J. Phys. Ther. Sci. 35: 93–98, 2023

The Journal of Physical Therapy Science

Original Article

Effects of n-3 polyunsaturated fatty acid supplementation on quadriceps weakness immediately after total knee arthroplasty: a pilot, randomized, open-label clinical trial

Yusuke Kubo, RPT, PhD[1)*], Masae Ikeya, RD, PhD[2)], Shuhei Sugiyama, RPT, MS[1)], Rie Takachu, RPT[1)], Maki Tanaka, RPT, MS[3)], Takeshi Sugiura, RPT[1)], Kaori Kobori, MD[1)], Makoto Kobori, MD, PhD[1)]

[1)] *Department of Rehabilitation, Kobori Orthopedic Clinic: 548-2 Nearaichou, Kita-ku, Hamamatsu-shi, Shizuoka 433-8108, Japan*
[2)] *Department of Health and Nutrition Sciences, Tokoha University, Japan*
[3)] *Rehabilitation Sciences, Seirei Christopher University, Japan*

Abstract. [Purpose] Severe quadriceps weakness immediately after total knee arthroplasty can be problematic. The n-3 long-chain polyunsaturated fatty acids have antioxidant and anti-inflammatory effects against ischemia–reperfusion injury, whereas n-6 long-chain polyunsaturated fatty acids exert pro-inflammatory effects, thereby promoting ischemia–reperfusion injury. [Participants and Methods] We explored the efficacy of preoperative n-3 long-chain polyunsaturated fatty acid supplementation against early quadriceps weakness among 20 patients scheduled for total knee arthroplasty (intervention group, n=10; control group, n=10). The intervention group received 645 mg of eicosapentaenoic acid) and 215 mg of docosahexaenoic acid daily for 30 days preoperatively. Serum eicosapentaenoic acid, docosahexaenoic acid, and arachidonic acid levels were measured preoperatively. We compared serum derivatives of reactive oxygen metabolites as oxidative stress biomarkers, knee circumference, thigh volume, knee pain during the quadriceps strength test, and quadriceps strength preoperatively and 4 days postoperatively to quantify the change. [Results] Preoperative n-3 long-chain polyunsaturated fatty acid supplementation significantly increased the (eicosapentaenoic acid+docosahexaenoic acid)/arachidonic acid ratio in the intervention group. A significantly lower increase in quadriceps weakness was exhibited in the intervention group than in the control group. However, changes in oxidative stress, knee/thigh swelling, and knee pain during strength testing did not significantly differ between the two groups. [Conclusion] Preoperative n-3 long-chain polyunsaturated fatty acid supplementation exhibited beneficial effects on quadriceps weakness immediately after total knee arthroplasty.
Key words: N-3 long-chain polyunsaturated fatty acids, Quadriceps weakness, Total knee arthroplasty

(This article was submitted Sep. 4, 2022, and was accepted Nov. 9, 2022)

INTRODUCTION

Total knee arthroplasty (TKA) is generally performed for severe knee osteoarthritis (OA) to alleviate OA-related pain and disability. In the postoperative period, recovery is often compromised by quadriceps weakness (QW), leading to reduced walking speed and endurance, lowered stair negotiation ability, and an increased risk of falling[1, 2)]. The quadriceps strength immediately after TKA decreases to approximately 20% of its preoperative level[3)]. Early postoperative significant QW can be particularly problematic, because it may cause persistent QW throughout the postoperative course[4)]. Thus, early QW following TKA needs to be addressed to optimize postoperative recovery.

*Corresponding author. Yusuke Kubo (E-mail: yusuke.kubo11@gmail.com)

Earlier studies have demonstrated that early QW is caused by knee swelling, knee pain during the quadriceps strength test (QST), and quadriceps muscle atrophy after TKA[3, 5, 6]. These factors can be induced by surgical trauma and/or ischemia-reperfusion (IR) injury caused by tourniquet application[7, 8]. IR injury is often accompanied by oxidative stress and inflammatory responses that can induce increased vascular permeability (endothelial barrier dysfunction), leading to interstitial edema and tissue damage subjected to ischemia and reperfusion[9–11]. This study focused on tourniquet-induced IR injury, as it is preventable by nutritional preconditioning[12, 13].

