Article Classification: Original article

COMPARISON OF EFFECTIVENESS OF THE ADDITION OF NEUROMUSCULAR ELECTRICAL STIMULATION OF QUADRICEPS MUSCLE TO STANDARD REHABILITATION PROTOCOL OF ACL RECONSTRUCTION

Anamika Lohiya[1], Himanshu Kataria[2], Himanshu Gupta[3], Diganta Bohra[4], Vineet Jain[5]

[1]Sports Injury Centre, Safdarjung Hospital, New Delhi, India
[2]Arthroscopy and Sports Medicine, Venkateshwar Hospital, Dwarka, New Delhi, India
[3]Orthopaedics (Sports Medicine), Venkateshwar Hospital, Dwarka, New Delhi, India
[4]Physical Medicine and Rehabilitation Department, Safdarjung Hospital, New Delhi, India
[5]Sports Injury Centre, Safdarjung Hospital, New Delhi, India

OPEN ACCESS

Submitted: 09 October 2024
Accepted: 03 February 2025
Published: 14 July 2025

ORCID
Anamika Lohiya
https://orcid.org/0009-0001-7120-6458

Cite this article as:
Lohiya, A., Kataria, H., Gupta, H., Bohra, D., Jain, V. (2025). Comparison of effectiveness of the addition of neuromuscular electrical stimulation of quadriceps muscle to standard rehabilitation protocol of ACL reconstruction. *Journal of Applied Sports Sciences*, *9*(1), pp. 3 - 11.
DOI: *10.37393/JASS.2025.09.01.1*

ABSTRACT

Background: Weak quadriceps after ACL reconstruction (ACLR) may derail patients' return to sport or regular physical activity levels. Neuromuscular electrical stimulation (NMES) activates muscles in precise sequence and magnitude to directly accomplish functional tasks. This prospective comparative study compared the outcomes of rehabilitation post-ACLR with and without NMES.

Methods: A total of 70 post-ACLR patients were divided into 2 groups. Group 1 received the standard rehabilitation protocol, and Group 2 received additional NMES therapy twice weekly for 6 weeks. Patients were evaluated for Thigh circumference, Quadriceps Strength, and Single and Triple leg hop.

Results: The thigh girth in the NMES groups showed a consistent increase throughout the follow-up period, whereas in the control group, it showed an initial dip and later improved. The difference was significant at 3 and 6 weeks follow-up ($p < .001$). The two groups had no significant difference in Quadriceps strength at 6 months ($p = .545$). At 6 months, the single leg hop, triple leg hop, Lysholm score, IKDC score, and KT readings gave comparable results between the control and NMES groups.

Conclusions: The addition of NMES in post-ACLR rehabilitation better restored the quadriceps muscle mass in the early phase but gave comparable results at 6 months in terms of quadriceps strength and functional scores.

Keywords: *Neuromuscular Electrical Stimulation, ACL Reconstruction, Quadriceps, Strength, Rehabilitation, Muscle Mass*

INTRODUCTION

The knee joint houses the anterior cruciate ligament (ACL), a specialized connective tissue band extending from the femur to the tibia. A torn ACL can lead to complaints of recurrent instability in daily and sporting activities and the subsequent risk of meniscal tear or chondral damage, making an early diagnosis an important factor in successful rehabilitation. (Dhillon, Bali, and Prabhakar, 2012; Duthon et al., 2006). An isolated ligament reconstruction cannot get the athlete back in the game. Along with the ACL, the quadriceps play an essential role in dynamic stability. Post-ACL reconstruction (ACLR), quadriceps weakening is often associated with hampering performance.

