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# High frequency transcutaneous electrical stimulation in the immediate postoperative period of anterior cruciate ligament reconstruction: a randomized clinical trial

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## ABSTRACT

**Introduction:** The anterior cruciate ligament (ACL) is an important structure for knee stability. Transcutaneous electrical nerve stimulation (TENS) is an electrical current applied for significant pain relief. **Objective:** To evaluate the effects of high-frequency TENS on the immediate postoperative period of ACL reconstruction. **Methods:** 46 patients in the postoperative period of ACL reconstruction were randomly assigned to a control group (CG=23) and a TENS group (TG=23). Knee range of motion (ROM), pain, muscle strength, and drug intake were assessed before surgery and 24 and 48 hours after surgery. The TENS intervention protocol started in the recovery room, shortly after surgery, and was maintained continuously for the first 48 hours after surgery. **Results:** The TENS group (TG) significantly controlled the increased level of postoperative pain ($p<0.05$) and significantly increased flexion ROM ($p<0.05$). When compared to the Control group (CG), the TENS group had a lower intake of ketoprofen (48.27%), diazepam (256.98%), and dipyrone (121.21%), morphine (320.77%), and tramadol (437.46%). **Conclusion:** Continuous high-frequency TENS significantly reduced pain intensity and significantly improved ROM, muscle strength, and drug intake in the postoperative period of ACL reconstruction.

**Keywords:** Transcutaneous Electric Nerve Stimulation; Anterior Cruciate Ligament; Physical Therapy Specialty.

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Declaration of interests: nothing to declare



## INTRODUCTION

The anterior cruciate ligament (ACL) is an important knee stabilizer against tibial translational and rotational forces on the femoral condyle[1]. Injury in this ligament interferes with motor control since there is usually a loss of sensory information, which affects proprioception and postural control[2]. This is a very common sports injury,

affecting approximately 200,000 people in the United States[3]. In the immediate postoperative period, this injury usually includes pain and functional limitation[3].

Transcutaneous electrical nerve stimulation (TENS) is a technique that emits low-voltage electrical impulses through electrodes attached to the surface of the painful area[4,5]. This technique is effective in treating various musculoskeletal disorders, as it influences and modulates nerve conduction[6]. Combined with other physiotherapeutic therapies, TENS may increase activity level, reduce hospital stay, and improve function in the affected region[7]. Studies show it to be an efficient noninvasive technique that is easy to apply, non-toxic, and comfortable for the patient in 95% of cases[2,3,5-7]. In addition, it is a relatively low-cost therapeutic resource[5,7].

Postoperative ACL rehabilitation initially aims to decrease pain and postoperative inflammation, focusing on graft protection, restoration of range of motion, and muscle activation[3,4,8,9]. Using TENS for analgesia is a common approach in several postoperative rehabilitation protocols[3]. Other therapeutic techniques, such as exercise, can use the analgesic effect of TENS to increase function and accelerate recovery[3]. The TENS procedure is comfortable for the patient in 95% of cases and has no side effects[10]. The use of TENS significantly reduces drug intake, causing fewer side effects and reducing drug cost[11,12].

This study evaluates the effects of high-frequency TENS on pain, function, and opioid analgesic intake in the immediate postoperative period of ACL reconstruction.

## METHODS

### Study Design

This is a randomized, blinded clinical trial in 46 male patients who underwent reconstructive surgery (bone-tendon-bone graft) in the period from March to July 2020. The participants and the evaluator were blinded in the study. We assessed outcome measures before surgery and on the 1st and 2nd postoperative days. The study received ethical approval from the Ethics Committee of the Lutheran University of Brazil (2,175,301) and is registered in the Brazilian Registry of Clinical Trials (REBEC) under number RBR-9FZFYS. The protocol was not registered retrospectively.

### Participants

Initially, we referred a total of 47 male participants presenting for ACL reconstruction surgery to physical therapy before surgery. The surgeries were performed by the same surgeon using the bone-tendon-bone technique. A blinded assessor examined these subjects, who were aware of the inclusion and exclusion criteria. Only one patient did not consent to participate in the study. Therefore, 46 consecutive patients were eligible for the study.

