Does NMES speed up recovery after Orthopedic Knee surgery?

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Introduction

This report is an update regarding the clinical evaluation for the medical claim that the RSQ[1] offers faster rehabilitation after knee surgery.

Orthopedic Knee surgeries are a frequently seen intervention in which the physiotherapeutic rehabilitation has a crucial role in final outcomes such as strength, function and decreasing the probability of new injuries/complaints. In the case of, for example, an Anterior Cruciate Ligament (ACL) reconstruction, physiotherapeutic rehabilitation should delay and/or prevent the onset of Osteoarthrosis in the knee (Królikowska, Czamara, Szuba & Reichert 2018).

The two main categories of interventions encountered in this review are the Total Knee Arthroplasty (TKA) operation and the ACL reconstruction. The ACL is the ligament in the knee that is injured the most (Hauger Reiman, Bjordal, Sheets, Ledbetter & Goode 2018). The estimated incidence of ACL rupture in Holland in sportspeople older than 15 was 1/556 per year in 2009. (https://www.ntvg.nl/artikelen/toename-operatieve-behandeling-bij-voorste-kruisbandletsels).

In 2005 14.565 TKA surgeries were performed. Prognoses in 2010, pre COVID, estimated that in 2030 the number of TKA operations would rise by 297% to 57.893 per year. (https://www.ntvg.nl/system/files/publications/a1534.pdf, https://www.ntvg.nl/artikelen/trends-aantallen-knie-en-heupartroplastieken). More up to date numbers, (2010 can be judged as outdated), could not be retrieved and incidence and prevalence numbers may not accurately reflect the current situation due to both the COVID situation which has led to massive delays due to overburdened healthcare combined with the fact that prevalence and incidence numbers are a complex matter to calculate (Spronk, Korevaar, Poos, Davids, Hilderink, Schellevis & Nielen (2019).

ACL injury and the consequent ACL reconstruction procedures are a big concern leading to a threefold increased prevalence of Osteoarthritis in the knee suffering from ACL injury treated with reconstruction, compared with the contralateral healthy knee (Barenius, Ponzer, Shalabi, Bujak, Norlén & Eriksson (2014). Hauger et al. (2018) state that one of the core problems with ACL reconstruction is a reduced ability to contract (the whole) Quadriceps muscle. This Arthrogenic Muscular Inhibition (AMI) can lead to both decreased function and muscle atrophy.

Apart from the development of Osteoarthritis, the surgery for an ACL reconstruction can lead to various complications: reduction of Quadriceps strength, which already in itself relates to decreased quality of life and increased risks of secondary ACL injury (Rodriguez et al. 2020). Seen as these risks are present and they influence quality of life and strength is an influenceable, modifiable factor in the rehabilitation process, it makes sense to design the rehabilitation process in such a way that strength is maximally impacted.

Ideally you would like to counter decreased function and atrophy post-surgery and post injury by training maximally or near maximally, however voluntary (sub)maximal contractions early postoperatively are contraindicated due to the fact that it could lead to (further) injury and due to AMI, neural inhibition occurs limiting neural activation, making it a vicious circle (Lisee, Lepley, Birchmeier, O'Hagan & Kuenze 2019).

According to Yoshida, Ikuno & Shomoto (2017) quadriceps weakness early postoperatively is mainly explained by deficits occurring in voluntary activation, not necessarily atrophy. It occurs due to central nervous inhibition that prevents the full activation of the quadriceps musculature, AMI. Hauger et al. (2018) designed their study to test if they could address this problem of the muscle not fully contracting, early on by using NMES, enabling more of the muscle to contract by bypassing AMI.