(McLean et al., 2004; McLean, Lipfert, and van den Bogert, 2004), potentials for reinjury (Boden et al., 2010; McLean et al., 2004), and the Development of osteoarthritis (Shelbourne, Davis, and Klootwyk, 1998). It may be detrimental in delaying return to sport or prior physical activity levels, among other factors. Quadriceps muscle atrophy also contributes to persistent muscle weakness (Olsen et al., 2004; Souryal and Freeman, 1993) due to alterations in muscle architecture (Hewett et al., 2005; Micheo, Hernández, and Seda, 2010), and selective fiber atrophy (Makhmalbaf et al., 2013; Spindler and Wright, 2008; Vaudreuil et al., 2019). Focussed eccentric training programs result in a more significant increase in quadriceps femoris and gluteus maximus muscle volume and function compared to a standard rehabilitation protocol (Scholten et al., 2003). Proprioceptive recovery plays an important role; therefore, perturbation training is used in the conservative and surgical treatment of ACL injuries. A significant correlation exists between quadriceps strength indices and functional stability both before and after surgery (Aglietti et al., 2004).

Sanders et al. (Sanders et al., 2016) suggest restoring symmetric quadriceps strength at Return to Sports (RTS) after ACLR, which may promote a higher longitudinal knee function. Neuromuscular electrical stimulation (NMES) activates muscles in precise sequence and magnitude to accomplish functional tasks directly. It may help by being an adjunct therapy to help enhance a particular function. Apart from the functional effect, it has a therapeutic effect of motor relearning, which can be defined as the "recovery of previously learned skills that may have been lost due to damage" (Hagmeijer et al., 2019). NMES is delivered as a waveform of electrical current characterized by stimulus frequency, amplitude, and pulse width.

The minimum stimulus frequency that generates a fused muscle response is around 12.5 Hz. The frequency range for the NMES system is 10-50 Hz. Increasing the stimulus amplitude or pulse duration (typically 200 microseconds) to activate neurons farther from the activating electrode achieves more significant muscle force generation. However, there is conflicting evidence regarding the effectiveness of NMES post-ACLR on quadriceps function. Hence, with this background, this randomized controlled study was planned to compare the outcomes of rehabilitation post-ACLR with or without NMES.

Purpose and objectives of the study

The prospective comparative study was performed to compare the outcomes of rehabilitation post-ACLR with or without NMES.

Hypothesis

NMES in post-ACLR improves quadriceps muscle recovery outcomes.

METHODOLOGY

The study included patients who underwent arthroscopic ACLR for symptomatic grade III post-traumatic ACL injury with instability. They further underwent post-ACLR rehabilitation. Only patients fulfilling the inclusion and exclusion criteria were enrolled for the study after obtaining informed consent. The Inclusion criteria were a) consecutive patients undergoing single bundle ACL reconstruction with or without meniscectomy and b) patients between 18-45 years of age.

The following patients were excluded:

a) patients with additional knee ligament injuries,
b) patients with generalized inflammatory arthritis, including rheumatoid arthritis,
c) patients with revision ACL graft reconstruction,
d) patients with any neuromuscular disorder or disease,

e) patient with bony deformity of lower limbs, and/or
f) patients with additional injury to any other joint of the same limb or any injury to the contralateral lower limb, which makes rehabilitation difficult.

The sample size calculated for the outcome variable was 70 (35 in each group).

The sample size was calculated by taking the increase in the strength of quadriceps in NMES and control as the outcome variable. Using the minimum required sample size with 80% power of study and 5% level of significance based on previous studies, patients in each study group were kept at 35.

Data were recorded on a proforma entered in Microsoft® Excel workbook 2019 and exported into SPSS v21.0 (IBM, USA) for statistical analysis. Categorical variables were expressed as frequency and percentages, and the chi-square test was used. Quantitative variables were expressed as mean ± SD or median (inter-quartile range)—quantitative variables between two different intervals. P value < .05 was considered statistically significant.

The patients were allotted into two groups using sealed envelopes: A and B. In group A, Patients were provided standard ACLR rehabilitation after their surgery, including exercise and cold therapy. In group B, Patients were given NMES sessions and the standard ACLR rehabilitation after surgery.