### Eligibility criteria

The study included men aged between 18 and 40 years, with ACL rupture, who underwent arthroscopic surgery using the bone-tendon-bone technique. These subjects were attended by the Brazilian Unified Health System (SUS) and admitted to a regional hospital. This hospital is a reference in Orthopedics and Traumatology.

Exclusion criteria were: previous meniscus rupture requiring repair, evidence of degenerative disease on radiological imaging or magnetic resonance imaging (MRI), superficial sensitivity deficit, loss of consciousness and cognitive impairment preventing understanding, stroke sequelae, surgical wound infection, or death during the research period.

### Sample Calculation and Randomization

The administered dose of dipyrone was used as an outcome of the study. To calculate it, we adopted the sample calculation methods suggested by Silva et al.[9] considering the differences between the means and standard deviation of the initial and final dipyrone dose of the participants who underwent TENS. The dipyrone dose of the TENS group on the first postoperative day was 1,000±1,240.35 mg, and the final dipyrone dose was 500.00±1,091.93 mg after treatment. The initial dipyrone dose of the control group was 1,357.14±744.95 mg, and the final dipyrone dose was 857.14±534.52 mg. Using a confidence level of 95%, a study power of 80%, and a sample size ratio of 1:1 (intervention group: control group), we reached the estimated number of 23 subjects for each group, totaling a sample of 46 participants.

An external researcher, not involved in the recruitment and evaluation process, randomly allocated the participants into two groups according to a list of random numbers provided by the EPI-INFO® software. The TENS group (TG) had 23 patients, and the control group (CG) had 23 patients.

### Intervention Protocol

An independent researcher previously trained in the administration of TENS and who had not participated in its evaluation applied the intervention protocol. Both study groups received the standard postoperative rehabilitation protocol for ACL reconstruction. The protocol consisted of continuous passive motion (CPM) exercises and isometric and active exercises for knee flexion and extension according to the patient's tolerance. This standard protocol was performed twice a day, with an approximate duration of 45 minutes each session.

We initiated the TENS intervention protocol in the recovery room of the surgical block, after the consent of the nurse responsible for this ward. We maintained the intervention 24 hours a day and finished it 48 h after surgery, turning the equipment off only for personal hygiene needs. We subjected the patients to continuous high-frequency TENS (conventional mode) using

two channels with 3 X 5 cm self-adhesive electrodes surrounding the surgical wound[10]. For that, we used the following parameters: frequency of 120 Hz, the pulse width of 100 µs, and intensity at the sensory level aiming to promote intense paresthesias without, however, causing discomfort[10].

We instructed the patient's companion to observe and control the position of electrodes during the period of absence of any team member or researcher. If there was any disconnection of the device, he/she should immediately contact the nurse responsible for the shift, who would contact the intervening researcher to adjust the equipment.

As instructed by the Hospital Infection Control Commission (HICC) of Hospital Santa Luzia, we cleaned the electrodes in running water after the end of each application. For greater infection control, we disinfected the device and cables with a cloth moistened with Incidin®.

## Outcomes and evaluation

The primary outcome was medication intake, and secondary outcomes were pain intensity, joint mobility, and isometric muscle strength.

A blinded assessor performed the examinations before surgery and on the 1st and 2nd postoperative days.

## Pain Intensity Assessment

We assessed pain intensity using the visual analog scale (VAS), asking the patient about his/her degree of pain. In this scale, zero means total absence of pain and then corresponds to the maximum tolerable pain[3].

## Drug Intake Assessment

The analgesic routine adopted by the attending physician remained unaltered. The prescription protocol for analgesic drugs and that adopted by the entire medical team of the orthopedics and traumatology department included: ketoprofen (100 mg every 12 hours), sodium dipyrone (2 mg in case of pain or fever), tramadol (100 mg in case of pain), morphine (3 mg every 3 hours in case of pain), and diazepam (10 mg). We recorded daily and total drug intake on a registration form on each of the first three postoperative days for each study group. Afterward, we calculated the total dose administered to each study participant in both groups.

