4-23-2021

Pain Response of Transcutaneous Electrical Nerve Stimulation to Different grades of Knee Osteoarthritis

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Lee Honors College Thesis

Acknowledgment

I would like to acknowledge all who have played a role in my academic accomplishments. First and foremost, my family and fiancé, who supported me with love and encouragement throughout my education. Without you guys, I would never have reached all my academic dreams.

Secondly, my committee members, who have each played a role in guiding me throughout this process and encouraging me to challenge myself. To my mentor and thesis committee chair, Dr. Daryl Lawson, who introduced me to the realm of research in physical therapy and dedicated his time to being my chair advisor for the Lee Honors College. Thank you for taking me under your wing and showing me the value of research. To my committee member, Dr. Kevin Lee, who took the time to discuss and teach me statistics about my thesis. To my committee member, Dr. Christina Woytal, who dedicated time out of her practice to guiding me and provide feedback to help me grow as a pre-professional.

Completing this project could not have been possible without my committee and I am grateful for the amount of time they put aside to help me achieve this academic accomplishment. Thank you all.

Abstract

Knee osteoarthritis (OA) is diagnosed worldwide and affects nearly 250 million people (Wallace et al., 2017, pg. 1). Additionally, people who are 45 years and over are prone to this degrative disease (Wallace et al., 2017, pg. 1). Knee OA can be graded into five categories (0-4) levels associated with the Kellgren-Lawrence grading scales (Kellgren & Lawrence, 1957, pg. 494). Symptoms will develop overtime; thus, it is important to find non-pharmacological ways to help alleviate pain for individuals affected. A non-pharmacological modality of interest is the transcutaneous electrical nerve stimulation (TENS) units, which can be tailored to a patient's specific needs to reduce acute/chronic pain (Vance et al., 2014, pg. 198). This paper examined results obtained from a study by Dr. Lawson at Western Michigan University. Results analyzed the use of TENS units during functional testing on knee grading levels 2A, 2B, and 3 (Lawson &Lee et al., 2020). The study showed promising evidence to finding low-cost modalities for people who are affected by this degrading disease.

Keywords: Knee osteoarthritis (OA), TENS, non-pharmacological, adults

Introduction

For decades, a dismaying amount of people across the globe have been diagnosed with knee osteoarthritis (OA). Knee osteoarthritis (OA) is considered to be a highly prevalent disease that provokes onset pain and/or disability but causes of increased prevalence remain abstruse (Wallace et al., 2017, pg. 1). Symptoms of knee osteoarthritis develop over time and consist of pain, stiffness, bone spurs, reduced range of motion, sensitivity to light pressure in the joint, and swelling ("Osteoarthritis", 2020). According to Mora, Przkora, and Cruz-Almeida (2018), "This degenerative and progressive joint disease affects around 250 million people worldwide[2] and more than 27 million people in the United States[3,4]" (pg. 2189). In addition, individuals 45 years and older are 19% likely to be affected by this degrading disease (Wallace et al., 2017, pg. 1). Abominably, progression of OA raises concerns for the quality of life and the importance of identifying nonpharmacological treatments to alleviate associated pain.

In previous years, radiological assessments were used to determine grading levels along with magnetic resonance imaging (MRI), but most currently, ultrasound (MSK US) has been used to diagnose/assess the severity grades of the knee. This assessment method has advanced the diagnosis process by detecting the osteophytes, and additional measures, to grade what level of severity (none too severe) may be present in the knee (Mortada et al., 2016, pg.161). Additionally, ultrasounds are cost-effective, portable, real-time dynamic, no radiation exposure to the patient, and they have the ability to take various images of structures within the joint (Abraham et al., 2011, pg.1, Oo WM. et al., 2016, pg. 324). Knee OA can be diagnosed with an x-ray, which has been the gold standard, by identifying features consist of the formation of osteophytes, periarticular ossicles, narrowed joint cartilage, and disfigured bone ends (Kellgren & Lawrence, 1957, pg.494). Detectable osteophytes identify the presence of OA along with the

progression of it (Mortada et al.). One cross-sectional study examined 45 patients to evaluate the reliability and validity of a musculoskeletal ultrasound (MUS) system to detecting knee OA (Riecke et al., 2014, pg.1675). It was determined by this study that MUS was reliable and valid in determining knee OA (Riecke et al., 2014, pg. 1675). Other previous work has also identified US to be reliable and in accordance with the Kellgren-Lawrence (K&L) grading scale (Mortada et al., 2016, pg.161).