Group A received a standard physiotherapy protocol and rehabilitation routinely followed in the Centre post-ACLR. In Group B, in addition to routine post-ACLR rehabilitation, patients were given two sessions of NMES per week for the first six weeks, starting from day two. The subject was positioned supine with the knee in full extension. Self-adhesive electrodes were placed on the vastus lateralis proximally and the vastus medialis distally. A medium-frequency EMS (ITO EU-940) was used to provide electrical stimulation. The stimulus characteristics used during the treatment were similar to those described by Shaerf et al. (Shaerf et al., 2014). They included a 2500-Hz alternating current, time modulated to deliver 75 Hz, with a 2-second ramp-up and ramp-down time, a 10-second stimulation period at the maximum amplitude, followed by a 50-second rest period. The amplitude is set at an intensity high enough to produce a full, sustained, tetanic contraction of the quadriceps (no fasciculations observed visually) with visual and or palpable evidence of superior glide of the patella. To achieve this, stimulus intensity was increased to maximum subject tolerance. Ten contractions were performed during a treatment session, with an approximate time of 15 minutes. A total of 12 sessions were given. The follow-up assessment was done pre-operatively, 3 weeks, 6 weeks, 12 weeks, and 24 weeks postoperatively by a team of consultants and resident doctors working in the team, and the reviewer assessing the patient at follow-up was blinded to the treatment arm.

The following parameters were compared between the two groups:

1. The objective quadriceps strength at baseline and 6 months of follow-up.
2. The functional outcomes 'Single leg hop test', 'Triple leg hop test', Lysholm's functional score, and International Knee Documentation Committee (IKDC) score at 6 months of follow-up.
3. Thigh girth was compared between the two groups at baseline, 3 weeks, 6 weeks, 3 months, and 6 months.

RESULTS

The study had 70 patients, and all patients completed the 6-month follow-up. The baseline characteristics of patients in both groups are given in Table 1.

Table 1. *Comparison of Baseline Characteristics of Patients between NMES and control group.*

Baseline Characteristics	NMES	Control	*P* value
Gender			
Male	25	22	.445
Female	10	13	
BMI	24.64±3.34 kg/m^2	23.73±2.90 kg/m^2	.227
Beighton Score	1.57±1.44	1.94±1.67	.324
Duration of injury	6.65±3.64 months	6.48±3.82 months	.849
Level of play			
Professional	18	20	.631
Recreational	17	15	

The mean age of the NMES and Control groups were 24.94 years and 26.26 years, respectively. There were 25 males (71%) in the NMES group and 22 males (62%) in the control group. There were ten females (28%) in the NMES group and 13 females (37%) in the control group. The mean BMI of the NMES and control groups were 24.65 kg/m^2 and 23.73kg/m^2, respectively. There was no significant difference in the age and BMI of the NMES and control group patients ($p > .05$).

Thigh girth of the patients in the control group showed a dip initially and later improved. The thigh girth in the NMES groups showed a consistent increase throughout the follow-up period ($p < .001$) (Figure 1). While assessing differences at individual points of time between groups with the baseline values, the thigh girth of the patients increased significantly in the NMES groups than the control at 3 weeks and 6 weeks ($p < .001$), while no significant difference was found at 12 and 24 weeks ($p > .05$).