Long-chain polyunsaturated fatty acids (PUFAs) are involved in modulating IR injury in various organs and tissues. N-3 PUFAs, such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), have antioxidant and anti-inflammatory effects against IR injury[14], whereas n-6 PUFAs, particularly arachidonic acid (AA), exert pro-inflammatory effects and promote IR injury[15]. Several studies using animal models have demonstrated that higher n-3/n-6 PUFA ratios prevent IR injury by attenuating the increase in oxidative stress and inflammatory responses[16, 17]. Therefore, it is presumed that an elevated n-3/n-6 PUFA ratio in preoperative nutrition would attenuate tourniquet-induced oxidative stress and inflammatory responses immediately after TKA.

This study aimed to clarify the preventive and therapeutic effects of n-3 PUFA supplementation on QW immediately after TKA. We hypothesized that the n-3 PUFA supplementation group would have lower oxidative stress, less knee and thigh swelling, and less knee pain, resulting in less QW immediately after TKA than the control group (no intervention).

PARTICIPANTS AND METHODS

This prospective single-center randomized controlled open-label pilot study was conducted between September 2017 and July 2019 among patients with knee OA who were scheduled to undergo unilateral TKA at an orthopedic clinic in Japan. Preoperative examination for TKA was conducted at 3 months and 1 month before surgery. Candidates for this study were asked to enroll in the study at 3 months before surgery. The inclusion criteria were as follows: age of 60–79 years, Kellgren–Lawrence grade 3 or 4, body mass index of 20–30 kg/m^2, ability to understand the study, and provision of written informed consent. The exclusion criteria were as follows: dementia, serious cardiovascular disease (e.g., disease requiring warfarin or heparin), respiratory disease excluding asthma, uncontrolled diabetes, rheumatoid arthritis, kidney disease, digestive diseases, significant neurologic impairment, inability to undergo a muscle strength test due to other diseases or trunk and lower extremity orthopedic conditions, the average daily intakes of n-3 PUFA more than 2,000 mg (with the exception of n-3 PUFA >2,000 mg and n-6/n-3 PUFA ratio >4) in the preoperative nutritional assessments by registered dietitian, ongoing n-3 PUFA supplementation, a recent history of cigarette smoking, abnormal blood coagulation and fibrinolytic systems, and participation in research on preoperative exercise training before TKA at our clinic.

All participants were fully informed about the purpose of this study, procedures involved, and potential risks associated with their participation. Written informed consent was obtained from all participants in accordance with the Declaration of Helsinki. The study protocol was approved by the ethics committee of Seirei Christopher University (approval no. 17014). The trial was registered at the University Hospital Medical Information Network Clinical Trials Registry (UMIN000028140). The study adhered to the CONSORT guidelines to ensure transparent and standardized reporting of trials.

All participants were admitted on the day of surgery and discharged home or to a rehabilitation hospital on postoperative day 7. All participants underwent a tricompartmental uncemented TKA with a low-contact-stress implant (LCS Complete; DePuy, Johnson & Johnson Co., New Brunswick, NJ, USA) via a midvastus approach, which was performed by two experienced surgeons. Before wound closure, 1,000 mg tranexamic acid was applied topically to the perisurgical area. A pneumatic tourniquet (ATS 2000; Zimmer, Dover, OH, USA) was applied to the superior aspect of the thigh and inflated to 300 mmHg. A wound drainage system was placed and removed 48 h postoperatively. Blood transfusions were not administered. Intra- and postoperative anesthesia as well as postoperative pain management and physical therapy were performed similarly to that described in a previous study[18].