Furthermore, symptom control is the most predominant intervention for the management of knee OA. Considering this, non-pharmacological approaches are suggested first for treatment options. Approaches such as non-pharmacological can be great as the exercise is tailored to the tolerance of the patient (Mora et al., 2018, pg. 2190). This way, you can see what may or may not be helping the patient. In addition to therapeutic exercise, another intervention is the use of transcutaneous electrical nerve stimulation (TENS). TENS units are an intervention that is intended to reduce acute/chronic pain (Vance et al., 2014, pg. 198). TENS units are placed in the area of pain at the knee and delivers high frequency and/or low-frequency stimulation based on the patient's preference (Vance et al., 2014, pg. 197). They work by activating afferent fibers, which then send a message to our central nervous system (CNS) to activate our inhibitory system, which in return makes sure the brain functions smoothly (Vance et al., 2014, pg.198). The initiation of our inhibitory system is to help reduce the sensitivity to pain (Vance et al., 2014, pg. 198).

In addition, there have been a few studies conducted that explored the use of TENS units on knee pain and utilize various functional testing and outcome questionnaires. Outcome Measures such as visual analog scale (VAS) and knee disability, osteoarthritis outcome score (KOOS), and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) to

gather symptom/pain information on subjects (Lundgren-Nilsson et al., 2018, pg.1-6, McConnell et al., 2001, pg. 453). Studies, such as the one conducted by Shimoura et. al (2019), showed positive responses in terms of reducing pain while walking (pg. 303-305). Whereas other studies determined inconclusive results (Vance et al., 2014, pg.203) or lack of beneficial effects for pain levels (Palmer et al., 2014, pg. 390-393). In addition, there are sparse studies that analyze the pain during functional interventions while utilizing TENS units. With such variety in studies, it is ambiguous if TENS is successful in pain management for people diagnosed with knee OA.

Collectively, it is important to analyze treatment options that are effective, low cost, and identify evidence-based treatment to nonpharmacological pain reduce pain. Considering this, I aim to investigate different levels of knee osteoarthritis and analyze their pain response to TENS units during functional testing.

Methods

Subjects

Recruitment of subjects for the study titled "The use of transcutaneous electrical nerve stimulation (TENS) along with functional tasks for immediate pain relief in individuals with knee osteoarthritis (OA)" by Dr. Lawson was completed by placing flyers throughout the Kalamazoo area, sending emails to Western Michigan Universities faculty members, and use of social media platforms. Individuals interested were asked to contact the research assistants to review the inclusion and exclusion criteria. An interview was then conducted over the phone to determine the eligibility of the individuals. If all criteria were met, they proceeded to schedule a date to participate in the study. Also, subjects who met the criteria in both knees were asked which knee was the most painful. After the subject indicated which knee, it was then evaluated for the study. On the day of participation, all subjects sign an informed consent form.

The inclusion criteria for the research study consisted of the subject being a male or female, at least forty-five years or older, have an ultrasonography scale of 1-3 grading of knee OA, and perceived pain of a 3/10 on a 0-10 scale. In addition, the potential subject had to have no phobia of electrical stimulation, not taking pain or anti-inflammatory medication during the study, and they had to have an injury and/or pain that began at least six weeks prior to the study.

Additionally, the exclusion criteria consisted of pregnancy, neuropathy, smoker, previous surgery in the area to be treated by the TENS unit, Diabetes Mellitus, uncontrolled hypertension, arthritis, and allergy to tape and/or electrodes. There had to be no intra-articular corticosteroid or hyaluronic acid injection six months prior to the study, dementia, a history of tibial osteotomy, a history of a knee joint replacement, currently in physical therapy, major joint pain (high pain level that could lead to hospitalization) that was limiting functional ability, contraindications to TENS unit such as a pacemaker, and severe medical or neurological conditions. Lastly, not utilizing the stairs in daily living and inability to walk without ambulatory assistive devices such as a cane.

Materials

To assess the degree of knee osteoarthritis (OA) in the subjects' knee, a musculoskeletal ultrasound (MSK-US) imaging machine was used. MSK-US can visualize structures involved in the progression of osteoarthritis (Abraham et al., 2011, pg. 1). Using the MSK-US machine allows for the classification of the knee OA in relation to the Kellgren-Lawrence grading scale. There are five grading (0-4) levels associated with the Kellgren-Lawrence grading scales (Kellgren & Lawrence, 1957, pg. 494). Grade 0 indicates no signs of osteoarthrosis, grade 2 indicates the presence of osteoarthrosis and minimally severe, and grade 4 is the most severe (Kellgren & Lawrence, 1957, pg. 494). Using an MSK-US imaging machine comes with

advantages such as no radiation use, more cost efficient, and the ability to view area of interest in multiple planes (Abraham et al., 2011, pg. 1).