## Joint Mobility Assessment

We assessed the range of motion (ROM) of flexion and extension of the affected knee both passively and actively using a Carci® goniometer[3]. We measured active knee flexion ROM with the patient in the prone position, initially positioning his/her knee at the maximum comfortable extension[3]. We centered the fixed axis of the goniometer on the lateral articular surface, aligning one arm of the goniometer with the lateral axis of the femur and the other with the lateral axis of the leg[3]. To measure active flexion, the assessor instructed the participant to bend his/her knee as far as comfortable[3]. In the assessment of passive ROM, the examiner performed the flexion until the participant reported any discomfort in the operated knee.

We determined passive and active knee extension ROM with the patient sitting on the bed with the lower limbs out of the bed[3]. The examiner held the patient's heel during the initial flexion to avoid excessive discomfort for the patient[3]. In the assessment of passive ROM, the examiner conducted the extension movement until the participant reported any discomfort in the operated knee[3]. For active ROM, the examiner instructed the patient to extend his/her knee (affected knee) as far as possible. The position of the goniometer was the same used to measure flexion[3].

## Isometric Muscle Strength Assessment

We assessed isometric muscle strength using manual dynamometry. For that, we measured the maximum voluntary isometric contraction (MVIC) of the hamstrings and quadriceps of the affected limb with a Saehan® manual push-pull dynamometer.

We determined knee flexion MVIC with the participant in the prone position, with the knee flexed at an angle of 60 degrees[13]. Under the command of the therapist, the patient flexed his/her knee against the dynamometer positioned on the posterior distal third of the leg[13].

To assess quadriceps MVIC, the individual remained seated on the bed, with the knee flexed at 60 degrees[13]. The examiner positioned the dynamometer on the anterior distal third of the leg[13]. The patient then received the same stimulus used to assess flexion, but now he/she should extend the knee[13]. We measured each movement three times and considered the median value in each group[13].

## Data analysis

Data are presented as mean ± standard deviation or mean (95% confidence interval) and median (interquartile range). Initially, we tested the data for normal distribution using the Shapiro-Wilk test. We then compared the values using $\chi$-square tests. We used one-way ANOVA to compare baseline characteristics between groups. We statistically analyzed parametric data by one-way analysis of variance (ANOVA) for repeated measures, followed by the Bonferroni post hoc test for intragroup analyses. For intergroup analyses, we used the Student t-test. We analyzed nonparametric data using the Kruskal-Wallis test. We established the value of $p<0.05$ for statistical significance. We performed all statistical analyses using commercial software (Statistical Package for the Social Sciences, version 23, SPSS Inc., Chicago, IL, USA).

## RESULTS

A total of 46 patients underwent arthroscopic ACL reconstruction using a bone-tendon-bone graft. All subjects who started the intervention completed the study and there were no losses or exclusions (Figure 1). Table 1 shows demographic characteristics and outcome measures before the intervention and in the two groups (TG and CG). The participants in the TG had more right knee injuries than those in the CG.

### Pain Intensity

The pain increased significantly in both groups in the immediate postoperative period. However, the TG showed a significantly lower pain intensity compared to the CG on both the 1st and 2nd postoperative days ($p<0.005$) (Figure 2).

### Joint Mobility

Both groups demonstrated a significant loss of ROM in the 24-hour postoperative evaluation ($p<0.05$). The TG showed a lower loss of ROM than the CG ($p<0.001$). The TG had a significantly greater gain in active ROM than the CG ($p<0.001$) between the first and second days after surgery ($p<0.001$).