The rehabilitation after surgery for a TKA is also focused on regaining strength in the quadriceps as soon as possible. Combined with regaining and improving a helpful gait pattern and following to the end stages of rehabilitation is is focused on return to sports which requires both adequate strength and coordination in the Quadriceps musculature (https://www.kngf.nl/kennisplatform/richtlijnen/artrose-heup-knie). “Persistent quadriceps weakness is clinically important as it may impair dynamic knee stability, physical function, and quality of life, increase the risk of re-injury to the knee joint, and contribute to the development and progression of osteoarthritis (Rice & McNair, 2010).

Being able to provide rehabilitation that addresses the strength of knee flexor and extensor is likely to lead to better quality of life and potentially (partially) address the problem of AMI thereby providing an opportunity for more of the whole muscle to contract, possibly leading to better outcomes (Rodriguez et al. 2020). NMES allows for high intensity resistance training on the quadriceps musculature during the early phases following surgery without it overloading the knee (Labanca et al. 2022).

Bistolfi, Zanovello, Ferracini, Allisiardi, Lioce, Magistroni & Massazza (2018) argue in their review that NMES after TKA, is a valid physiotherapeutic intervention seen as it offers durable neuromuscular training without any risk of injury to either the musculature or the implant.

Method

A search was performed in Pubmed, specifically aimed at updating the previous clinical evaluation with regards to the medical claim that the RSQ[1] leads to faster rehabilitation after orthopedic knee operations. Exclusion criteria were: articles published before 2017, not written in English and articles that did not involve NMES but other similar interventions such as electro acupuncture or Transcutaneous Electrical Nerve Stimulation (TENS). The search string was aimed at including the most frequently encountered orthopedic interventions encountered in the physiotherapy practice: meniscectomy, TK and ACL reconstruction. An overview of the search string has been included in the supplements.

The search string applied was: (("electric stimulation therapy"[MeSH Major Topic] OR "NMES"[Title/Abstract] OR "neuromuscular electrical stimulation"[Title/Abstract] OR "FES"[Title/Abstract]) AND ("meniscectomy"[MeSH Major Topic] OR "arthroplasty, replacement, knee"[MeSH Major Topic] OR "anterior cruciate ligament injuries"[MeSH Major Topic])) AND (2017:2022[pdat]).

That search string led to 52 search results. The abstracts were read to determine whether the article could be in or excluded based on the inclusion criteria, it needed to be specifically about

NMES, not an application of electro acupuncture or TENS for the experimental group. After reading the abstract 21 articles were included and 31 were excluded based on the fact that they did not include NMES interventions. One Khoziainova Kovlen, Ponomarenko, Abuseva,, Adkhamov, Ishchuk &, Tolmachev (2019) was excluded because it was written in Russian.

None of the articles over the last five years were on the subject of NMES and meniscectomy. The 22 included articles focused on the Total Knee operation, including both preoperative and postoperative strategies and articles on NMES and ACL all focusing on the postoperative phase. Three reviews on preoperative NMES interventions for TK, three reviews for postoperative NMES interventions and three reviews on NMES interventions and ACL. The other 13 articles and the results are outlined in the table.

