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# The Effect of Therapeutic Arthrocentesis on Quadriceps Activation, Strength, And Function in Individuals with Knee Osteoarthritis or After Total Knee Arthroplasty: An Exploratory Study

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## Abstract

**Introduction:** Experimentally induced swelling in a healthy human knee joint immediately decreases quadriceps muscle activation and strength. Knee arthrocentesis is a common clinical procedure to remove swelling with the intent to improve quadriceps activation and strength. Whether this common clinical practice has its intended effects among those with knee osteoarthritis (OA) or after total knee arthroplasty (TKA), where swelling is more chronic, remains unclear.

**Materials/Methods:** This was a pre-post interventional study to explore the immediate effects of therapeutic arthrocentesis in those with knee OA or after TKA if they had at least a 1+ effusion on the stroke test. Individuals were tested immediately before and after arthrocentesis of the swollen knee. The primary outcome was quadriceps activation and secondary outcomes were strength, timed-up-and-go (TUG), 30-second sit-to-stand (30STS), pain, swelling, and ROM.

**Results:** Seven participants with OA (4 female, median age 71.5) and ten with TKA (8 males, median age 71.5) completed testing. There was no significant difference in quadriceps activation from pre- to post-arthrocentesis with a median difference of 2.9% (p=0.47) for OA and 0.5% (p=0.95) for TKA. TUG time significantly improved by a median difference of 0.75 seconds (p=0.02) for OA. There were no significant differences in any other outcome for either group. Target sample size was 34 OA and 34 TKA participants, but recruitment was terminated early due to limited resources, the COVID-19 pandemic, and slow recruitment.

**Conclusions:** This was an exploratory study with small sample sizes. Definitive conclusions cannot be reached. However, therapeutic arthrocentesis did not induce an immediate change in quadriceps activation or strength in this small sample of individuals with knee OA or TKA. Mechanisms underlying quadriceps activation and strength deficits in knee conditions with chronic swelling may differ from experimentally induced swelling in otherwise healthy knee joints.

**Keywords:** Effusion; Total Knee Arthroplasty; Knee Osteoarthritis; Therapeutic Arthrocentesis

**Abbreviations:** AMI: Arthrogenic Muscle Inhibition; OA: Osteoarthritis; ROM: Range of Motion; TKA: Total Knee Arthroplasty; TUG: time-up-and-go; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; 30STS: 30-second sit-to-stand

## Introduction

It is estimated that there are over 654 million individuals over the age of 40 years living with knee osteoarthritis (OA) worldwide, equating to a global prevalence of 16% [1]. Total knee arthroplasty (TKA) is commonly performed to address the chronic pain and functional disability that accompanies knee OA. Quadriceps muscle weakness affects both of these populations, as those with knee OA [2-5] and TKA [6-12] are consistently weaker than their age-matched peers, leading to functional deficits such as decreased gait speed, balance, ability to climb stairs, and even an increased risk for falls [3,7,13-17].

While the cause of quadriceps weakness in these populations is not fully understood and may differ between those with OA and after TKA, one theorized factor is atherogenic muscle inhibition (AMI) [18-23]. AMI is the inability to fully activate the quadriceps muscle voluntarily [24]. In the absence of the ability to fully activate the quadriceps, traditional strength training programs to address quadriceps weakness likely prove ineffective [18,25,26]. In those with knee OA, quadriceps activation deficits have been found to explain 40% of the variance in quadriceps strength [18]. In the first month after TKA, activation deficits explain 65% of quadriceps strength loss, [19,23] and AMI can continue to persist for years after surgery [11,27]. One mechanism underlying AMI is a change in afferent discharge of joint sensory receptors due to inflammation, joint laxity, structural damage to the receptors, or swelling [24]. Thus, one possible way to counter AMI clinically is to address the swelling in the knee joint that frequently occurs with OA [28] and that often persists after TKA [29,30].

Arthrocentesis, a procedure that uses a needle to aspirate fluid from a joint, is often performed with the intent to improve pain and function. However, it is largely unknown whether this common clinical practice has its intended effects in those with knee OA and after TKA. Its premise is based upon studies of healthy populations in which experimentally induced knee effusions using 60-75 mL of saline have consistently demonstrated immediate inhibition of quadriceps activation and decreased strength of up to 30% [31-33]. However, the scarcity of literature investigating the effects of chronic intraarticular swelling on quadriceps activation in those with clinical knee swelling due to OA has been inconclusive [34-37]. Furthermore, to the best of our knowledge, no studies have investigated the relationship between intraarticular swelling and quadriceps activation after TKA.