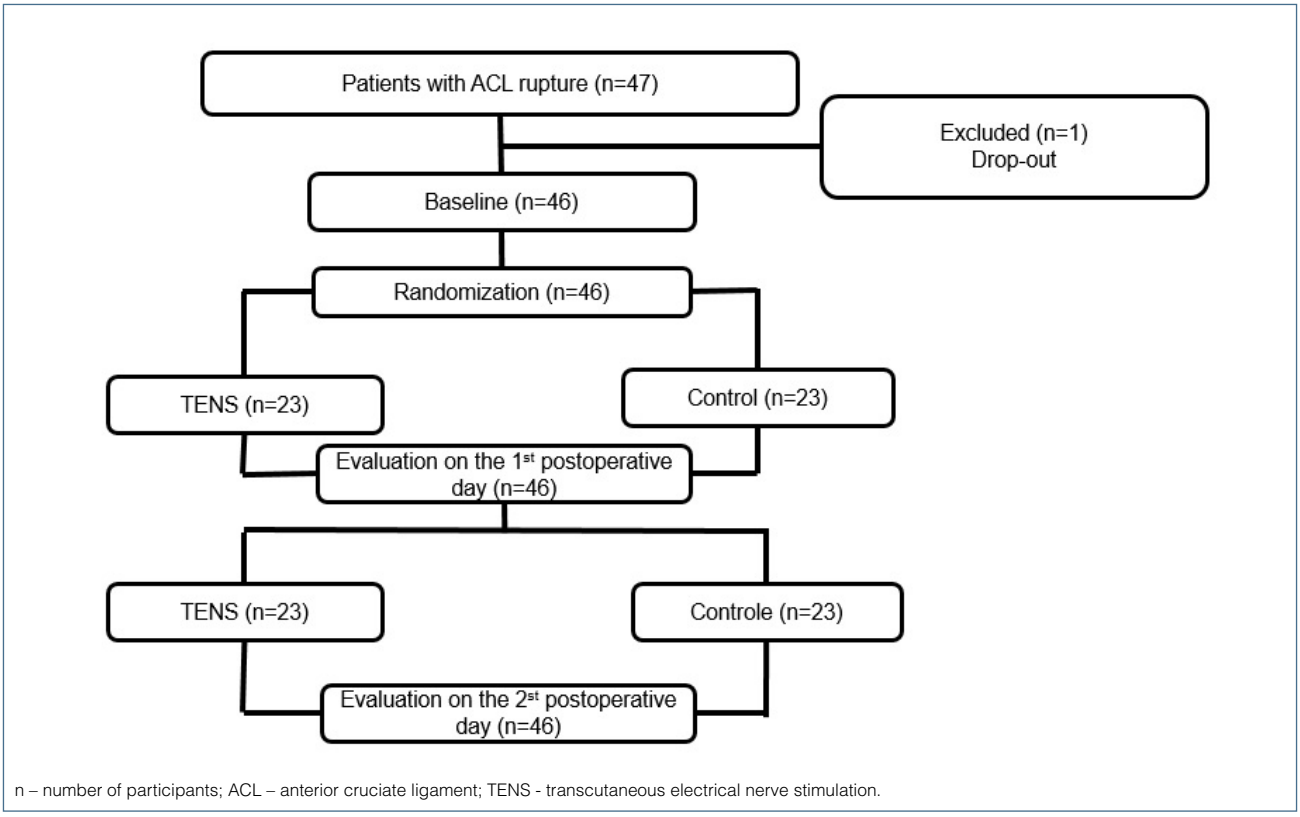
Both groups showed extension loss only in the 24-hour postoperative evaluation compared to baseline ($p<0.05$). The groups did not differ for active extension (Table 2).

Regarding passive ROM, both groups showed a significant loss of knee flexion on the 1st postoperative day. However, this loss was significantly less for the TG ($p<0.001$). Both groups significantly increased ROM on the 2nd postoperative day compared to the 1st postoperative day ($p<0.05$). However, the TG also showed a significantly higher ROM than the CG ($p<0.001$). Both groups did not decrease knee extension passive ROM (Table 2).

**Table 1:** Demographic characteristics of the sample (n=46).

| | Intervention group | | p value |
|---|---|---|---|
| | TG (n=23) | CG (n=23) | |
| Age, years (±sd) | 26.52 ± 6.27 | 29.68 ± 6.73 | 0.110# |
| Injury time, months (± sd) | 19.61 ± 22.82 | 32.55 ± 36.39 | 0.158# |
| Smoking, n (%) | | | |
| Yes | 1 (4.3) | 2 (9.1) | 0.524$ |
| No | 22 (95.7) | 20 (90.9) | |
| Skin color, n (%) | | | |
| White | 23 (100.0) | 22 (100.0) | >0.999$ |
| Black | 0 (0.0) | 0 (0.0) | |
| Affected knee, n (%) | | | |
| Right | 18 (78.3) | 10 (45.5) | 0.023$ |
| Left | 5 (21.7) | 12 (54.5) | |
| Dominant member | | | |
| Right | 21 (91.3) | 20 (90.9) | 0.963$ |
| Left | 2 (8.7) | 2 (9.1) | |