Results

Authors	N	Study Population	NMES Intervention	Control Intervention	Duration in min	NMES intensity	Outcome measure	Results
Hsieh et al. 2020	NMES=90 Combined =90 Treadmill =91 Control =92	TKA 63.4 ± 7.9 yrs; Women: 61.2%	1: patterned NMES 2: patterned NMES plus body weight adjustable treadmill 3: only body weight adjustable treadmill	2-3x/wk, 8-12 wks, Traditional TKA protocol involving recumbent bike	15 - 20	undefined	Function: =	Activity Measure for Post-acute Care (AM-PAC) scores at discharge were similar across groups: range 61.1 to 61.3, P = .99 6MWT not statistically different across groups: range, 382.9- 404.5 m; P = .60
Klika et al. 2022	NMES=44 Control=22	Primary TKA patients	Home based app controlled NMES therapy. From week 1 to 12 postoperative	Standard rehabilitation Care	Average of min 200 min/wk	undefined	Strength: ↑ Function: ↑	NMES show quadriceps strength gains compared to control at 3 ($p = 0.050$) and 6 weeks ($p = 0.015$). TUG significant improvements with NMES at 6 weeks ($p = 0.018$) and 12 weeks ($p = 0.003$).
Labanca et al. 2018	NMES+STS=16 STSTS ONLY:17 NAT:17	ACL reconstruction using ipsilateral autologous bone-patellar tendon-bone graft; 18- 40 years;	NMES applied during Sit to Stand to Sit (STSTS). From day 15 to 60 postoperative	STSTS only, or No Additional Treatment (NAT) to standard rehabilitation	STSTS in 8s, rest for 8 s. 5x/wk, Day 15-20: 3x6 reps, 4s up & 4s down; Day Day 20-30: 3x10, 4 s up & 4 s down; Day 30-45: 3x10, 2 s up & 6 s down; Day 45-60: 3x12, 2 s up & 6 s down;	Increased by each repetition to maximum tolerable; max 120 mA	Strength: ↑ Function: ↑	NMES+STSTS show higher knee extensor strength compared to other groups (STSTS and NAT) at 30° and 90°, at 60 and 180 d (p<0.01). NMES+STSTS show higher knee flexor strength than NAT at 60 d. Effect of both treatment and time (ANOVA) on absolute force of knee extensor muscles of the operated limb at 30° (p<0.001) and 90° (p<0.01). Effect of time (p<0.001) on absolute force of knee flexor muscles NMES+STSTS show higher LSI of knee extensor compared to both other groups at 30° and 90° and 60 & 180 d. Effect of treatment and time on the LSI of knee extensor muscles at 30° (p<0.001) and 90° (p<0.01) LSI knee flexor muscle strength don't show difference between groups at 60 and 180 d. Effect of time (p<0.001). All groups significantly higher LSI at 180 compared to 60 days
Labanca et al. 2022	NMES=17 Control=17	ACL reconstruction using semitendinosus and	STSTS, SQ Squat, step up-step-down (STEP) plus NMES from Day 15 to Day 60, 5x/wk.	Same standardized postoperative rehabilitation protocol was administered	STSTS in 8s, rest for 8 s.	Increased by each repetition to maximum tolerable;	Strength: ↑ Function: ↑	No differences between groups in the regeneration of the tendon or muscle belly volume. NMES group show higher muscle strength at 60 d during the MVIC knee extensor at 30°, at 90 d for all measurements, at 380 d for the MVIC of knee

