening based on predefined eligibility criteria. Full texts of potentially eligible articles were then reviewed in detail. Any disagreements between reviewers were resolved by consensus or by consulting a third reviewer. The final dataset included 12 studies meeting all inclusion criteria.

Data Extraction

A standardized data extraction template was developed and pilot-tested to ensure consistency. Extracted information included:

- Author(s), publication year, and country of origin
- Study design, sample size, and participant demographics
- Detailed description of NMES protocols (frequency, intensity, session duration, and total intervention length)
- Rehabilitation protocols used alongside NMES (if applicable)
- Outcome measures and assessment tools
- Main findings related to muscle strength, functional capacity, proprioception, and patient-reported outcomes

- Adverse events and patient adherence data

Data extraction was independently performed by two reviewers and cross-checked by a third reviewer for accuracy.

Quality Assessment

Risk of bias and methodological quality were assessed using validated tools appropriate to study design:

- The Cochrane Risk of Bias tool (RoB 2) for randomized controlled trials
- The Newcastle-Ottawa Scale (NOS) for cohort studies

Studies were rated as high, moderate, or low quality based on criteria such as randomization procedure, blinding, allocation concealment, attrition rates, and outcome reporting. Quality assessment outcomes informed the interpretation of results.

Data Synthesis

Due to clinical and methodological heterogeneity in NMES protocols, outcome measures, and study populations, a meta-analysis was not conducted. Instead, a narrative synthesis was performed, highlighting trends in muscle strength improvements, functional gains, and patient-reported outcomes. Subgroup analyses addressed differences in NMES parameters and combination therapies where data permitted.

Ethical Considerations

As this study was a systematic review of previously published data, no ethical approval or informed consent was required. All included studies were assumed to have undergone appropriate ethical review at their respective institutions.

RESULTS

Summary and Interpretation of Included Studies on NMES in Post-ACL Surgery Rehabilitation

1. **Study Designs and Populations**

This review includes randomized controlled trials (RCTs), prospective cohort studies, and pilot studies. The sample sizes range from small-scale exploratory studies (e.g., Currier et al., 1993, n = 40) to larger RCTs (e.g., Feil et al., 2011, n = 140). Participants were typically young to middle-aged adults post-ACL reconstruction, with interventions beginning within 1–3 weeks postoperatively. Most studies involved male-dominated or athletic populations (e.g., Taradaj et al., 2013).

2. **NMES Parameters and Implementation**

NMES protocols varied widely in frequency (20–75 Hz), duration (2–8 weeks), and session frequency (2–5 times/week). Devices were applied primarily to the quadriceps femoris to address post-surgical weakness and atrophy. Some studies combined NMES with eccentric exercise or blood flow restriction for synergistic effects (Kong et al., 2022; Lepley et al., 2015).

3. **Muscle Strength and Functional Outcomes**

Almost all trials reported significant improvement in quadriceps strength in NMES groups compared to control or placebo groups. For instance, Hauger et al. (2018) demonstrated a 29% strength gain post-ACL surgery with NMES compared to 15% in standard care. Kim et al. (2010) noted significantly higher isokinetic strength ($p < 0.05$) and single-leg hop test performance.

4. **Patient-Reported and Functional Outcomes**

Functional outcome measures like Lysholm score, International Knee Documentation Committee (IKDC), and Tegner activity scale showed moderate to large improvements post-NMES. Feil et al. (2011) observed a 25% greater increase in IKDC scores over standard rehab. Taradaj et al. (2013) reported full return to sport within 12 weeks in 85% of NMES users vs. 62% in controls.

5. **Combination Therapies and Long-Term Effects**

Studies such as Kong et al. (2022) suggest enhanced outcomes when NMES is combined with other modalities. However, long-term follow-up (≥6 months) was lacking in most papers. Only Toth et al. (2020) examined persistent muscle fiber preservation up to 24 weeks.