# Student t-test.
$ Chi-square.



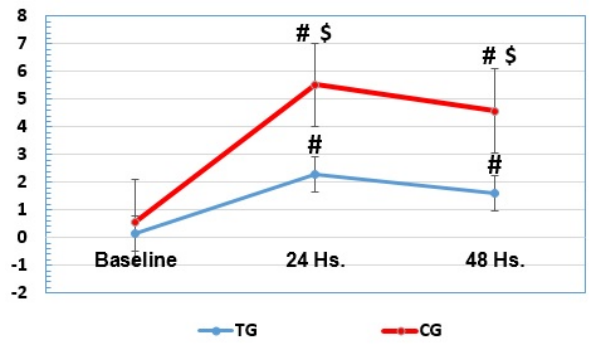

n – number of participants; ACL – anterior cruciate ligament; TENS - transcutaneous electrical nerve stimulation.

**Figure 1:** Study flowchart.

## Isometric Muscle Strength

Both groups reduced knee flexion strength 24 hours after intervention (p<0.05). However, the TG showed a significantly higher flexion strength than the CG at both 24 and 48 hours after surgery (p<0.001). The TG showed significantly less quadriceps strength loss at 48 hours after intervention (p<0.005) (Table 3).

The TG showed a significantly lower intake of dipyrone, morphine, and tramadol than the CG at both 24 and 48 hours after intervention (p<0.05). Only the TG reduced the intake of dipyrone, morphine, and tramadol from the 1st to the 2nd postoperative day (p<0.05).




# p<0.005 compared to baseline. One-way ANOVA for repeated measures.
$ p<0.005 compared to the same evaluation in the TG. Student t-test.

**Figure 2:** Pain intensity (VAS) before and after surgery in each study group.

## Pharmacological analgesia

Diazepam intake was 256.98% lower in the TG compared to the CG from preintervention to 48 hours postintervention (p<0.001). Total dipyrone intake was 121.21% lower in the TG compared to the CG during the study period (p<0.001). Morphine intake was 320.77% lower in the TG compared to the CG during the study period (p<0.001). Ketoprofen intake decreased by 48.27% in the TG compared to the CG from preintervention to 48 hours postintervention (p<0.001) (Table 4). Finally, the TG decreased total tramadol intake by 437.46% compared to the CG (p<0.001) (Table 4).

# DISCUSSION

This randomized clinical trial assessed the effect of associating TENS with an exercise protocol in the first 48 hours after ACL reconstruction.

The literature shows different interventions for ACL reconstruction rehabilitation, but there are almost no reports of TENS as a complement to exercise and mobilization after surgery. Studies usually address the use of neuromuscular electrostimulation (NMES) for neuromuscular activation rather than for pain control.

The results of the present clinical trial show that continuous use of TENS in the first 48 hours after surgery led to significantly less pain, significantly less joint flexion loss, better muscle activation, and significantly less drug intake in the postoperative inflammatory phase when compared to performing the

**Table 2:** Active and passive range of motion (ROM) of the operated knee from preintervention to 48 hours after intervention in the study groups (n=46).