Blocked randomization was used to ensure balanced assignment of participants to the intervention and control groups by gender and decade of age, with random block sizes of 2, 4, or 6. The randomization sequence was generated by a blinded physiotherapist who was not involved in the data collection and analysis. Group assignment occurred after the eligibility criteria were met and before the preoperative testing session. The intervention group received n-3 PUFA-enriched capsules containing 645 mg of EPA and 215 mg of DHA (Nippon Suisan Kaisha, Ltd., Tokyo, Japan). The amount of n-3 PUFA supplementation was determined to prevent overdose at approximately 40% of daily adequate intake of n-3 PUFA in the dietary reference intakes for Japanese. Participants in the n-3 PUFA supplementation group were asked to consume one capsule per day (after breakfast, lunch, or dinner) for 30 days before surgery. The control group did not undergo any intervention. All participants were asked not to change their current dietary habits during the course of the study.

To measure serum EPA, DHA, and AA levels, blood sampling was performed immediately before surgery after a fasting period of at least 12 h. Serum PUFA level measurements were outsourced to Medic (Shizuoka, Japan). Subsequently, free fatty acids extracted from the serum were analyzed by the higher multiple reaction monitoring methods using ultra-fast liquid chromatography coupled with tandem mass spectrometry (LCMS-8030; Shimadzu Corporation, Kyoto, Japan). Derivatives of reactive oxygen metabolites (d-ROMs) were used as biomarkers for oxidative stress[19].

Pre- and postoperative evaluations, which were performed at 1 month before surgery and again on postoperative day 4, included measurements of serum d-ROM levels, knee circumference at 1 and 10 cm proximal to the upper edge of the

patella, knee pain during the QST, and quadriceps strength. The thigh volume was calculated via the truncated cone method, as previously described[6]. This method has shown to be excellent criterion-related validity, intra-rater reliability, and good inter-rater reliability[20].

Relative changes (%) in serum d-ROM levels, knee circumference (1 and 10 cm), thigh volume, and quadriceps strength were calculated to determine Δ oxidative stress, knee swelling (1 and 10 cm), thigh swelling, and QW, respectively using the formula [(postoperative value − preoperative value) / preoperative value × 100]. Given that knee pain during the QST included 0, the absolute change was calculated to determine Δ knee pain using the formula (postoperative value − preoperative value). The Japanese Knee Osteoarthritis Measure scores[21] were evaluated only before surgery. Preoperative characteristics, tourniquet time, and postoperative ropivacaine dosage were obtained from the participants' medical records. The primary outcome was QW. The secondary outcomes were Δ oxidative stress, knee and thigh swelling, and Δ knee pain.

The measurement of d-ROM test was performed using the standard test procedures[22] as described in a previous study[18]. In brief, blood samples were collected and centrifuged within 5 min at 6,000 rpm for 2 min, and the supernatant was stored at −80 °C until the analysis. Serum d-ROM levels were measured using a free radical elective evaluator system (FREE Carrio Duo; Wismerll Co. Ltd., Tokyo, Japan). The level of d-ROMs is expressed in arbitrary units, named Carratelli units (U.CARR), with 1 U.CARR corresponding to 0.08 mg/100 mL H_2O_2.

The knee circumference (1 and 10 cm) was measured in a relaxed, supine position with knees extended using a non-stretchable tape measure. The mean of the two measurements was used in the analysis. Circumference measurements obtained using a tape measure demonstrates excellent intra-rater reliability and good inter-rater reliability[23, 24].

Quadriceps strength was evaluated using a pull-type hand-held dynamometer (Mobie; Sakai Medical Co., Ltd., Tokyo, Japan), as previously described[25]. The measurement consisted of three maximal isometric knee-extensor contraction (two warm-up trials and then three maximal contractions) at 75° knee flexion in a seated position separated by a 60-s pauses. The highest measurement of two valid trials was used in the analysis. Subsequently, quadriceps strength was expressed as the maximal voluntary torque per kilogram body mass (Nm/kg) using the external lever arm (m) and body mass (kg) of each participant. Similar quadriceps strength measurements have been proven to have excellent intra-rater reliability and good inter-rater reliability[26].