Thus, while arthrocentesis procedures are commonly performed in practice clinically for those with knee OA or after TKA, it's unclear if they have an immediate effect on quadriceps activation or strength. Additionally, none of the available literature has investigated how therapeutic arthrocentesis may affect performance outcomes. Lastly, in clinical practice and in previous literature, arthrocentesis is often performed with an intraarticular corticosteroid injection. Any potential benefits noted may be the result of either the arthrocentesis or the corticosteroid injection, or possibly a combination of both. There is a dearth of literature regarding the effects of arthrocentesis in isolation in those with knee OA and after TKA that warrants further investigation. If arthrocentesis results in acute increases in quadriceps muscle activation, then swelling can be implicated as a potential underlying mechanism to AMI, similar to that seen in experimentally induced swelling in otherwise healthy knees. Confirming the benefit of arthrocentesis in these populations is important as the procedure introduces the risk of joint infection which is particularly difficult to eradicate in the presence of prosthesis components after TKA [38].

Therefore, the purpose of this study was to explore the immediate effect of arthrocentesis on the primary outcome of quadriceps activation and on the secondary outcomes of quadriceps strength, function, knee range of motion, leg swelling, and pain in those with knee OA and after TKA. Additionally, we sought to explore the relationship between the volume aspirated and all outcomes. We hypothesized that all outcomes would improve immediately after arthrocentesis and that larger aspirate volume would be associated with greater improvements in all outcomes.

## Methods

### Study Design and Participants

This was a prospective exploratory study of individuals with

knee effusion associated with either knee OA or TKA conducted in a research laboratory setting. It was registered on ClinicalTrials.gov (NCT04146649) and approved by the CommonSpirit Health Research Institute Institutional Review Board and Colorado Multiple Institutional Review Board. Informed consent was obtained, and participants' rights were protected. This study adheres to the STROBE reporting guidelines using the extension for cohort studies. Study participation lasted 1 day. Participants were tested on all study outcomes. Immediately after, an arthrocentesis was performed to remove swelling from the knee joint. Finally, immediately after arthrocentesis, repeat testing on all outcomes was performed. We offered an optional 7-14 day follow up period for repeat testing of all outcomes. However, since only 5 participants with OA and 5 participants with TKA chose to return for the follow up visit we've only presented the primary endpoint in this manuscript.

For both OA and TKA, participants were evaluated for the presence of a knee effusion using a stroke test and graded on a 5-point scale (zero, trace, 1+, 2+, or 3+), which has shown good interrater reliability [39]. The stroke test was performed by an orthopedic surgeon, orthopedic physician assistant, or by other study personnel immediately before consenting and testing occurred. Patients with a mild to severe effusion (≥ 1+) were eligible for inclusion in the study. For both OA and TKA, participants were excluded if they had any of the following: effusion related to trauma or another underlying condition, e.g., fracture, ligamentous injury; effusion associated with septic arthritis or periprosthetic knee infection as determined from knee arthrocentesis; known history of gout or with synovial fluid sample testing positive for urate or calcium phosphate crystals; history of inflammatory arthritis, e.g., rheumatoid arthritis, psoriatic arthritis, or juvenile idiopathic arthritis; history of revision knee arthroplasty or uncompartmentalized arthroplasty; any ongoing neurologic, cardiac, or other unstable orthopedic conditions that limits function or ability to participate in outcome measures testing. Participants were recruited from May 2020 to September 2022.

### Knee Osteoarthritis

Knee OA participants aged 18 years or older were consecutively recruited by 4 orthopedic surgeons from 2 institutions in the Denver metro area during routine clinical practice or if they had visited a participating surgeon in the past 6 months for OA related complaints. The diagnosis of knee osteoarthritis was based on knee radiographs read and interpreted by an orthopedic provider or by study personnel. Patients with at least Grade II or higher on the Kellgren and Lawrence Grading System [40] were eligible for inclusion in the study.

### Total Knee Arthroplasty

Participants who had a primary unilateral total knee arthroplasty and were at least 6 weeks post-surgery were recruited by 1 orthopedic surgeon from an institution in the Denver metro area during routine clinical practice. If an individual had mild to moderate effusion and the orthopedic surgeon determined that an arthrocentesis was clinically indicated, they were informed of the research study and invited to participate. All participants had a medial parapatellar surgical approach.

## Intervention

Therapeutic arthrocentesis was performed by an orthopedic provider (surgeon, physician assistant, or resident). Skin was prepared with 2% chlorhexidine gluconate and aspiration was performed with an 18-gauge needle. A more sterile technique was utilized when aspirating knee joints with a prosthesis due to concern for introducing infection. The aspiration site was cleaned with chlorhexidine followed by betadine. An 18-gauge spinal needle was used for aspiration to avoid introduction of soft tissue into the joint. A superolateral approach with the knee extended was used to standardize the procedure between providers and to optimize accuracy [41]. The amount of fluid aspirated was recorded. Outcome assessors were not blinded to the aspirate amount.

## Outcome Measures

All outcomes were collected pre-arthrocentesis and acutely post-arthrocentesis, unless noted otherwise below.