| Range of Motion (ROM) | Intervention Group | Baseline, mean ± sd | 24 hours, mean ± sd | 48 hours, mean ± sd | Intragroup Variation 24/48 hours (95% CI) | P[a] |
|---|---|---|---|---|---|---|
| Active flexion | TG | 123.04 ± 4.61 | 75.87 ± 4.69 | 88.48 ± 2.93 | 12.60 (22.38 to 2.86) | **0.009** |
| | CG | 111.95 ± 28.75 | 35.43 ± 17.12 | 46.08 ± 19.94 | 11.14 (20.19 to 2.08) | **0.013** |
| | Mean difference (95% CI) | 11.09 (-4.05 to 26.32) | 40.44 (28.56 to 52.31) | 42.39 (32.13 to 52.65) | | |
| | Effect Size | 1.47 | 6.86 | 8.33 | | |
| | *Pb* | 0.150 | **p<0.001** | **p<0.001** | | |
| Active extension | TG | -0.21 ± 1.04 | -2.39 ± 3.33 | 0.44 ± 4.50 | 2.83 (6.26 to 0.61) | 0.134 |
| | CG | -0.21± 1.04 | -2.17 ± 3.64 | -1.09 ± 2.59 | 0.91 (2.75 to -0.93) | 0.640 |
| | Mean difference (95% CI) | (-0.62 to 0.62) | (-2.29 to 1.85) | 1.52 (-0.66 to 3.60) | | |
| | Effect Size | 0.00 | -0.21 | 1.40 | | |
| | *Pb* | p>0.999 | 0.834 | .167 | | |
| Passive flexion | TG | 131.30 ± 22.11 | 90.30 ± 23.19 | 102.39 ± 14.84 | 12.09 (21.38 to 2.79) | **0.008** |
| | CG | 121.26 ± 26.49 | 45.65 ± 19.90 | 57.39 ± 21.37 | 12.73 (22.36 to 3.09) | **0.007** |
| | Mean difference (95% CI) | 10.04 (-4.28 to 24.37) | 44.65 (31.81 to 57.50) | 45.00 (34.07 to 55.93) | | |
| | Effect Size | 1.41 | 7.00 | 8.30 | | |
| | *Pb* | 0.158 | **p<0.001** | **p<0.001** | | |
| Passive extension | TG | 0.00 ± 0.00 | -0.43 ± 1.44 | 0.86 ± 4.17 | 1.30 (4.15 to -1.54) | 0.744 |
| | CG | 0.00 ± 0.00 | -0.65 ± 1.72 | 0.00 ± 0.00 | 0.68 (1.66 to -0.29) | 0.374 |
| | Mean difference (95% CI) | 0.00 | 0.22 (-0.73 to 1.60) | 0.87 (-0.88 to 2.62) | | |
| | Effect Size | 0.00 | 0.46 | 1.00 | | |
| | *P* | p>0.999 | 0.645 | 0.323 | | |

Bold values are statistically significant.
*an* ANOVA for repeated measures;
b Student t-test between groups;

exercises usually recommended for postoperative ACL rehabilitation in isolation.

Only one study showed the effect of adding TENS to the exercise protocol on postoperative ACL rehabilitation[3]. However, some studies demonstrate the effects of TENS on other orthopedic trauma surgeries[4,9,10,12-15]. Moreover, many studies address the effects of TENS on other types of surgery[8,11,16-23].

The results showed that almost continuous stimulation by high-frequency TENS associated with a predefined exercise and mobilization protocol during the first phase of ACL reconstruction rehabilitation led to a significant additional effect in improving acute postoperative pain. Forogh et al.[3] added TENS to the immediate postoperative protocol in 70 athletes who underwent ACL reconstruction surgery. The authors used TENS for 35 minutes before exercise for four weeks[3]. However, differently in the results of the present study, pain intensity did not differ between the groups[3].

Lee et al.[15] approached 36 patients with Colles' fracture, divided into TENS group and placebo TENS group. The application started four to six hours after the patient arrived at the ward[14]. The authors used a frequency of 50 Hz in daily 15-minute applications for five days[14]. According to VAS scores, the pain did not differ significantly between the TENS and placebo TENS groups from the first to the fifth day after surgical treatment[14]. Several variables may have interfered with the desired analgesic effect in these studies. The variation in the frequency used and the stimulation time may not have been sufficient to achieve the significant analgesic effect in the acute phase and, thus, close the pain gate.

Silva et al.[9] approached 42 patients with proximal femoral fractures, divided into TENS group, placebo TENS group, and control group. All groups received the same exercise protocol in the postoperative period[9]. As in the present study, the authors applied TENS continuously[9]. The results showed significant pain reduction in the first 72 hours after intervention in the group that added TENS[9].

Another study addressed 41 patients with hip fractures, adding TENS for 30 minutes a day for the first five days after surgery[14]. The authors observed that the active TENS group significantly decreased pain during walking when compared to the placebo TENS group[14]. Rakel et al.[16] approached 317 patients after total knee arthroplasty. The authors applied TENS twice daily with a frequency of 150 Hz for 20 minutes[16]. Participants in the TENS group had less postoperative pain during active knee extension and brisk walking in comparison to the participants in the standard care group[16].