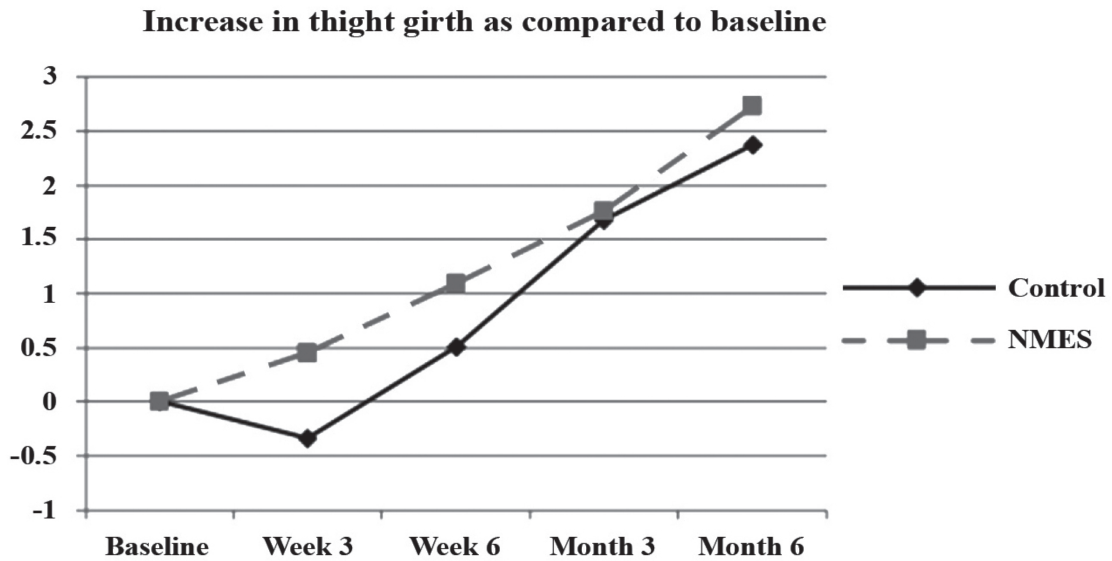

Figure 1. *Increase in thigh girth as compared to baseline.*

There was no significant difference in quadriceps strength deficit between the groups as well as over the period within each group ($p < .05$). There was no significant difference in KT scores over the period between the NMES and Control groups ($p = .157$). In both groups, the Lysholm and IKDC scores showed significant improvement at 6 months compared to baseline. However, there was no significant difference in Lysholm and IKDC between the NMES and control groups (p = .111 and p = .132). (Table 2)

Table 2. *Comparison of Quadriceps strength, Lysholms, and IKDC between NMES and Control group.*

	Control	NMES	*P* value
Quadriceps Strength Index			
Pre	60.11±11.64	61.23±11.56	.687
6 months	95.71±17.14	97.31±10.78	.641
Quadriceps Strength OPP			
Pre	86.43±16.47	80.97±10.89	.106
6 months	116.57±19	119.54±17.13	.494
Lysholms			
Pre	63.80±7.71	61.06±10.21	.209
6 months	87.29±13.94	89.83±3.52	.299
IKDC			
Pre	47.01±8.34	43.46±9.74	.106
6 months	77.83±3.36	77.91±4.95	.937

The mean single-leg HOP of the index leg of the NMES and Control groups were 89.51 and 90.03 years, respectively. The mean single-leg HOP of the opposite leg of the NMES and control groups were 111.40 and 108.34, respectively. No significant difference was found between the NMES and control groups (p > .05).

The mean triple leg hops of the index leg of the NMES and Control groups were 283.03 and 285.29 years, respectively. The mean triple leg HOP of the opposite leg of the NMES and control groups were 304.71 and 304.17, respectively. No significant difference was found between the NMES and control groups (p > .05). (Table 3)

Table 3. *Comparison of leg hop between NMES and control group.*

	Control	NMES	*P* value
Single Leg Hop			
Index Limb	90.03±12.58	89.51±8.16	.838
Opposite	108.34±13.09	111.40±8.72	.253
Triple Leg Hop			
Index Limb	285.29±20.27	283.03±14.44	.592
Opposite	304.17±18.13	304.71±11.66	.882

DISCUSSION

The most important finding of this study was that the thigh circumference of patients who received additional NMES postoperatively showed a significant increase at 3 and 6 weeks postoperatively compared to those who underwent standard rehabilitation protocol. There was a consistent increase in the quadriceps girth in the NMES group from baseline till the 24th week, whereas the control group showed a decrease in the quadriceps girth at the 3rd and 6th week and an increase thereafter. This consistent increase in the quadriceps girth during the initial rehabilitation phase in the NMES group corroborates with similar findings found in the literature (Ediz et al., 2012; Fitzgerald, Piva, and Irrgang, 2003; Labanca et al., 2018). This result demonstrates a positive correlation between using NMES immediately in the postoperative period. It further augments the activation of atrophied quadriceps while counterbalancing quadriceps inhibition caused by pain and effusion in the postoperative period.