### Quadriceps Strength and Activation

Quadriceps strength of the involved limb was assessed during a maximum voluntary isometric contraction (MVIC) at 60 deg of knee flexion using an electromechanical dynamometer (HUMAC NORM, CSMi, Stoughton, Massachusetts). Participants were given both visual and verbal feedback to encourage maximum contraction. Testing was repeated until 2 trials were within 5% of each other with one-minute rest between trials. The highest torque of these two trials was used for data analysis after normalizing to body weight (Nm/kg). Data were collected with a Biopac Data Acquisition System (Biodex Medical Systems Inc, Shirley, NY) at 2,000 samples per second and analyzed with Acknowledge software, version 5.0 (Biodex Medical Systems, Inc).

Quadriceps voluntary activation was quantified by the doublet interpolation technique, where a supramaximal stimulus is applied (Grass S48 stimulator and SIU8T stimulus isolation unit, Grass Instruments Co, West Warwick, Rhode Island) to the quadriceps muscle during MVIC and again immediately afterward while the muscle is at rest (stimulus parameters: 2 pulses, pulse duration of 600 microseconds, and frequency of 100 pulses per second) [27]. The intensity of the stimulation was first determined by delivering stimulations in increasing 10V increments until the electrically induced torque reached a plateau. Quadriceps activation was calculated as [1 – (a / b)] x 100 where "a" is the torque produced by the supramaximal stimulus during MVIC and "b" is the torque produced by the supramaximal stimulus at rest after the MVIC. Full voluntary activation of the quadriceps would equal 100%; whereas anything less than this represents an activation deficit.

### Functional Performance

Functional performance was assessed using the Timed-Up-and-Go (TUG) test and the 30-second Sit-to-Stand (30STS) test. The TUG test is a responsive, valid, and reliable functional measure of basic mobility and dynamic balance [42-44]. Participants were asked to walk as quickly as possible, and the fastest of two trials was used for analysis. The 30-STS assesses lower body strength and stamina [45] and has been used to evaluate patient functional fitness levels [46] and monitor rehabilitation [47]. One trial of 30-STS was performed.

### Range of Motion (ROM) and Swelling

Knee flexion and extension active ROM was measured in supine with a long arm goniometer [48]. Total limb swelling was assessed by single frequency bioelectrical impedance assessment (SF-BIA) using a RJL Systems Quantum® (Clinton Township, MI) device [30,49]. Swelling is presented as the percent difference between limbs and calculated as (1-(involved bioelectrical impedance assessment/uninvolved bioelectrical impedance assessment))x 100.

### Self-Reported Pain and Function

The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire was used to assess self-reported function, pain, and stiffness pre-arthrocentesis only [50,51]. Additionally, resting pain was assessed pre- and post-arthrocentesis using a verbal numeric pain rating scale (NPRS) from 0 to 10 where 0 represents "no pain" and 10 represents the "worst imaginable pain" [52].

## Power and Sample Size

The purpose of this study was to explore the immediate effects of arthrocentesis on quadriceps activation (primary outcome) in those with knee OA and after TKA. A power analysis was performed prior to recruitment to determine target population size for both study groups. We anticipated a moderate effect size (0.5) based upon previous literature among healthy populations with experimentally induced effusions [33]. To have 80% power at a Type 1 error rate of .05 we needed 34 OA and 34 TKA participants. However, we terminated recruitment after September of 2022 due to limited resources, the COVID-19 pandemic, and slow recruitment.

## Data Analysis

OA and TKA groups were analyzed separately. The difference between post-arthrocentesis and pre-arthrocentesis was calculated for each outcome and assessed for outliers and normality using scatterplots and histograms. Given the small sample sizes and non-normality, we assessed each group for immediate changes in all outcomes from pre- to post-arthrocentesis using the Wilcoxon signed rank test. Spearman's rank correlation was calculated to assess the relationship between the volume of aspirate and the change from pre- to post-arthrocentesis for all outcomes. SAS Version 9.4 (SAS Institute Inc, Cary, NC) was used for all statistical analysis, and the α level was set to .05 for all statistical tests.

# Results

Seven participants with knee OA (4 females) with a median age of 69.0 (interquartile range, IQR: 7.0) and ten participants with TKA (8 males) with a median age of 71.5 (IQR: 14.0) completed the study visit (Table 1). There were no adverse events. At the time of arthrocentesis, participants with TKA were a median of 3.3 months (IQR=9.9) post-surgery. The median aspirate volume was 22mL (IQR: 30mL) for OA and 43mL (IQR: 54mL) for TKA. All pre- and post-arthrocentesis outcomes are listed in (Table 2a) for OA and (Table 2b) for TKA participants.