In the present study, in addition to using a high frequency, the application was continuous in the first 48 hours after intervention, starting already in the recovery room of the surgical block. After 48 hours of surgery, knee ROM reached an average of 102.39º and 57.39º, respectively, in the TG and CG, this being a significant difference between the groups. At the same time, the TG showed significantly less isometric muscle strength loss in comparison to the CG

**Table 4:** Total dose of diazepam (A), dipyrone (B), morphine (C), ketoprofen (D), and tramadol (E) from preintervention to 48 hours postintervention. Student t-test (n=46).

| Drug | Intervention Group | Total Consumption (mg) |
|---|---|---|
| Dipyrone | TG | 3.3 ± 2.06 |
| | CG | 7.3 ± 2.46 |
| | % dif | 121.21 |
| | *P*[b] | **0.0001** |
| Morphine | TG | 0.13 ± 0.63 |
| | CG | 4.17 ± 2.67 |
| | % dif | 320.77 |
| | *P*[b] | **0.0001** |
| Diazepan | TG | 6.09 ± 6.56 |
| | CG | 21.74 ± 11.54 |
| | % dif | 256.98 |
| | *P*[b] | **0.0001** |
| Ketoprophen | TG | 252.17 ± 51.07 |
| | CG | 373.91 ± 96.38 |
| | % dif | 48.27 |
| | *P*[b] | **0.0001** |
| Tramadol | TG | 69,57 ± 82.21 |
| | CG | 373.91 ± 117.62 |
| | % dif | 437.46 |
| | *P*[b] | **0.0001** |

Bold values are statistically significant.
b Student t-test between groups;

**Table 3:** Muscle strength (MVIC, in kg) of the operated knee from preintervention to 48 hours after intervention in the study groups (n=46).

| Isometric Force (MVIC, kg) | Intervention Group | Baseline, mean ± sd | 24 hours, mean ± sd | 48 hours, mean ± sd | Intragroup Variation Baseline/Post-treatment (95% CI) | P[a] |
|---|---|---|---|---|---|---|
| Flexion | TG | 47.17 ± 23.15 | 9.56 ± 4.98 | 12.70 ± 5.79 | 3.13 (5.88 to 0.38) | **0.022** |
| | CG | 38.47 ± 22.88 | 2.61 ± 3.33 | 4.13 ± 5.77 | 1.59 (3.98 to -0.73) | 0.269 |
| | Mean difference (95% CI) | 8.70 (-4.98 to 22.38) | 6.96 (4.44 to 9.97) | 8.57 (5.13 to 12.00) | | |
| | Effect Size | 1.28 | 5.57 | 5.03 | | |
| | *P*[b] | .207 | **p<0.001** | **p<0.001** | | |
| Extension | TG | 52.61 ± 26.49 | 2.08 ± 2.47 | 4.26 ± 3.35 | 2.17 (4.03 to 0.32) | **0.018** |
| | CG | 41.52 ± 22.48 | 0.87 ± 2.46 | 1.30 ± 3.10 | 0.46 (1.27 to -0.36) | 0.314 |
| | Mean difference (95% CI) | 11.09 (-3.52 to 25.69) | 1.22 (-0.25 to 2.68) | 2.97 (1.04 to 4.87) | | |
| | Effect Size | 1.53 | 1.68 | 3.31 | | |
| | *P*[b] | 0.133 | 0.100 | **0.003** | | |

Bold values are statistically significant.
an ANOVA for repeated measures;
b Student t-test between groups;

in the postoperative period. Intentional exercises and TENS together are shown to be preliminary factors that reduce pain, increase ROM, and improve function in patients undergoing ACL reconstruction surgery[3]

Considering the distance traveled by patients who underwent surgical fixation of hip fracture, Elboim-Gabyzon et al.[14] reported functional improvement in the TENS group in comparison to the placebo TENS group. Nonetheless, the authors suggest that joint mobility may be limited by the pain evoked during this activity[12]. Based on this assumption, the role of TENS in blocking the transmission of acute pain can facilitate the exercise program, improving mobility and muscle strength in the postoperative period.