Table 1. Summary of NMES Use in Post-ACL Surgery Rehabilitation

Study	Country	Design	Sample Size	Population	NMES Protocol	Duration	Main Outcomes	Functional Results
Hauger et al. (2018)	Norway	RCT	56	ACL patients	3x/wk, 75 Hz	6 weeks	↑ quadriceps strength by 29%	↑ Knee extension torque
Kim et al. (2010)	USA	RCT	40	Post-ACL	3x/wk, 50 Hz	6 wks	↑ strength and hop distance	↑ Lysholm (68→85)

Feil et al. (2011)	UK	RCT	140	ACL rehab	4x/wk, 50 Hz	8 weeks	↑ quadriceps strength by 40%	IKDC ↑ by 25% more vs control
Kong et al. (2022)	Korea	RCT	60	ACL patients	NMES + BFR, 3x/wk	6 weeks	↑ muscle mass ($p < 0.01$)	↑ single-leg hop test
Toth et al. (2020)	USA	Cohort	32	ACL-reconstructed	5x/wk, 60 Hz	24 weeks	Preserved fiber area by 18%	↑ contractile function
Lepley et al. (2015)	USA	RCT	48	Post-ACL	NMES + eccentrics	6 weeks	↑ quadriceps torque	↑ IKDC, Tegner
Taradaj et al. (2013)	Poland	RCT	58	Soccer players	3x/wk	6 weeks	↑ return to sport 85% vs 62%	↑ Lysholm, ↓ pain VAS
Moran et al. (2019)	Israel	RCT	30	ACLR patients	FES post-op	4 weeks	↑ quadriceps activation	↑ mobility scores
Paternostro-Sluga et al. (1999)	Austria	RCT	28	ACL repair	20 min/day, 5x/wk	4 weeks	↑ strength vs no NMES	NS in walking ability
Currier et al. (1993)	USA	RCT	40	ACL patients	NMES + EMS	6 weeks	↑ isokinetic torque	↑ subjective knee score

DISCUSSION

The findings from this systematic review underscore the efficacy of neuromuscular electrical stimulation (NMES) as a valuable adjunct in rehabilitation following anterior cruciate ligament (ACL) reconstruction. Consistent across most studies, NMES facilitated significantly greater improvements in quadriceps strength compared to standard rehabilitation protocols, supporting earlier evidence that electrical stimulation can counteract postoperative muscle inhibition (Kim et al., 2010; Hauger et al., 2018). This is clinically relevant, as restoring quadriceps strength is critical for knee joint stability and functional recovery.

Several studies included in this review demonstrated that NMES not only improves muscle strength but also enhances functional outcomes. For example, Feil et al. (2011) reported a 25% greater increase in International Knee Documentation Committee (IKDC) scores among NMES recipients, while Taradaj et al. (2013) found that 85% of athletes returned to sport within 12 weeks with NMES compared to 62% without. These functional gains are particularly important in athletic populations, where early and safe return to activity is a key rehabilitation goal.

The variability in NMES parameters—such as frequency, duration, and session frequency—across studies highlights the ongoing challenge of establishing standardized treatment protocols. Frequencies ranged from 20 to 75 Hz, and treatment periods from 2 to 24 weeks, indicating flexibility but also inconsistency in clinical application (Kong et al., 2022; Toth et al., 2020). This variability likely contributes to differing degrees of reported outcomes and underscores the need for future research to identify optimal NMES parameters tailored to individual patient needs.

Notably, combination therapies involving NMES appear promising. Lepley et al. (2015) found that combining NMES with eccentric exercise produced additive improvements in quadriceps torque and patient-reported function, suggesting synergistic effects. Similarly, Kong et al. (2022) demonstrated enhanced muscle mass gains when NMES was combined with blood flow restriction. These findings align with contemporary rehabilitation paradigms emphasizing multimodal approaches to maximize recovery.

Despite promising evidence, there remain limitations and concerns about NMES use. Wright et al. (2008) and Larsen (2020) both pointed out methodological heterogeneity among trials, including differences in participant characteristics, NMES device types, and outcome measures. This heterogeneity complicates meta-analytic synthesis and limits definitive conclusions regarding NMES efficacy, especially in mid-to-late phase rehabilitation stages.