A numeric rating scale (NRS) was used to quantify knee pain during the QST. Participants rated pain in and around the knee immediately after all measurements using an NRS ruler with a scale from 0 to 10, with 0 representing no pain and 10 representing the worst pain imaginable. The highest pain intensity during the QST was used in the analysis. The NRS has excellent validity and reliability[27].

The sample size calculation was based on a previous study[6] with similar methods, and we used 14% as the standard deviation and 12% as the distinction in the mean (d) of the early QW after TKA. A sample size of 23 participants in each group was adequate to reject the null hypothesis with a statistical power of 80% and a significance level of $p<0.05$. However, this study failed to recruit the required number of participants.

Statistical analyses were performed using SPSS version 26 (IBM Corp., Armonk, NY, USA). Normality was assessed using the Shapiro–Wilk test. Between-group comparisons of preoperative characteristics, tourniquet time, and postoperative ropivacaine dosage were performed using the χ^2 test or the independent-samples t-test, as appropriate. Measurement changes in both groups were compared using the independent-samples t-test for normally distributed continuous data and the Mann–Whitney U test for non-normally distributed data. Effect sizes (Cohen's *d*) for measurement changes were calculated using the online software available on the following website: https://www.psychometrica.de/effect_size.html.

RESULTS

The flow diagram of patient recruitment and randomization is presented in Fig. 1. Of the 317 patients who were scheduled to undergo unilateral TKA between September 2017 and July 2019, 297 were excluded based on the eligibility criteria. In total, 20 participants underwent all pre- and postoperative assessments, and all participants completed the intervention.

Preoperative n-3 PUFA supplementation led to a significant increase in the EPA ($p=0.01$) and the (EPA + DHA)/AA ratio ($p=0.02$) in the n-3 PUFA supplementation group than in the control group. In contrast, there were no significant differences in preoperative characteristics, tourniquet time, and postoperative ropivacaine dosage between the groups (Table 1). Table 2 presents the results and measurement changes for both groups.

Compared with the control group, the n-3 PUFA supplementation group exhibited a significantly lower increase in QW ($p=0.04$), with outcome measures demonstrating a large effect size difference. However, no significant differences in Δ oxidative stress, knee and thigh swelling, and Δ knee pain during the QST were observed between the groups ($p>0.05$ for all), with outcome measures demonstrating a small effect size difference.

DISCUSSION

In this study, the n-3 PUFA supplementation group exhibited superior preventive and therapeutic effects on QW immediately after TKA to the control group. However, no significant differences in increased oxidative stress, knee and thigh swelling, and knee pain during the QST performed immediately after TKA were observed between the groups.