**Table 1:** Participant Pre-Arthrocentesis Characteristics.

| | OA n=7 | TKA n=10 |
|---|---|---|
| | **Median (IQR)** | **Median (IQR)** |
| **Age, years** | 69.0 (7.0) | 71.5 (14.0) |
| **BMI, kg/m²** | 27.4 (11.9) | 27.2 (3.2) |
| **Time since TKA, months** | - | 3.3 (9.9) |
| **Quadriceps Activation, %** | 77.0 (18.6) | 83.9 (7.6) |
| **Quadriceps Strength, Nm/kg** | 1.6 (1.2) | 1.2 (0.4) |
| **TUG, seconds** | 7.4 (0.86) | 7.4 (2.0) |
| **30STS, repetitions** | 11.0 (6.0) | 11.5 (4.0) |
| **AROM Flexion, °** | 125.0 (10.6) | 118.5 (15.0) |
| **AROM Extension, °** | 3.4 (1.9) | 4.5 (4.0) |
| **Total Limb Swelling, %** | 8.2 (14.0) | 17.7 (21.2) |
| **Resting Pain** | 3.0 (5.0) | 1.5 (3.0) |
| **WOMAC** | 41.0 (24.0) | 26.5 (11.0) |
| **Aspirate Volume, mL** | 22.0 (30.0) | 42.5 (54.0) |

**Abbreviations:** IQR, interquartile range; OA, osteoarthritis; TKA, total knee arthroplasty; BMI, body mass index; kg/m2 kilograms per square meter; %, percent; Nm/kg, newton meter per kilogram; TUG, timed up-and-go; 30STS, 30-second sit-to-stand; reps, repetitions; AROM, active range of motion; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

**Table 2a:** OA Participant Outcomes Pre- and Post-Arthrocentesis.

| ID | Aspirate volume (mL) | Time[a] | Quadriceps Activation (%) | Quadriceps Strength (Nm/kg) | TUG (sec) | 30STS (reps) | AROM (Ext° - Flex°) | Total Limb Swelling (%) | Resting Pain |
|---|---|---|---|---|---|---|---|---|---|
| OA 01 | 10 | Pre | 70 | 1.69 | 7.4 | 11 | 3 - 132 | -4 | 1 |
| | | Post | 67 | 1.70 | 6.3 | 15 | 0 - 135 | -3 | 2 |
| OA 02 | 25 | Pre | 60 | 0.83 | 14.2 | 8 | 3 - 123 | 7 | 6 |
| | | Post | 67 | 0.82 | 10.5 | 9 | 2 - 126 | 7 | 7 |
| OA 03 | 50 | Pre | 71 | 0.20 | 8.1 | 7 | 0 - 135 | 21 | 6 |
| | | Post | 78 | 0.21 | 7.3 | 7 | 0 - 130 | 22 | 7 |
| OA 04 | 22 | Pre | 77 | 1.18 | 7.2 | 14 | 5 - 135 | 10 | 4 |
| | | Post | 63 | 0.80 | 6.8 | 13 | 6 - 125 | 7 | 6 |
| OA 05 | 5 | Pre | 92 | 2.40 | 7.3 | 11 | 6 - 125 | - | 0 |
| | | Post | 95 | 2.34 | 6.1 | 12 | 5 - 125 | - | 1 |
| OA 06 | 18 | Pre | 82 | 1.56 | 7.5 | 10 | 4 - 105 | 23 | 3 |
| | | Post | 92 | 1.34 | 7 | 12 | 6 - 117 | 8 | 3 |
| OA 07 | 40 | Pre | 88 | 2.05 | 7.1 | 16 | 3 - 120 | 7 | 1 |
| | | Post | 91 | 2.11 | 6.9 | 15 | 2 - 120 | 5 | 1 |