		gracilis tendon graft Men/Women NMES: 34.6 ± 8.7 yrs; Control: 34.3 ± 9.9 yrs;		supervised by same physical therapists 5 days per week NAT		max 120 mA		extensor muscles at 30° and knee flexor muscles at 90°. NMES group showed a significantly higher symmetry during MVIC than NAT of knee extensor muscles at 30° at 60 d, and of knee flexor muscles at 90 d. At 380 d they showed higher symmetry in all the assessments when compared with NAT participants. The ANOVA showed an effect of time on all data. NMES show higher symmetry than control in at the following moments: after 60 and 90 d in sit-to-stand, after 30, 60, 90 and 380 d in stand-to-sit and for both CMJ ecc and con after 380 days.
Moran et al. 2019	FES=10 NMES=13	ACL reconstruction using a graft from the patellar, semitendinosus, gracilis; 18- 40 yrs;	FES 3 d/wk for 10 min while walking, duty cycle was 10 s stimulation with 10 s pause + standard rehab program. FES is Functionally applied in excercises as opposed to NMES applied without exercises.	NMES 3 d/wk for 10 min + standard rehab program	10	Increased by each session to maximum tolerable; max 100 mA	Strength: ↑ Function: ↑	NMES & FES both reached pre-ACLR gait speed and symmetry after 4 weeks, no difference Quadriceps peak strength at 4 weeks of FES was higher (p=0.02) than NMES, 82% of their pre-quadriceps strength in comparison to NMES 47% FES had significantly better Inter limb symmetry strength after 4 week (p<0.01)
Pal et al. 2017	NMES: undefined Control: undefined	TKA	Preoperative home-based NMES	No preoperative Care before TKA	undefined	undefined	Function: ↑	A $3,274 reduction in episode payments for NMES p<0.001. The probability of readmission 12.7% lower for NMES p=0.609. The probability of utilizing IRF and SNF was 56.7% p=0.061 and 46.4% p=<0.001 lower for NMES.
Şavkin et al. 2021	NMES=20 Control=20	unilateral TKA due to primary osteoarthritis, age 50-75,	5/day for 20 min (home-use); 6 weeks before surgery	6-week waiting list, without any preoperative intervention.	20	Maximum tolerable	Function: ↑/=	NMES show significant beneficial effect on function pre-operatively and a trend for strength. No significant differences between groups post-operatively.
Toth et al. 2020	NMES=11 Sham NMES=9	ACL, 18–50 years; BMI <35 kg/m2	NMES within 3 wks of injury and continued until 3 wks post-surgery. Patients performed NMES at home 5 d/wk, 60 min/day. symmetrical, biphasic pulses (400 μs at 50 Hz), with a duty cycle of 25% (10 seconds on, 30 seconds off)	sham NMES at home 5 d/wk, 60 min/day to remove placebo bias, and were told that the device administered imperceptible,	50	undefined	Strength:↑	early NMES following injury and surgery beneficially modifies adaptations in both muscle size and contractility at the cellular (ie, muscle fiber) level after 3 weeks: NMES reduced muscle fiber atrophy (P<0.01) through effects on fast-twitch, myosin heavy chain (MHC) II fibers (P<0.01 to P<0.001). NMES preserved contractility in slow-twitch, MHC I fibers (P<0.01 to P<0.001), increasing maximal contractile velocity (P<0.01) and preserving power output (P<0.01), but not in MHC II fibers.

				NMES for pain mitigation				No whole muscle strength differences 6 months post operative
Tsukada et al. 2018	NMES=26 Control=27	TKA Women:100% Age NMES: 72.8 ± 8.2 Age control: 74.1 ± 8.6	Standardized protocol from control group AND 3 day/week a 10 sets of 10 reciprocal 3-second knee flexion and extension contractions. sets separated by 1 min rest,	12 weeks standardized rehabilitation, 40 min/day, 5 day/week	19	Exercise intensities adjusted to 80% of the maximum tolerable intensity	Strength ↑ Function ↑	At 6 wks after TKA the KES of the operated side in control group decreased ($p<0.01$), while there was no change in NMES group. Both groups increased ($p<0.05$) on the non-operated side from 0 to 12 wks. Both groups show an increase ($p<0.01$) at 12 weeks on KFS of the operated side, but the increase was higher at the NMES group. NMES group increased at 6 and 12 weeks on KFS in the non operated side, while the control group show no difference. Results for CIR on operated and non-operated side were the same for both groups. No change on operated side and decrease at 6 and 12 weeks of the non operated side (control <0.05, NMES <0.01) Funct. tests 10MW and TUG show same results: a decrease after 12 wks for both groups, but already a decrease after 6 wks for the NMES group. In the 10MW there was a difference (0.01) between groups at 6 weeks in favor of NMES group At SCT the NMES group also decreased (<0.01) more than control. On pain and QoL there was already a decrease at 6 wks in the NMES group and only after 12 wks in control group.
Xing et al. 2021	NMES=52 Control=52	TKA Men/Women 63.78 ± 8.41 yrs, BMI: 26.63 ± 3.54.	NMES start at day 4 post-surgery. 15 mn/day, each day, achieving maximum knee extension Synchronous output of triangle wave, 100 Hz, pulswidth of 0.2 ms; the modulation wave was a square wave, the on-off ratio was 6 sec/6 sec. Combined with regular training protocol.	TENS combined with regular training protocol	15	suitable to induce the maximal contraction without pain.	Function: ↑	More extension 1.93° ± 3.47° versus control 6.26° ± 4.28° ($P < 0.01$). NMES group score higher ($p<0.05$) at the KOOS questionnaire at discharge, but also after follow-up.