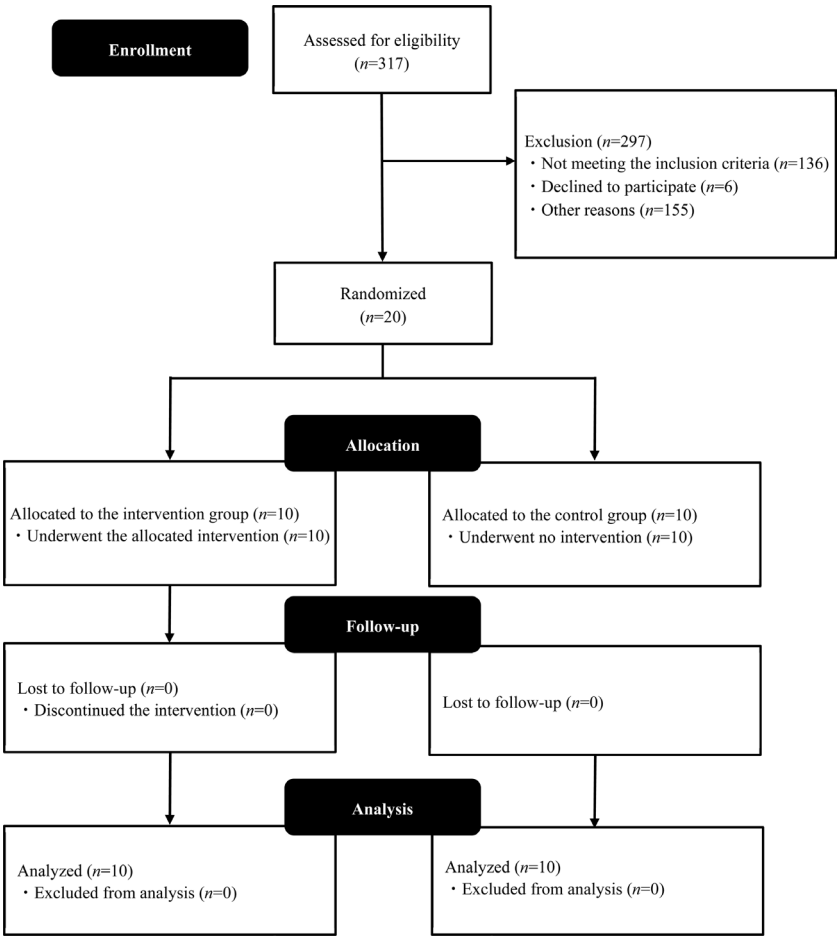

Fig. 1. Flow diagram of the progress through the study phases.

Table 1. Preoperative characteristics, tourniquet time, and postoperative ropivacaine dosage in the control and n-3 PUFA groups

	Control (n=10)	n-3 PUFA (n=10)
Age (years)	73 (66, 77)	69 (65, 76)
Male, n	2	2
BMI (kg/m^2)	26 (25, 28)	25 (24, 28)
EPA (μg/mL)	64 (48, 103)	158 (90, 175)*
DHA (μg/mL)	137 (120, 162)	180 (131, 203)
EPA + DHA (μg/mL)	207 (167, 259)	344 (230, 383)
AA (μg/mL)	208 (179, 232)	192 (184, 214)
(EPA + DHA)/AA ratio	1.0 (0.9, 1.3)	1.4 (1.2, 2.0)*
Current medical history, n		
Diabetes	2	0
Hyperlipidemia	5	4
Hypertension	7	6
JKOM score (points)	41 (32, 50)	42 (23, 53)
Tourniquet time (min)	59 (59, 64)	62 (61, 63)
Postoperative ropivacaine dosage (mL)	115 (89, 170)	138 (111, 150)

Continuous variables are presented as the median (interquartile range). *indicated statistical significance as compared to control group; $p<0.05$.
Preoperative characteristics, tourniquet time, and postoperative ropivacaine dosage in the groups were compared using the χ^2 test or the independent-samples t-test, as appropriate. The n-3 PUFA supplementation group consumed one capsule containing 645 mg of EPA and 215 mg of DHA a day for 30 days before surgery. The control group underwent no intervention.
AA: arachidonic acid; BMI: body mass index; DHA: docosahexaenoic acid; EPA: eicosapentaenoic acid; IQR: interquartile range; PUFAs: polyunsaturated fatty acids; JKOM: Japanese Knee Osteoarthritis Measure.

Table 2. Results of pre- and postoperative measurements and changes therein between the control and n-3 PUFA groups

Parameters	Control (n=10)			n-3 PUFA (n=10)			Change ES
	Pre	Post	Change	Pre	Post	Change	
Serum d-ROMs (×10 U.CARR)	34 (33, 38)	42 (37, 45)	17 (14, 18)	31 (27, 36)	35 (32, 39)	13 (2, 41)	0.14
Knee circumference (1 cm) (cm)	40 (38, 41)	44 (43, 45)	10 (7, 12)	40 (38, 41)	43 (42, 44)	8 (7, 11)	0.33
Knee circumference (10 cm) (cm)	45 (42, 46)	48 (46, 49)	8 (4, 10)	43 (43, 46)	46 (45, 47)	6 (2, 8)	0.41
Thigh volume ($\times 10^2$ cm^3)	13 (11, 13)	16 (14, 16)	18 (11, 23)	12 (12, 14)	15 (13, 15)	13 (10, 19)	0.40
Knee pain during the QST (mm)	1.5 (0, 3.0)	6.5 (5.3, 7.0)	5.0 (3.3, 5.8)	0 (0, 1.5)	5.0 (3.3, 5.8)	3.0 (2.3, 5.8)	0.09
Quadriceps strength (Nm/kg)	1.0 (1.0, 1.4)	0.3 (0.2, 0.4)	−76 (−80, −64)	1.1 (1.0,1.3)	0.4 (0.2, 0,5)	−62 (−72, −57)*	0.99