Our results demonstrate that using continuous TENS with control of stimulation and intensity can be an important resource to produce a more significant effect on the ascending and descending pathways of pain inhibition. The stimulation of large-diameter afferent nerves by TENS inhibits the nerve fibers that transmit pain signals in the dorsal horn of the spine[20]. However, the presence of descending pathways affects spinal neurons[20].

Some authors[20] analyzed the role of endogenous opioids to explain the mechanism underlying the effect of TENS, particularly in high-frequency stimulation. There are three types of opioid receptors (μ, δ, and κ) in the spine and in the regions involved in descending inhibition, namely the Magnus raphe nucleus, medial ventromedial nucleus, and periaqueductal gray substance. However, the appropriate duration of TENS treatment to produce analgesia and the duration of the analgesic effect of a TENS session are not fully known, requiring further studies[19].

Proper selection of TENS parameters is important for their effectiveness. Studies commonly address the actual current intensity, the location of the electrodes, and the stimulation frequency[20]. Moreover, it is noteworthy that beta-endorphin levels increase in blood and cerebrospinal fluid (CSF) after using high or low-frequency TENS[19].

Another study showed that a strong but painless electrical stimulation intensity with an adequate frequency significantly reduced the need for analgesic intake[5]. DeSantana et al.[19] investigated the hypoalgesic effect of high-frequency TENS after unilateral inguinal herniorrhaphy. The authors applied TENS with a frequency of 100 Hz during the first 24-hour postoperative period[19]. The results showed that active TENS significantly reduced pain intensity and analgesic requirements when compared to placebo TENS[19]. Significant reductions in postoperative pain with high-frequency TENS occur when using intensity at the sensory level, that is, producing a strong but comfortable tingling sensation, without muscle contraction[19,23].

The standard analgesics used in surgical care in our Department of Orthopedics and Traumatology are ketoprofen, dipyrone, tramadol, and morphine. We observed a greater intake of all these painkillers in the CG compared to the TG. These findings corroborate previous studies that analyzed analgesic intake with TENS application after several types of surgeries. Some authors addressed the use of opioids after thoracic surgery and showed a lower intake for patients receiving TENS compared to the control group[21].

Silva et al.[10] showed that continuous TENS application for 72 hours after proximal femoral fracture surgery significantly decreases drug intake. After 48 hours of surgery, the authors observed that the tramadol dose was significantly higher in the control group compared to the TENS group[10].

Kara et al.[4] evaluated the effect of TENS on analgesic consumption in the immediate postoperative period of spinal surgery. Application started when the patients arrived at the postsurgical ward (two to three hours after surgery)[4]. The examiners administered TENS twice a day, each application lasting 30 to 40 minutes, with a rest interval of three to four hours between applications[4]. The TENS group consumed fewer analgesics in the first 24 hours and the total study period[4].

Husch et al.[21] evaluated analgesic intake after TENS application in the postoperative period of posterior thoracotomy. The examiners applied TENS with the frequency of 100 Hz, pulse duration of 100 μs, and intensity up to the maximum sensory threshold for pain, with a total session time of 30 minutes[21]. The authors observed increased use of morphine and acetaminophen in the control group 24 to 48 hours after surgery[21]. These studies corroborate our findings, where patients undergoing TENS significantly reduced drug intake. Ketoprofen intake decreased by 48.27%, dipyrone intake by 121.21%, diazepam intake by 256.98%, tramadol intake by 437.46%, and morphine intake by 320.77%.

Finally, the results found in this study show that TENS implementation in the immediate postoperative period of several orthopedic trauma surgeries can significantly reduce drug intake and, consequently, the costs of drugs to the health system. However, success with the use of TENS depends on the proper selection of parameters and an understanding of the applicable principles. For effective postoperative analgesia, the current intensity must be strong but comfortable for the patient, and examiners must place the electrodes around the surgical incision area or at corresponding acupuncture points.

### Study limitations

The main limitation of the study is the small number of patients. Another limitation of the study is the absence of a placebo group. Finally, the fact that the participants in the TG had more right knee injuries than those in the CG may have influenced the results.

## Conclusion

The findings of the present research demonstrate that continuous use of TENS in the postoperative period of ACL reconstruction significantly reduced drug intake and pain intensity, thus improving ROM, muscle strength, and earlier function.

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