Quadriceps strength was assessed between the two groups at baseline and 6 months post-surgery. There was no significant difference in quadriceps strength deficit in the index limb between the NMES and control groups (p = .545) at 6 months postoperatively.

Most studies on this topic have shown that the benefits of NMES are in the early recovery phase. We assessed the quadriceps power at 6 months post-surgery. At 6 months, there was no difference in the quadriceps strength between the two groups. In comparison, studies with further shorter intervals between NMES and strength testing post-surgery found a significant gain in quadriceps strength (Stevens-Lapsley et al., 2012; Labanca et al., 2018). The studies showing better quadriceps strength with NMES at shorter follow-ups of 3 months could be attributed to other confounding factors like different parameters of NMES (frequency, timing, duration) used, prior quadriceps strength, and athlete characteristics (Conley et al., 2021). There is a paucity of literature assessing quadriceps strength at 6 months or more in the postoperative period, and there is a further need for studies assessing the long-term effects of NMES on quadriceps strength.

Subjective assessment scoring was done at baseline and 6 months post-operative for both groups. There was no significant difference in the Lysholm score between the NMES and control groups (p = .111) similar to Kawakami et al. 2001 and Moran et al. 2019. No significant difference in the IKDC score was found between the NMES and control groups (p = .132) (Toth et al., 2020).

There was no significant difference in KT scores between the NMES and control groups (p = 0.157) in this study, which was similar to the previous study in the literature (Ross, 2000). On the other hand, some studies showed significant differences in self-reported outcome evaluation at their 3 months follow (Ediz et al., 2012; Fitzgerald, Piva, and Irrgang, 2003). In this study, functional evaluations were done at 6 months, not 3 months.

Thus, the application of NMES in the post-operative rehabilitation of athletes can hasten recovery in the early phase and positively affect the atrophy of quadriceps muscle. However, no positive effect could be found beyond this early phase. There was no significant difference in functional scores between the NMES and control groups. There was no significant difference in hop tests between the NMES and control groups over the period. Thus, adding NMES in post-ACLR rehabilitation restored the quadriceps muscle mass earlier but gave comparable results at 6 months in terms of quadriceps strength and functional outcome.

Limitations

One of the limitations of this study is the short follow-up, considering that ACL reconstruction takes a minimum of 9-12 months for complete recovery. However, most studies on this topic have shown that the benefits of NMES are in the early recovery phase (Ediz et al., 2012; Kim et al., 2010). Further, many studies assessing NMES in ACL rehabilitation had a short follow-up of 6 months or less after surgery (Ediz et al., 2012; Toth et al., 2020).

Another limitation is that after baseline, we assessed only the thigh girth before 6 months follow-up, and the quadriceps power was assessed only at 6 months post-surgery. At 6 months, the two groups had no difference in the quadriceps strength. Studies with further shorter intervals between surgery and strength testing post-surgery found a significant gain in quadriceps strength (Stevens-Lapsley et al., 2012). More frequent muscle strength testing could be planned in future studies at 6 weeks and 3 months post-surgery. However, the downside of earlier testing of quadriceps strength is that at such an early period of follow-up, many a time, the patient is unable to put in full efforts in muscle testing due to residual pain, leading to erroneous results.

CONCLUSION

To conclude, the application of NMES in the post-operative rehabilitation of athletes after ACL reconstruction can hasten recovery in the early phase and positively affect the atrophy of quadriceps muscle. However, the quadriceps strength and functional scores were found to be similar beyond 6 weeks with and without NMES.

REFERENCES

Aglietti, P., Giron, F., Buzzi, R., Biddau, F., & Sasso, F. (2004). Anterior cruciate ligament reconstruction: Bone-patellar tendon bone compared with double semitendinosus and gracilis tendon grafts. A prospective, randomized clinical trial. *The Journal of Bone and Joint Surgery (American). Volume, 86*(10), 2143–2155.