The results of pre- and post-operative measurements and changes therein are presented as the median (interquartile range). Measurement changes in both groups were compared using the independent-samples t-test or the Mann–Whitney U test as appropriate. *indicated statistical significance as compared to control group; $p<0.05$. ES indicates the effect size (Cohen's d), quantifying the difference in measurement changes between both groups. d-ROMs: derivatives of reactive oxygen metabolites; ES: effect size; PUFAs: polyunsaturated fatty acids; QST: quadriceps strength test.

Several studies on human models have shown that QW can be caused by knee swelling, knee pain, and quadriceps muscle atrophy[3, 5, 6], which are partially induced by tourniquet application during TKA[7, 8]. Tourniquet application and its subsequent release can induce IR injuries[28]. IR injury is often accompanied by oxidative stress and inflammatory response, both of which can induce increased vascular permeability, leading to interstitial edema and tissue damage caused by ischemia and reperfusion[9–11]. Thus, stronger resistance to tourniquet-induced oxidative stress and inflammatory response could attenuate knee swelling, knee pain, and quadriceps muscle loss, resulting in less QW immediately after TKA. In addition, n-3 PUFA supplementation as nutritional preconditioning for IR injury has been shown to suppress IR-induced oxidative stress and inflammatory responses in various organs and tissues, including skeletal muscles[12, 13, 16, 17]. Hence, this study investigated whether preoperative n-3 PUFA supplementation would attenuate increased oxidative stress, knee and thigh swelling, and knee pain, resulting in decreased QW immediately after TKA.

Studies[16, 17] have reported that a high ratio of dietary n-3/n-6 PUFAs suppresses IR injury-induced oxidative stress and pro-inflammatory cytokine expression, including that of interleukin-1 beta. Interleukin-1 beta may play a role in edema formation and ischemic myalgia characterized by local mechanical hypersensitivity, decreased muscle strength, and decreased voluntary activity[29, 30]. In this context, the elevation of the n-3/n-6 PUFA ratio in preoperative n-3 PUFA supplementation may be assumed to attenuate increased oxidative stress, knee and thigh swelling, and knee pain caused by tourniquet-induced IR injury, resulting in a suppression of QW immediately after TKA. In the present study, preoperative n-3 PUFA supplementation in the intervention group led to a significant increase in the (EPA + DHA)/AA ratio compared with that in the control group. In addition, the n-3 PUFA supplementation group exhibited a significantly lower increase in QW than the control group. However, no significant differences in Δ oxidative stress, knee and thigh swelling, and Δ knee pain during QST performed immediately after TKA were observed between the two groups. There were no significant differences in these factors causing QW between the groups, which is likely due to the small sample size; however, the median increase in these factors in the n-3 PUFA supplementation group was lower than that in the control group. The synergistic effect of these factors in the n-3 PUFA supplementation group might have contributed to the significantly lower QW immediately after TKA than that in the control group.

This study had several limitations. First, the sample size of each group was too small due to our failure to recruit the required number of participants on time. Second, the study lacked blinding of the participants, care providers, and outcome assessors. Finally, given that QW was evaluated only on postoperative day 4, it remains uncertain whether early QW attenuation can optimize long-term postoperative recovery. In the future, a large-scale, double-blind, randomized, controlled trial with long-term follow-up is needed to address these limitations.