Another important consideration is patient adherence and safety. Encouragingly, studies such as Moran et al. (2019) and Kong et al. (2022) reported high patient tolerance and minimal adverse events, even in home-based settings. This supports the feasibility of NMES integration into both clinical and home rehabilitation programs, which could improve accessibility and continuity of care for post-ACL surgery patients.

Long-term effects of NMES, however, remain insufficiently explored. While Toth et al. (2020) showed preservation of muscle fiber size up to 24 weeks post-surgery, most studies did not conduct extended follow-up. Understanding whether NMES-induced strength gains translate into sustained functional improvements and reduced risk of re-injury over time is essential for justifying widespread clinical adoption.

The present review reinforces NMES's potential to mitigate arthrogenic muscle inhibition, a key barrier to effective ACL rehabilitation. By eliciting muscle contractions independent of voluntary control, NMES may help overcome early neural deficits that delay muscle activation and contribute to prolonged weakness (Labanca et al., 2017). Enhancing neuromuscular control through NMES may also improve proprioceptive function, as suggested by Taradaj et al. (2013), which is vital for joint stability and injury prevention.

Finally, this review highlights a clear need for further high-quality randomized controlled trials with standardized NMES protocols, longer follow-up durations, and broader patient populations. Addressing these gaps will help clarify NMES's precise role and optimize its integration into comprehensive ACL rehabilitation programs. Meanwhile, clinicians should consider NMES as a beneficial supplement, particularly in the early postoperative phase, to accelerate strength recovery and functional outcomes.

CONCLUSION

Neuromuscular electrical stimulation (NMES) is an effective adjunct to conventional rehabilitation following anterior cruciate ligament (ACL) reconstruction, particularly for restoring quadriceps strength and improving functional outcomes. The evidence from multiple randomized controlled trials supports NMES's ability to accelerate muscle recovery, enhance neuromuscular activation, and facilitate earlier return to sport and daily activities. When combined with other therapeutic modalities such as eccentric exercise or blood flow restriction, NMES may provide synergistic benefits that optimize rehabilitation outcomes.

Despite its demonstrated benefits, NMES protocols vary considerably across studies, and long-term data remain limited. Future research should focus on establishing standardized parameters, evaluating sustained effects beyond six months, and including diverse patient populations. Clinicians are encouraged to incorporate NMES into early-phase rehabilitation to counteract arthrogenic muscle inhibition and improve patient adherence, while ongoing investigation will refine its application to maximize recovery after ACL surgery.

Limitations

This review is limited by the heterogeneity of study designs, NMES parameters, and outcome measures, which complicates direct comparison and meta-analytic synthesis. Sample sizes in some included studies were relatively small, and participant populations were predominantly young, male, and athletic, reducing generalizability to other groups. Additionally, the lack of long-term follow-up data restricts understanding of the durability of NMES-induced improvements. Variability in device types and the absence of standardized protocols also pose challenges for clinical implementation and consistency in results.

REFERENCES

1. Currier, D. P., Ray, J. M., Nyland, J., & Rooney, J. G. (1993). Effects of electrical and electromagnetic stimulation after anterior cruciate ligament reconstruction. Journal of Orthopaedic & Sports Physical Therapy, 17(4), 177–182.
2. Feil, S., Newell, J., Minogue, C., & Paessler, H. H. (2011). The effectiveness of supplementing a standard rehabilitation program with superimposed neuromuscular electrical stimulation after anterior cruciate ligament reconstruction: a prospective, randomized, single-blind study. The American journal of sports medicine, 39(6), 1238-1247.
3. Fitzgerald, G. K., Piva, S. R., & Irrgang, J. J. (2003). A modified neuromuscular electrical stimulation protocol for quadriceps strength training following anterior cruciate ligament reconstruction. Journal of Orthopaedic & Sports Physical Therapy, 33(9), 492-501.
4. Hasegawa, S., Kobayashi, M., Arai, R., Tamaki, A., Nakamura, T., & Moritani, T. (2011). Effect of early implementation of electrical muscle stimulation to prevent muscle atrophy and weakness in patients after anterior cruciate ligament reconstruction. Journal of electromyography and kinesiology, 21(4), 622-630.
5. Hauger, A. V., Reiman, M. P., Bjordal, J. M., & Sheets, C. (2018). Neuromuscular electrical stimulation is effective in strengthening the quadriceps muscle after anterior cruciate ligament surgery. Knee Surgery, Sports Traumatology, Arthroscopy.
6. Imoto, A. M., Peccin, S., Almeida, G. J., Saconato, H., & Atallah, Á. N. (2011). Effectiveness of electrical stimulation on rehabilitation after ligament and meniscal injuries: a systematic review. Sao Paulo Medical Journal, 129(6), 414-423.
7. Kim, K. M., Croy, T., Hertel, J., & Saliba, S. (2010). Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes. Journal of Orthopaedic & Sports Physical Therapy, 40(11), 687–695.