**Table 2b:** TKA Participant Outcomes Pre- and Post-Arthrocentesis.

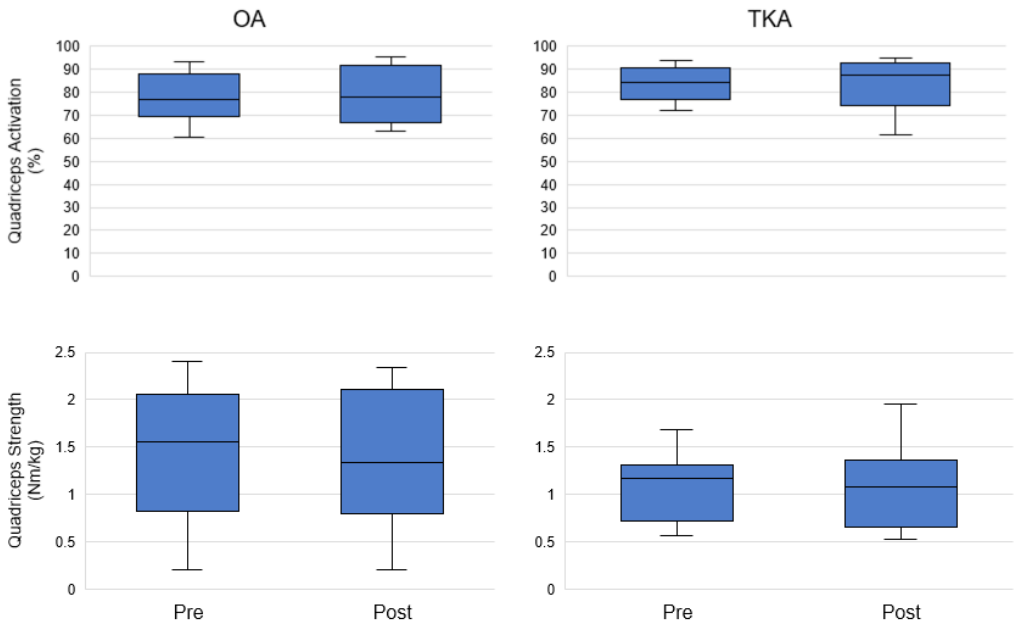
| ID | Aspirate volume (mL) | Time since TKA (months)[a] | Time[b] | Quadriceps Activation (%) | Quadriceps Strength (Nm/kg) | TUG (sec) | 30STS (reps) | AROM (Ext° - Flex°) | Total Limb Swelling (%) | Resting Pain |
|---|---|---|---|---|---|---|---|---|---|---|
| TKA 01 | 85 | 3.6 | Pre | - | - | 7.3 | 12 | 1 - 124 | 12 | 0 |
| | | | Post | - | - | 7.9 | 13 | 1 - 120 | 9 | 0 |
| TKA 02 | 66 | 12.1 | Pre | 86 | 1.17 | 9.2 | 8 | 4 - 131 | 7 | 0 |
| | | | Post | 95 | 1.22 | 9.5 | 9 | 2 - 127 | 6 | 0 |
| TKA 03 | 30 | 1.6 | Pre | 94 | 1.07 | 7.5 | 11 | 10 - 105 | 27 | 3 |
| | | | Post | 87 | 0.92 | 6.4 | 15 | 10 - 102 | 29 | 0 |
| TKA 04 | 16 | 3.9 | Pre | 83 | 0.67 | 6.0 | 13 | 6 - 130 | 14 | 5 |
| | | | Post | 88 | 0.65 | 5.4 | 17 | 4 - 115 | 14 | 5 |
| TKA 05 | 45 | 1.8 | Pre | 91 | 1.41 | 6.7 | 16 | 2 - 113 | 30 | 0 |
| | | | Post | 90 | 1.49 | 5.0 | 16 | 3 - 114 | 31 | 0 |
| TKA 06 | 9 | 11.5 | Pre | - | 0.56 | 8.7 | 0 | 8 - 110 | 7 | 1 |
| | | | Post | - | 0.53 | 8.7 | 0 | 5 - 110 | 0 | 0 |
| TKA 07 | 75 | 3.0 | Pre | 81 | 1.22 | 7.6 | 10 | 6 - 124 | 21 | 2 |
| | | | Post | 82 | 1.09 | 5.7 | 12 | 7 - 125 | 15 | 1 |
| TKA 08 | 40 | 1.4 | Pre | 75 | 1.18 | 7.3 | 13 | 3 - 100 | 38 | 3 |
| | | | Post | 72 | 1.08 | 8.3 | 12 | 10 - 90 | 29 | 3 |
| TKA 09 | 70 | 1.67 | Pre | 72 | 0.78 | 9.4 | 8 | 5 - 125 | 28 | 0 |
| | | | Post | 61 | 0.65 | 9.9 | 7 | 2 - 138 | 27 | 1 |
| TKA 10 | 15 | 45.3 | Pre | 90 | 1.68 | 6.4 | 13 | -2 - 110 | -2 | 4 |
| | | | Post | 93 | 1.96 | 6.0 | 16 | -2 - 113 | -13 | 2 |

**Abbreviations:** ID, participant's study identification; %, percent; Nm/kg, newton meter per kilogram; TUG, timed up-and-go; sec, second; 30STS, 30-second sit-to-stand; reps, repetitions; AROM, active range of motion; ext, extension; flex, flexion; OA, osteoarthritis.

[a] Time since TKA, the time in months from TKA surgery to first study visit.

[b] Timepoint, pre-arthrocentesis and post-arthrocentesis.

For OA, there were no significant differences in quadriceps activation or strength from pre- to post-arthrocentesis with a median difference of 2.9% (p=0.47) and 0.0 Nm/kg (p=0.47), respectively (Figure 1a and Table 3). TUG time significantly improved by a median difference of 0.75 seconds (p=0.02). There were no significant differences in any other outcomes after arthrocentesis (Table 3). There were no significant correlations between aspirate volume and change from pre- to post-arthrocentesis in any outcome for the OA group (Figure 2a and Table 4).




Pre = pre-arthrocentesis; Post = post-arthrocentesis.