In summary, this study suggested that preoperative n-3 PUFA supplementation exerts beneficial effects on QW immediately after TKA. Future research that addresses the limitations of this study is needed to confirm the validity of our findings.

Funding and Conflict of interest

This research was funded by Seirei Christopher University Grants-in-Aid of Research. The authors declare no conflict of interest. The funder had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

ACKNOWLEDGMENTS

The authors thank all participants and ward nursing staff for their valuable contribution to this study, as well as Editage (www.editage.jp) for English language editing.

REFERENCES

1) Marmon AR, Milcarek BI, Snyder-Mackler L: Associations between knee extensor power and functional performance in patients after total knee arthroplasty and normal controls without knee pain. Int J Sports Phys Ther, 2014, 9: 168–178. [Medline]
2) Levinger P, Menz HB, Wee E, et al.: Physiological risk factors for falls in people with knee osteoarthritis before and early after knee replacement surgery. Knee Surg Sports Traumatol Arthrosc, 2011, 19: 1082–1089. [Medline] [CrossRef]
3) Holm B, Kristensen MT, Bencke J, et al.: Loss of knee-extension strength is related to knee swelling after total knee arthroplasty. Arch Phys Med Rehabil, 2010, 91: 1770–1776. [Medline] [CrossRef]
4) Kittelson AJ, Stackhouse SK, Stevens-Lapsley JE: Neuromuscular electrical stimulation after total joint arthroplasty: a critical review of recent controlled studies. Eur J Phys Rehabil Med, 2013, 49: 909–920. [Medline]
5) Mizner RL, Petterson SC, Stevens JE, et al.: Early quadriceps strength loss after total knee arthroplasty. The contributions of muscle atrophy and failure of voluntary muscle activation. J Bone Joint Surg Am, 2005, 87: 1047–1053. [Medline] [CrossRef]
6) Kubo Y, Sugiyama S, Takachu R, et al.: Effects of preoperative low-intensity training with slow movement on early quadriceps weakness after total knee arthroplasty in patients with knee osteoarthritis: a retrospective propensity score-matched study. BMC Sports Sci Med Rehabil, 2020, 12: 72. [Medline]
7) Wang K, Ni S, Li Z, et al.: The effects of tourniquet use in total knee arthroplasty: a randomized, controlled trial. Knee Surg Sports Traumatol Arthrosc, 2017, 25: 2849–2857. [Medline] [CrossRef]
8) Guler O, Mahirogullari M, Isyar M, et al.: Comparison of quadriceps muscle volume after unilateral total knee arthroplasty with and without tourniquet use. Knee Surg Sports Traumatol Arthrosc, 2016, 24: 2595–2605. [Medline]
9) Zhang Y, Li H, Wang M, et al.: Vagus nerve stimulation attenuates acute skeletal muscle injury induced by ischemia-reperfusion in rats. Oxid Med Cell Longev, 2019, 2019: 9208949. [Medline]
10) Rodrigues SF, Granger DN: Role of blood cells in ischaemia-reperfusion induced endothelial barrier failure. Cardiovasc Res, 2010, 87: 291–299. [Medline] [CrossRef]
11) de Souza M, Conde CM, Laflôr CM, et al.: n-3 PUFA induce microvascular protective changes during ischemia/reperfusion. Lipids, 2015, 50: 23–37. [Medline] [CrossRef]
12) Farías JG, Carrasco-Pozo C, Carrasco Loza R, et al.: Polyunsaturated fatty acid induces cardioprotection against ischemia-reperfusion through the inhibition of NF-kappaB and induction of Nrf2. Exp Biol Med (Maywood), 2017, 242: 1104–1114. [Medline] [CrossRef]
13) Shih YM, Shih JM, Hou YC, et al.: Pretreatment with fish oil-based lipid emulsion modulates muscle leukocyte chemotaxis in murine model of sublethal lower limb ischemia. Mediators Inflamm, 2017, 2017: 4929346. [Medline] [CrossRef]