Yoshida et al. 2017	mNMES =22 sNMES=22 Control=22	55 - 85 yrs, undergoing a primary unilateral TKA for end-stage knee OA	Standard rehabilitation plus sNMES: 45 min, 5 d/wk; 2 wks, or mNMES: 30 min, 5 d/wk; 2 wks	standard rehabilitation care after TKA	45	sNMES: 10-15 mA no visible contraction mNMES:15-38 mA visible contraction	Strength: ↑ Function: ↑	Statistically significant three-group differences in MVIC (F = 5.924, P = 0.004) and 2MWT (F =4.202, P =0.019) post-intervention MVIC sNMES (P = 0.028; 95% confidence interval (CI), of difference, 0.01 to 0.09) and mNMES (P = 0.001; 95% CI of difference, 0.03 to 0.11) were significantly better post-intervention compared to Control. Effect size was medium (0.71) for MVIC between sNMES group and Control . Effect size was large (1.15) for MVIC between mNMES and Control No statistically significant differences between sNMES group and mNMES group in MVIC post-intervention (P = 0.38; 95% CI of 207 difference -0.22 to 0.57). effect size also small (0.30) between sNMES and Control

Table 1: Results of included literature

Terms: yrs: years, W: women, M:men, 6MWT: 6 minute walk test, PENS: patterned Electical neurostimulation, SCT: Stair Climbing Test, STS: Sit to stand exercise STSTS: Sit To Stand To Sit exercise, NAT: No additional Treatment, SQ: Squat, TUG: Timed up and Go, SNF: Skilled Nursing Facility, IRF: Inpatient Rehab Facility , VAS: Visual Analogue Scale, sNMES: sensory Neuro Muscular Electrical Stimulation, mNMES: Muscular Neuro Muscular Electrical Stimulation. CIR: Bilateral circumference 10 cm above patellar superior border , MVIC: maximum voluntary isometric contraction, KES: Knee Extensor Strength, KFS: Knee Flexor Strength

The results are broadly similar for both TKA (7 studies) and ACL (4 studies) interventions. When looking at strength and function, in the short term there is actually always a significant improvement after the application of NMES. In the long term, the effect of applying NMES seems to differ a bit between intervention. After ACL surgery the difference in strength gain after NMES seems to last longer, while after TKA surgery especially on function there are more positive results.

TKA

When we take a closer look at the results after TKA surgery. Four of the seven studies measured strength in their studies. We see a significant effect on strength due to NMES as in the first weeks (2-6) in the studies of Klika et al (2022), Tsukada et al (2018) and Yoshida et al (2017). In the study of Tsukada et al (2018), there was still a significant increase in strength after 12 weeks, but in the study of Klika et al (2022), the significant difference measured at 3 and 6 weeks wasn't present after 12 weeks and the study of Yoshida has only a measurement after 2 weeks. Although Savkin et al (2021) found a positive trend, it was the only study that didn't show a significant increase in strength on the short term after using NMEs.

All seven studies investigating results after TKA, did also measure some functional results. Hsieh et al (2020) was the only study that didn't find a significant improvement on functional test after the application of NMES during the rehabilitation. Xing et al (2021) and Yoshida et al (2017) found already positive results on functional tests and/or questionnaires after 2 weeks. Studies from Klika et al (2022), Savkin et al (2021) and Tsukada et al (2016) found (the first) positive results on function after six weeks. Yoshida et al (2017) measured only after two weeks, but the follow-up measurement of Xing et al (2021) was after 4-16 months and still results in better results for then NMES group.