**Figure 1:** Quadriceps Activation and Strength at Pre- and Post-Arthrocentesis for OA and TKA.

**Table 3:** Median of the Differences from Pre- to Post-Arthrocentesis for OA and TKA.

| | OA | | | TKA | | |
|---|---|---|---|---|---|---|
| | **n** | **Median of the Differences[a]** | **P Value** | **n** | **Median of the Differences[a]** | **P Value** |
| Quadriceps Activation, % | 7 | 2.91 | 0.47 | 8 | 0.49 | 0.95 |
| Quadriceps Strength, Nm/kg | 7 | -0.01 | 0.47 | 9 | -0.03 | 0.50 |
| TUG, seconds | 7 | -0.75 | 0.02[b] | 10 | -0.22 | 0.38 |
| 30STS, repetitions | 7 | 1.00 | 0.38 | 10 | 1.00 | 0.13 |
| AROM Flexion, ° | 7 | 0.00 | 1.00 | 10 | -1.50 | 0.38 |
| AROM Extension, ° | 7 | -1.00 | 0.66 | 10 | 0.00 | 0.50 |
| Total Limb Swelling, % | 6 | -0.85 | 0.44 | 10 | -2.01 | 0.08 |
| Resting Pain | 7 | 1.00 | 0.06 | 10 | 0.00 | 0.25 |

**Abbreviations:** OA, osteoarthritis; TKA, total knee arthroplasty; %, percent; Nm/kg, newton meter per kilogram; TUG, timed up-and-go; 30STS, 30-second sit-to-stand; AROM, active range of motion.

[a] The difference from pre- to post-arthrocentesis is calculated for each participant. Then the median is taken of these differences.

[b] Statistically significantly different from pre- to post-arthrocentesis (p<0.05).

For TKA, there were no significant differences in quadriceps activation or strength from pre- to post-arthrocentesis with a median difference of 0.5% (p=0.95) and 0.0 Nm/kg (p=0.50), respectively (Figure 1b and Table 3). Similarly, there were no significant differences in any other outcomes after arthrocentesis (Table 3). There were no significant correlations between aspirate volume and change from pre- to post-arthrocentesis in any outcome for the TKA group (Figure 2b and Table 4).