Boden, B. P., Sheehan, F. T., Torg, J. S., & Hewett, T. E. (2010). Noncontact anterior cruciate ligament injuries: Mechanisms and risk factors. *The Journal of the American Academy of Orthopaedic Surgeons, 18*(9), 520–527. https://doi.org/10.5435/00124635-201009000-00003

Conley, C. E. W., Mattacola, C. G., Jochimsen, K. N., Dressler, E. V., Lattermann, C., & Howard, J. S. (2021). A comparison of neuromuscular electrical stimulation parameters for postoperative quadriceps strength in patients after knee surgery: A systematic review. *Sports Health, 13*(2), 116–127. https://doi.org/10.1177/1941738120964817

Dhillon, M. S., Bali, K., & Prabhakar, S. (2012). Differences among mechanoreceptors in healthy and injured anterior cruciate ligaments and their clinical importance. *Muscles, Ligaments and Tendons Journal, 2*(1), 38–43.

Duthon, V. B., Barea, C., Abrassart, S., Fasel, J. H., Fritschy, D., & Ménétrey, J. (2006). Anatomy of the anterior cruciate ligament. Knee Surgery, *Sports Traumatology, Arthroscopy, 14*(3), 204–213. https://doi.org/10.1007/s00167-005-0679-9

Ediz, L., Ceylan, M. F., Turktas, U., Yanmis, I., & Hiz, O. (2012). A randomized controlled trial of electrostimulation effects on effusion, swelling and pain recovery after anterior cruciate ligament reconstruction: A pilot study. *Clinical Rehabilitation, 26*(5), 413–422. https://doi.org/10.1177/0269215511421029

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. *The Journal of Orthopaedic and Sports Physical Therapy, 33*(9), 492–501. https://doi.org/10.2519/jospt.2003.33.9.492

Hagmeijer, M. H., Hevesi, M., Desai, V. S., Sanders, T. L., Camp, C. L., Hewett, T. E., Stuart, M. J., Saris, D. B. F., & Krych, A. J. (2019). Secondary meniscal tears in patients with anterior cruciate ligament injury: Relationship among operative management, osteoarthritis, and arthroplasty at 18-year mean follow-up. *The American Journal of Sports Medicine, 47*(7), 1583–1590. https://doi.org/10.1177/0363546519844481

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G., van den Bogert, A. J., Paterno, M. V., & Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. *The American Journal of Sports Medicine, 33*(4), 492–501. https://doi.org/10.1177/0363546504269591

Kawakami, Y., Akima, H., Kubo, K., Muraoka, Y., Hasegawa, H., Kouzaki, M., Imai, M., et al. (2001). Changes in muscle size, architecture, and neural activation after 20 days of bed rest with and without resistance exercise. *European Journal of Applied Physiology, 84*(1–2), 7–12. https://doi.org/10.1007/s004210000330

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: A systematic review. *The Journal of Orthopaedic and Sports Physical Therapy, 40*(7), 383–391. https://doi.org/10.2519/jospt.2010.3184

Labanca, L., Rocchi, J. E., Laudani, L., Guitaldi, R., Virgulti, A., Mariani, P. P., & Macaluso, A. (2018). Neuromuscular electrical stimulation superimposed on movement early after ACL surgery. *Medicine and Science in Sports and Exercise, 50*(3), 407–416. https://doi.org/10.1249/MSS.0000000000001462

Makhmalbaf, H., Moradi, A., Ganji, S., & Omidi-Kashani, F. (2013). Accuracy of Lachman and anterior drawer tests for anterior cruciate ligament injuries. *Archives of Bone and Joint Surgery, 1*(2), 94–97.

McLean, S. G., Huang, X., Su, A., & van den Bogert, A. J. (2004). Sagittal plane biomechanics cannot injure the ACL during sidestep cutting. *Clinical Biomechanics, 19*(8), 828–838. https://doi.org/10.1016/j.clinbiomech.2004.06.006

McLean, S. G., Lipfert, S. W., & van den Bogert, A. J. (2004). Effect of gender and defensive opponent on the biomechanics of sidestep cutting. *Medicine and Science in Sports and Exercise, 36*(6), 1008–1016. https://doi.org/10.1249/01.mss.0000128180.51443.83