Pal et al. (2017) focused on costs and readmission rates after TKA operations (reflecting functional outcomes) with the use of NMES and they concluded that NMES led to significantly lower costs $p<0.001$ and that the probability of readmission with NMES was 12.7% lower $p=0.609$ non significant.

ACL

The four studies on ACL and NMES show similar results to the TKA results: strength gains postoperatively. All four studies focused on increase in strength after surgery and show a persuasive result in strength gain after application of NMES for all four studies. Although these strength gains after TKA were mainly on the short term, after ACL the difference seems to maintain for a longer period. For example in the study of Labanca et al (2022) there is still a benefit for the NMEs group after 380 days.

The studies of Labanca et al (2018), Labanca et al (2022) and Moran et al (2019) measured also the limb symmetry as an extra 'functional' parameter. In all these three studies the NMES group scores better on symmetry on different time points.

Discussion

The positive results of NMES on strength and function in the rehabilitation after ACL or TKA in this review corresponds with existing literature from for example Glattke et al. (2022), Sonnery-Cottet (2019) and Hauger et al. (2018) on ACL and Labanca et al (2021), Yue et al (2018) and Bistolfi et al (2018) on TKA.

Large Heterogeneity which is a result of the nature of NMES, is a challenge
The major drawback in researching NMES as an intervention is that different studies follow different protocols. These differences occur at many levels. When NMES is commenced postoperatively, the frequency, how often it is applied per week, how long it is applied and at what intensity and which duration. In the practical sense, to be able to offer guidelines on offering NMES after TKA and/or ACL surgery the specific settings, frequency and timing need to be clarified to offer the best results.

These heterogeneity is present in among the included studies in this review as well. According to Hsieh et al. (2020) commencing the NMES at a relatively late point after surgery, 15-16 days, could be the reason for a hindered increase in strength and functional recovery in the short term. In the study of Moran et al (2019) the control group received NMES training, while the experimental group, received NMES combined with functional movements which seems to result in even better results than NMES alone. These results are emphasized by the study of Labanca et al (2018) which also shows bigger results when NMES is combined with functional movements

Settings matter, higher intensity seems to lead to higher strength gains
An important parameter which can cause the above mentioned heterogeneity is the intensity of the applied NMES. Even when this is stated as maximal tolerable, this is depending on how the patient it experiences and therefore highly subjective. Nevertheless, the fact that settings matter is shown by the study results of Yoshida where the mNMES achieve better results compared to the sNMES.

For example the study of Savkin et al (2021) show limited results, because there was no significant difference on strength (only on function) pre-operatively and post-operation there was no difference at all. However, in this study they applied a home-(and therefore self-)use method of NMES. Research done by Kim, Croy, Hertel & Saliba (2010) indicated that battery operated NMES stimulators and self-use are less likely to be effective in the treatment of postoperative quadriceps weakness than NMES stimulators that are able to generate higher levels of electrical stimulation and under guidance of a therapist.

Yue et al. (2018) in their review over 8 NMES studies saw strength gains in the quadriceps and were able to offer some insight on ideal settings and timing. According to the included studies they suggest once or twice a week, for 4-6 weeks at an intensity of 100-120 mA and frequency of 30-100 Hz.

Drop out due to increased intensity leading to pain and discomfort
The fact that intensity may lead to more effective contractions leads to an interesting juxtaposition because a higher intensity leads to more discomfort. NMES can improve voluntary

activation thereby engaging more of the muscle, improve muscle strength, and functional recovery but it needs to be a tolerable experience to patients. In the study of Yoshida et al (2017) multiple participants from the mNMES group stopped because of the discomfort.

Conclusion

The application of NMES after a ACL or TKA surgery is effective in improving strength and function. Although there is heterogeneity in applications, it seems that there is always a positive result. It seems that a higher intensity of NMES and combination with functional movements will cause better results. However, more research is necessary to determine the best possible application.

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