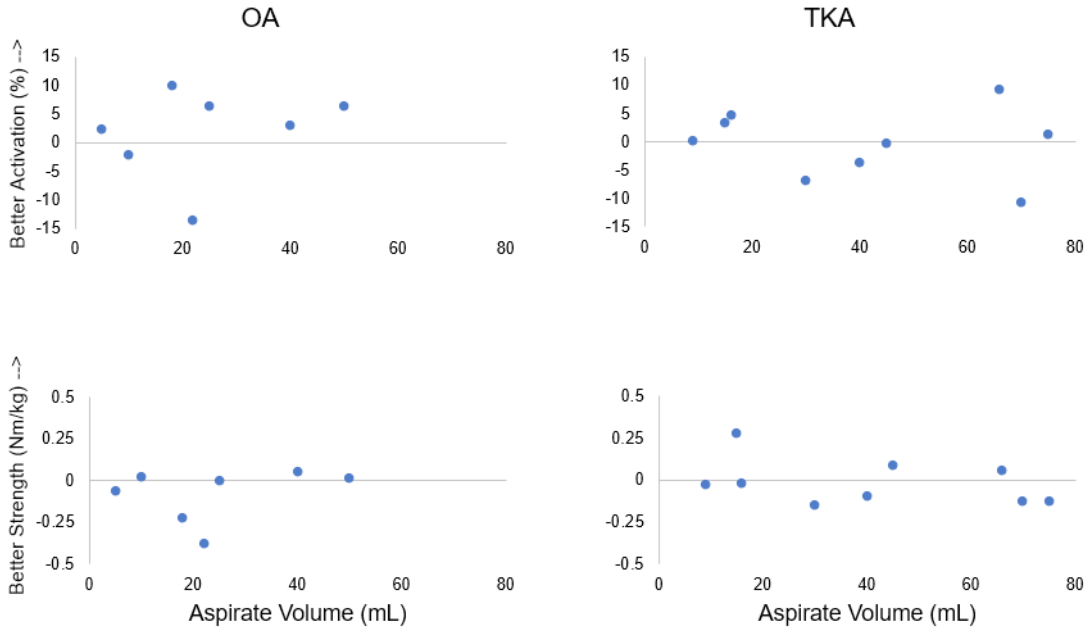



**Figure 2:** Change in Quadriceps Activation and Strength from Pre- to Post-Arthrocentesis vs. Aspirate Volume.

**Table 4:** Spearman's Rank Correlation between Aspirate Volume and All Outcomes for OA and TKA.

| | OA | | | TKA | | |
|---|---|---|---|---|---|---|
| | ρ | 95% CI | P Value | ρ | 95% CI | P Value |
| **Quadriceps Activation** | 0.30 | -0.59, 0.86 | 0.51 | -0.20 | -0.79, 0.59 | 0.63 |
| **Quadriceps Strength** | 0.33 | -0.56, 0.87 | 0.45 | -0.33 | -0.82, 0.43 | 0.37 |
| **TUG** | 0.33 | -0.56, 0.87 | 0.45 | 0.13 | -0.54, 0.70 | 0.71 |
| **30STS** | 0.59 | -0.93, 0.30 | 0.15 | 0.24 | -0.76, 0.46 | 0.49 |
| **AROM Flexion** | -0.34 | -0.87, 0.56 | 0.45 | 0.07 | -0.58, 0.67 | 0.83 |
| **AROM Extension** | 0.20 | -0.65, 0.83 | 0.65 | 0.23 | -0.47, 0.75 | 0.51 |
| **Total Limb Swelling** | 0.08 | -0.78, 0.84 | 0.88 | 0.15 | -0.53, 0.71 | 0.66 |
| **Resting Pain** | -0.11 | -0.80, 0.70 | 0.81 | 0.47 | -0.23, 0.85 | 0.16 |

**Abbreviations:** OA, osteoarthritis; TKA, total knee arthroplasty; ρ, Spearman's rank correlation coefficient; TUG, timed up-and-go; 30STS, 30-second sit-to-stand; AROM, active range of motion.

## Discussion

We sought to explore the immediate effect of arthrocentesis on quadriceps muscle activation, strength, and function in those with knee OA and after TKA. We did not find a significant change in quadriceps activation or strength for either group immediately after arthrocentesis. Furthermore, we did not find a correlation between aspirate volume and change from pre- to post-arthrocentesis for any outcome for either group. While our data are limited, preliminary results suggest that therapeutic arthrocentesis does not significantly improve quadriceps strength or function in patients with either knee OA or TKA.

After arthrocentesis, quadriceps activation had a median difference of 2.91% for OA and 0.49% for TKA. This finding is similar to Jones et al., who found a nonsignificant increase in activation of 1.9% after arthrocentesis among individuals with knee OA or chronic inflammatory synovitis [37]. Additionally, our findings concur with previous studies that measured quadriceps voluntary activation indirectly by changes in surface electromyography (EMG) activity [36,53]. Using EMG of the vastus medialis and vastus lateralis during maximal voluntary contractions of the quadriceps muscle after arthrocentesis, Lim et al., and Geborek et al., found no change in muscle activity among individuals with osteoarthritis or rheumatoid arthritis [36,53] Conversely, Rice et al., did find a

significant increase in flexion reflex threshold after aspirating 24mL from individuals with chronic knee arthritis [35]. The flexion reflex threshold is theorized to affect AMI along a different pathway, [35] but this pathway also appears unrelated to measures of quadriceps activation [54]. Our findings are also in contrast to other studies that have experimentally induced effusion into otherwise healthy knee joints and saw decreases in quadriceps activation [33] and quadriceps activity on surface EMG [32,55].

Similar to what we found for quadriceps activation; we did not find a change in quadriceps muscle strength immediately after arthrocentesis for either group. Our findings concur with Lim et al., who also did not find an immediate change in quadriceps strength after injecting 20mL of normal saline into knees with osteoarthritis but without any current intraarticular swelling, i.e., experimentally inducing intraarticular swelling [36]. But our findings appear to be in contrast to Fahrer et al., Geborek et al., and Rice et al., who found statistically significant improvements in quadriceps strength after arthrocentesis in individuals with knee OA, rheumatoid arthritis, psoriatic arthritis, or reactive arthritis [34,35,53]. However, Geborek et al., and Rice et al., reported only a 9 Nm increase in torque [35,53]. This is less than the 25 Nm minimal detectable change (MDC) at the 90% confidence level found for quadriceps isometric strength testing in individuals with knee OA [56]. Thus, while statistically significant, we cannot be confident that the changes in strength reported reflect a true improvement as opposed to error in the measurement. Similarly, Fahrer et al., only found a 13% increase in strength from pre- to post-arthrocentesis indicating that if arthrocentesis does influence strength, its effect is likely small. Thus, if findings across studies are considered collectively and interpreted with regard to clinical meaningfulness and not just statistical significance, arthrocentesis does not appear to have an effect on quadriceps strength. Interestingly, our findings do contrast with other studies that have experimentally induced effusion into otherwise healthy knee joints and saw immediate decreases in quadriceps strength [31-33,55]. However, it must be noted that we did not reach our target sample size, and we may have been underpowered to detect relevant differences.

We did find a statistically significant improvement in TUG immediately after arthrocentesis for the OA group with a median difference of -0.75 seconds (p=.02). This finding is likely due to the practice effect as we did not find an improvement in any other outcome to corroborate a true change in function. Additionally, the MDC at the 95% confidence level for the TUG in individuals with knee OA is 1.1 seconds, which is greater than our finding [57]. We did not find an immediate change in any outcome for the TKA group. Given that TKA participants varied widely in their time since index surgery (range: 1.4 - 45.3 months), we performed 2 sensitivity analyses to determine if time since surgery influenced the immediate effects of arthrocentesis. First, we removed participant TKA10 (45.3 months), but we still did not find any change in any outcome after arthrocentesis. Next, we removed participants TKA02 (12.1 months), TKA06 (11.5 months), and TKA10, leaving only participants who were less than 4 months since surgery. Still, we did not find any significant change in any outcome after arthrocentesis.