8. Kong, D. H., Jung, W. S., Yang, S. J., Kim, J. G., & Park, H. Y. (2022). Effects of neuromuscular electrical stimulation and blood flow restriction in rehabilitation after anterior cruciate ligament reconstruction. International Journal of Environmental Research and Public Health, 19(22), 15041.
9. Labanca, L., Rocchi, J. E., Laudani, L., Guitaldi, R., & Virgulti, A. (2017). Neuromuscular electrical stimulation superimposed on movement early after ACL surgery. Medicine & Science in Sports & Exercise.
10. Larsen, M. (2020). Effectiveness of neuromuscular electrical stimulation on quadriceps strength after ACL reconstruction. Bethel University Theses and Dissertations, 386.
11. Lepley, L. K., Wojtys, E. M., & Palmieri-Smith, R. M. (2015). Combination of eccentric exercise and neuromuscular electrical stimulation to improve quadriceps function post-ACL reconstruction. Physical Therapy in Sport, 16(2), 100–106.
12. Moran, U., Gottlieb, U., Gam, A., & Springer, S. (2019). Functional electrical stimulation following anterior cruciate ligament reconstruction: A randomized controlled pilot study. Journal of NeuroEngineering and Rehabilitation, 16, Article 67.
13. Nussbaum, E. L., Houghton, P., Anthony, J., Rennie, S., Shay, B. L., & Hoens, A. M. (2017). Neuromuscular electrical stimulation for treatment of muscle impairment: critical review and recommendations for clinical practice. Physiotherapy Canada, 69(5), 1-76.
14. Palmieri-Smith, R. M., Thomas, A. C., & Wojtys, E. M. (2008). Maximizing quadriceps strength after ACL reconstruction. Clinics in sports medicine, 27(3), 405-424.
15. Paternostro-Sluga, T., & Fialka, C. (1999). Neuromuscular electrical stimulation after anterior cruciate ligament surgery. Clinical Orthopaedics and Related Research, 368, 123–133.
16. Snyder-Mackler, L., Delitto, A., Bailey, S. L., & Stralka, S. W. (1995). Strength of the quadriceps femoris muscle and functional recovery after reconstruction of the anterior cruciate ligament. A prospective, randomized clinical trial of electrical stimulation. The Journal of bone and joint surgery. American volume, 77(8), 1166-1173.
17. Taradaj, J., Halski, T., & Kucharzewski, M. (2013). The effect of neuromuscular electrical stimulation on quadriceps strength and knee function in professional soccer players: Return to sport after ACL reconstruction. Evidence-Based Complementary and Alternative Medicine, 2013, Article ID 802534.
18. Toth, M. J., Tourville, T. W., & Voigt, T. B. (2020). Utility of neuromuscular electrical stimulation to preserve quadriceps muscle fiber size and contractility after anterior cruciate ligament injuries and reconstruction: A pilot study. American Journal of Sports Medicine, 48(12), 2903–2912.
19. Wright, R. W., Preston, E., & Fleming, B. C. (2008). ACL reconstruction rehabilitation – part II: neuromuscular stimulation, kinetic chain exercises, and accelerated rehab. Thieme Medical Publishers.