During functional testing, transcutaneous electrical nerve stimulation (TENS) units (*Omron Healthcare) and electrodes were placed under the patella on the subject's knee of interest. The placement of the TENS units under the patella was to ensure that the subjects were able to exhibit the full range of motion and knee pain. For example, if you were to place it on the patella, that does not leave the participant the ability to bend during functional testing and would hinder what the full effect of the TENS unit was on their expressed knee pain. TENS units were also placed on each subject by the same research assistant under the supervision of a licensed physical therapist. The use of the TENS units is intended to induce physiological effects such as activating the neuronal network to help reduce pain (Vance et al., 2014, pg. 198). Subjects received either an active or placebo TENS unit, and the dispersion of units was double-blinded.

Procedures

Protocol from the study included an initial visit and then a second visit one to six weeks after the initial visit. During each visit, the subjects underwent two trials of functional tests: one with the TENS units off and one with the TENS unit on. Subjects performed all functional tests under the supervision of a licensed physical therapist, who has clinical experience in orthopedics.

During the first visit, subjects gave informed consent, filled out demographic data such as age, gender, and their occupation, and baseline measurements including the Visual Analog Scale (VAS), Hospital Anxiety and Depression Scale (HADS), Knee Disability and Osteoarthritis Outcome Score (KOOS), and Pain Catastrophizing Scale (PCS). The HADS, KOOS, and PCS measurements were obtained at the beginning of each visit before any functional tests. The VAS measurement was provided by the subject by drawing a mark between a scale of 0-cm to 10-cm.

The VAS score was obtained before the trial and TENS use, and then after each functional test was completed. The VAS indicates 0-cm being no pain and 10-cm being extremely painful (Delgado et al,.2018, pg.1).

After completion of paperwork, the supervising physical therapist utilized the MS-US imaging tool to obtain multiple views of the symptomatic knee. The subject laid in a supine position while the supervising physical therapist took images of their symptomatic knee. Once the MS-US imaging tool was positioned, an image of the area was saved for further analysis. The supervising physical therapist was then able to classify the knee OA in relation to the Kellgren-Lawrence grading scale.

Once MSK-US images were completed, electrodes and the TENS unit were placed under the patella of the knee. The TENS unit was not turned on for the first trial of functional testing but was turned on for the second trial of testing of the visit. After each functional test was performed, subjects were asked to fill out a VAS to determine their pain level after completing that test. The functional tests the subjects underwent included the following:

- Stair climb test (Bennell et al., 2011, pg. 353-356)
- Timed Up and Go test (Bennell et al., 2011, pg. 360-362)
- 6-minute walk test (Bennell et al., 2011, 356-358)
- Knee extensor strength test (Hirano et al., 2020, pg. 120-124; Kim et al., 2014, pg. 84-93)
- Locomotive Syndrome Risk test (Kojima et al., 2017, pg. 1025-1028).

After completion of the first trial of functional tests (TENS unit not on), subjects rested for 30-minutes. After the duration of rest, the TENS units were turned on and the subjects performed the same functional tests and provided VAS measurements after completion of the tests. Once the subject completed both trials and VAS assessments, the subjects were asked to answer

another measurement of the PCS questionnaire. Subjects then returned one to six weeks after the initial visit for their second (last) visit. The same functional tests and questionnaires were performed for their second visit, but the subject used a different TENS unit than the one provided in their first visit.

Results

Twenty subjects participated in the study which consisted of sixteen females and four males. The MKS US imaging results of the twenty subjects identified ten subjects as grade 2A, two subjects as grade 2B, and eight subjects as grade 3 of knee OA (Lawson & Lee et al., 2020, pg. 12). Table 1 highlights the significance of each grading level of knee OA.

Grade 0 -No osteophytes. Regular femoral condyle without any projection.
Grade 1- Minor osteophyte (small projection) from the femoral condyle.
Grade 2 ***2A*** -Small osteophytes (small projections) from the femoral condyle that appears to have an inferior part in the joint space zone. ***2B***- Large osteophyte (large projection) that appears to be separated from the femoral condyle and has an inferior part in the joint space zone.
Grade 3 -Large osteophyte (large projection) that appears to be separated from the femoral condyle and has an inferior part in the joint space zone with small superior extension parallel to the femoral bone.
Grade 4 -Mainly superior osteophyte (superior projection) parallel to the femoral bone, with or without an inferior part in the joint space zone.

Table 1. *Note.* Adapted from "Reliability of a Proposed Ultrasonographic Grading Scale for Severity of Primary Knee Osteoarthritis", by Mortada et al., 2016, *Clinical Medicine Insights: Arthritis and Musculoskeletal Disorders*, pg. 162 (DOI:10.4137/CMAMD.S38141), licensed under CC-BY-NC 3.0.