We also sought to examine the relationship between aspirate volume and all outcomes. The median aspirate volume was 22mL for OA and 43mL for TKA. These volumes are similar to that reported in previous research investigating the effects of arthrocentesis on quadriceps activation and strength in individuals with chronic knee arthritis with mean or median volumes ranging from 15-50 mL [34,35,53]. We did not find any significant relationships for either group, even after performing the sensitivity analyses described above. These findings concur with previous literature in which no relationship was found between aspirate volume and quadriceps activation [37] or strength [34,53] among individuals with OA, rheumatoid arthritis, reactive arthritis, or chronic inflammatory synovitis. Conversely, in healthy knees with experimentally induced effusion, Torry et.al, found that quadriceps strength decreased as effusion volumes increased [55].

Collectively, our results and those of previous studies investigating conditions with knee effusions suggest that chronic intraarticular swelling may not be the predominant mechanism behind the well documented quadriceps activation deficits and weakness in these populations. An alternate explanation is that chronic or recurrent effusions may alter the joint capsule compliance or damage articular sensory receptors so that swelling does not affect joint afferent discharge in the same way that an acute experimental or injurious effusion does [36]. Instead, in individuals with OA or TKA, pain, inflammation, or joint laxity could be the predominant factors affecting the excitability of spinal reflex pathways and leading to AMI [24]. Additionally, growing evidence suggests that the mechanisms of AMI likely adapt over the course of an injury or pathology [58]. Experimentally induced or acute traumatic knee effusions cause an immediate change in joint afferent discharge, resulting in decreased excitability in spinal reflex pathways and ultimately inhibition of alpha motor neuron activation at the spinal cord level [58]. But recent evidence has shown that this decreased excitability in spinal reflex pathways usually resolves after the acute injury stage [58]. Thus, persistent quadriceps AMI and strength loss in chronic knee conditions may be predominantly explained by mechanisms within the central nervous system [58]. Systemic neuroplastic alterations have been shown to occur in the somatosensory cortex and motor cortex after a joint injury and collectively can lead to decreased descending motor output [58]. Thus, in the early stages of joint disease or injury, muscle inhibition could be arthrogenic dominated (i.e., due to spinal reflex inhibition brought about by changes in, or injury to, joint tissue) and then change over time to be supraspinal-dominated (i.e., due to changes in neural processes of the somatosensory and motor cortices) [59]. Our findings suggest that quadriceps AMI in those with knee OA or at least 6 weeks status-post TKA is not driven by intraarticular swelling. It remains to be determined if other arthrogenic mechanisms, central nervous system mechanisms, or a combination of both can explain the quadriceps activation deficits and weakness exhibited by individuals with these conditions.

## Study Limitations

There are several limitations to this study. This study did not assess how long swelling was present or differentiate between

acute versus chronic swelling. We also did not specifically look at which individuals in the TKA group had a tourniquet used in surgery which has been shown to affect quadriceps strength up to 3 months after surgery [60]. Additionally, this study only assessed the immediate response in outcomes after therapeutic arthrocentesis. This may have been too short a period to see any potential benefit from this procedure. Lastly, we did not achieve our desired sample size. We chose to terminate the study early due to resource limitations, the COVID-19 pandemic, and slow recruitment. Poor recruitment is the most frequent reason for premature discontinuation of prospective clinical studies, but this should not preclude publication of study findings [61]. Thus, we chose to present our results as an exploratory study rather than a confirmatory study to transparently report this potential bias. As such, we were underpowered to detect a significant change in our outcomes from pre- to post-arthrocentesis. Similarly, it is possible that true correlations with aspirate volume may be detected with larger sample sizes, but there was no indication of support for the mechanistic effects of arthrocentesis on AMI or associated outcomes. Our findings are in concordance with previous literature in which no meaningful changes in quadriceps muscle function were noted after arthrocentesis in individuals with knee conditions subject to chronic swelling.

## Conclusions

In this exploratory study that was prematurely discontinued, we found no immediate change in quadriceps muscle activation, strength, or function after therapeutic arthrocentesis in individuals with knee OA or after TKA. We also did not find any correlations between aspirate volume and the same outcomes. Therapeutic arthrocentesis is not without risks, especially following TKA, and our findings suggest that it may not provide immediate clinical benefit to quadriceps function. Given our limited sample size, future research is needed to definitively confirm these findings. This research should collect both short- and long-term data to determine if arthrocentesis may improve long-term quadriceps function. Additionally, other mechanisms surrounding AMI should be explored, such as other atherogenic or central nervous system mechanisms, so that targeted intervention strategies can be developed for individuals with OA or after TKA presenting with AMI.

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## Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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