14) Darwesh AM, Sosnowski DK, Lee TY, et al.: Insights into the cardioprotective properties of n-3 PUFAs against ischemic heart disease via modulation of the innate immune system. Chem Biol Interact, 2019, 308: 20–44. [Medline] [CrossRef]
15) Cambria RA, Anderson RJ, Dikdan G, et al.: The influence of arachidonic acid metabolites on leukocyte activation and skeletal muscle injury after ischemia and reperfusion. J Vasc Surg, 1991, 14: 549–556. [Medline] [CrossRef]
16) Iwasaki W, Kume M, Kudo K, et al.: Changes in the fatty acid composition of the liver with the administration of N-3 polyunsaturated fatty acids and the effects on warm ischemia/reperfusion injury in the rat liver. Shock, 2010, 33: 306–314. [Medline] [CrossRef]
17) Ma C, Xu Z, Lv H: Low *n*-6/*n*-3 PUFA ratio improves inflammation and myocardial ischemic reperfusion injury. Biochem Cell Biol, 2019, 97: 621–629. [Medline] [CrossRef]
18) Kubo Y, Ikeya M, Sugiyama S, et al.: Association between preoperative long-chain polyunsaturated fatty acids and oxidative stress immediately after total knee arthroplasty: a pilot study. Nutrients, 2021, 13: 2093. [Medline] [CrossRef]
19) Costantini D: Oxidative stress ecology and the d-ROMs test: facts, misfacts and an appraisal of a decade's work. Behav Ecol Sociobiol, 2016, 70: 809–820. [CrossRef]
20) Meijer RS, Rietman JS, Geertzen JH, et al.: Validity and intra- and interobserver reliability of an indirect volume measurements in patients with upper extremity lymphedema. Lymphology, 2004, 37: 127–133. [Medline]
21) Akai M, Doi T, Fujino K, et al.: An outcome measure for Japanese people with knee osteoarthritis. J Rheumatol, 2005, 32: 1524–1532. [Medline]
22) Matsuzawa Y, Kawashima T, Kuwabara R, et al.: Change in serum marker of oxidative stress in the progression of idiopathic pulmonary fibrosis. Pulm Pharmacol Ther, 2015, 32: 1–6. [Medline] [CrossRef]
23) Soderberg GL, Ballantyne BT, Kestel LL: Reliability of lower extremity girth measurements after anterior cruciate ligament reconstruction. Physiother Res Int, 1996, 1: 7–16. [Medline] [CrossRef]
24) Jakobsen TL, Christensen M, Christensen SS, et al.: Reliability of knee joint range of motion and circumference measurements after total knee arthroplasty: does tester experience matter? Physiother Res Int, 2010, 15: 126–134. [Medline] [CrossRef]
25) Kubo Y, Sugiyama S, Takachu R, et al.: Association between serum n-3 polyunsaturated fatty acids and quadriceps weakness immediately after total knee arthroplasty. PLoS One, 2020, 15: e0228460. [Medline] [CrossRef]
26) Suzuki T: Reliability of measurements of knee extensor muscle strength using a pull-type hand-held dynamometer. J Phys Ther Sci, 2015, 27: 967–971. [Medline] [CrossRef]
27) Williamson A, Hoggart B: Pain: a review of three commonly used pain rating scales. J Clin Nurs, 2005, 14: 798–804. [Medline] [CrossRef]
28) Muyskens JB, Hocker AD, Turnbull DW, et al.: Transcriptional profiling and muscle cross-section analysis reveal signs of ischemia reperfusion injury following total knee arthroplasty with tourniquet. Physiol Rep, 2016, 4: e12671. [Medline] [CrossRef]
29) Puhlmann M, Weinreich DM, Farma JM, et al.: Interleukin-1beta induced vascular permeability is dependent on induction of endothelial tissue factor (TF) activity. J Transl Med, 2005, 3: 37. [Medline] [CrossRef]
30) Queme LF, Ross JL, Jankowski MP: Peripheral mechanisms of ischemic myalgia. Front Cell Neurosci, 2017, 11: 419. [Medline] [CrossRef]