Micheo, W., Hernández, L., & Seda, C. (2010). Evaluation, management, rehabilitation, and prevention of anterior cruciate ligament injury: Current concepts. *PM&R, 2*(10), 935–944. https://doi.org/10.1016/j.pmrj.2010.06.014

Olsen, O. E., Myklebust, G., Engebretsen, L., & Bahr, R. (2004). Injury mechanisms for anterior cruciate ligament injuries in team handball: A systematic video analysis. *The American Journal of Sports Medicine, 32*(4), 1002–1012. https://doi.org/10.1177/0363546503261724

Ross, M. (2000). The effect of neuromuscular electrical stimulation during closed kinetic chain exercise on lower extremity performance following anterior cruciate ligament reconstruction. *Sports Medicine, Training and Rehabilitation, 9*(4), 239–251. https://doi.org/10.1080/15438620009512559

Sanders, T. L., Kremers, H. M., Bryan, A. J., Fruth, K. M., Larson, D. R., Pareek, A., Levy, B. A., et al. (2016). Is anterior cruciate ligament reconstruction effective in preventing secondary meniscal tears and osteoarthritis? *The American Journal of Sports Medicine, 44*(7), 1699–1707. https://doi.org/10.1177/0363546516634325

Scholten, R. J. P. M., Opstelten, W., van der Plas, C. G., Bijl, D., Deville, W. L. J. M., & Bouter, L. M. (2003). Accuracy of physical diagnostic tests for assessing ruptures of the anterior cruciate ligament: A meta-analysis. *The Journal of Family Practice, 52*(9), 689–694.

Shaerf, D. A., Pastides, P. S., Sarraf, K. M., & Willis-Owen, C. A. (2014). Anterior cruciate ligament reconstruction best practice: A review of graft choice. *World Journal of Orthopedics, 5*(1), 23–29. https://doi.org/10.5312/wjo.v5.i1.23

Shelbourne, K. D., Davis, T. J., & Klootwyk, T. E. (1998). The relationship between intercondylar notch width of the femur and the incidence of anterior cruciate ligament tears: A prospective study. *The American Journal of Sports Medicine, 26*(3), 402–408. https://doi.org/10.1177/03635465980260031001

Souryal, T. O., & Freeman, T. R. (1993). Intercondylar notch size and anterior cruciate ligament injuries in athletes: A prospective study. *The American Journal of Sports Medicine, 21*(4), 535–539. https://doi.org/10.1177/036354659302100410

Spindler, K. P., & Wright, R. W. (2008). Clinical practice: Anterior cruciate ligament tear. *The New England Journal of Medicine, 359*(20), 2135–2142. https://doi.org/10.1056/NEJMcp0804745

Stevens-Lapsley, J. E., Balter, J. E., Wolfe, P., Eckhoff, D. G., Schwartz, R. S., Schenkman, M., & Kohrt, W. M. (2012). Relationship between intensity of quadriceps muscle neuromuscular electrical stimulation and strength recovery after total knee arthroplasty. *Physical Therapy, 92*(9), 1187–1196. https://doi.org/10.2522/ptj.20110479

Toth, M. J., Voigt, T. B., Tourville, T. W., Prior, S. M., Guigni, B. A., Schlosberg, A. V., Smith, I. B., et al. (2020). Effect of neuromuscular electrical stimulation on skeletal muscle size and function in patients with breast cancer receiving chemotherapy. *Journal of Applied Physiology, 128*(6), 1654–1665. https://doi.org/10.1152/japplphysiol.00203.2020

Vaudreuil, N. J., Rothrauff, B. B., de Sa, D., & Musahl, V. (2019). The pivot shift: Current experimental methodology and clinical utility for anterior cruciate ligament rupture and associated injury. *Current Reviews in Musculoskeletal Medicine, 12*(1), 41–49. https://doi.org/10.1007/s12178-019-09529-7

Corresponding author:

Anamika Lohiya
Vardhman Mahavir Medical College and
Safdarjung Hospital - Sports Medicine
New Delhi, India
E-mail: anamikalohiya92@gmail.com