Once grading levels and data were obtained, statistical tests were then used to determine if the active TENS units were successful in decreasing pain during functional tests. The statistical tests included the mean pain scores, standard deviations that are present in the parenthesis, and p-values to determine if there was enough evidence to reject the null hypothesis. Additionally, p-values less than 0.05 concluded there was enough evidence to reject the null hypothesis.

Statistical significance affirmed a decrease in pain while using the active TENS unit for subjects who had grading levels of 2A, 2B, and 3 (Tables 2.1, Table 2.2, Table 2.3). As displayed, subjects with an indicated grading level of 2A (Table 2.1) show a statistical significance in lower pain response to active TENS unit versus the placebo unit during functional testing. As presented in table 2.1, there was enough significant evidence in the LSR_2ST to reject the null hypothesis.

Test	Active	Placebo	p-value
Star Climb Test	2.67 (2.07)	3.01 (2.14)	0.3048
Time Up and Go Test	1.54 (1.11)	2.11 (1.69)	0.1861
Six Minute Walk Test	3.08 (2.14)	2.52 (2.12)	0.7975
Knee Extensor Strength Test	2.12 (1.96)	2.42 (2.35)	0.0571(*)
Locomotive Syndrome Risk 2-Step Test	1.63 (1.65)	2.56 (2.19)	0.0076(**)

Table 2.1 Pain response to subjects(n=10) with grading level of 2A. *Note.* Reproduced from "*The use of transcutaneous electrical nerve stimulation along with functional tasks for immediate pain relief in individuals with knee osteoarthritis",* by Lawson & Lee et al., 2020, Manuscript submitted for publication.

Test	Active	Placebo	p-value
Star Climb Test	2.44 (1.95)	2.72 (2.08)	0.2303
Time Up and Go Test	1.48 (1.01)	1.96 (1.58)	0.2014
Six Minute Walk Test	2.74 (2.09)	2.29 (2.00)	0.7951
Knee Extensor Strength Test	1.93 (1.83)	2.19 (2.22)	0.0437(**)
Locomotive Syndrome Risk 2-Step Test	1.49 (1.54)	2.31 (2.09)	0.0074(**)

Table 2. 2 Pain response to subjects with grading levels of 2A or 2B. *Note.* Reproduced from "*The use of transcutaneous electrical nerve stimulation along with functional tasks for immediate pain relief in individuals with knee osteoarthritis",* by Lawson & Lee et al., 2020, Manuscript submitted for publication.

When analyzing table 2.1 versus 2.2, we see a decrease in mean VAS pain response to the active TENS units during all functional tests performed. For example, a mean of 1.54 was calculated for a grade level 2A with an active TENS unit, whereas a mean of 1.48 was calculated when assessing pain responses to subjects of grading levels 2A or 2B. As the grading level of knee OA increased with the use of active tens, respectively, there was a decrease in the mean response while performing the functional testing. In addition, in both table 2.1 and 2.2, we see an increase in the mean VAS pain response when using the placebo TENS unit during function testing.

Test	Active	Placebo	p-value
Star Climb Test	1.90 (1.99)	2.57 (2.23)	0.0313(**)
Time Up and Go Test	1.30 (1.36)	1.85 (1.73)	0.0411(**)
Six Minute Walk Test	2.25 (2.11)	2.31 (2.13)	0.4548
Knee Extensor Strength Test	1.72 (1.89)	2.07 (2.12)	0.2025
Locomotive Syndrome Risk 2-Step Test	1.44 (1.74)	2.03 (1.92)	0.0154(**)

Table 2. 3 Pain response to subjects with grading levels 2A, 2B, or 3. *Note.* Reproduced from "*The use of transcutaneous electrical nerve stimulation along with functional tasks for immediate pain relief in individuals with knee osteoarthritis",* by Lawson & Lee et al., 2020, Manuscript submitted for publication.

When incorporating the subjects who were categorized in either 2A, 2B, or 3, there is a displayed trend of decreased pain during functional tests while using the active TENS unit. This trend is apparent in table 2.3 where the VAS pain mean scores were reduced with active TENS units versus the placebo TENS, and a significant p-value is displayed to support the alternative hypothesis, active TENS during functional testing will reduce pain (Lawson & Lee et al., 2020). Table 2.3 also shows significant evidence in terms of the p-value section. In the SCT, TUG, and LSR_2ST, the p-values are lower than 0.05. This means the null hypothesis was rejected and there was significant evidence to argue that the active TENS reduces pain.

Grading levels (2A, 2B, or 3) in tables 2.2 and table 2.3 were combined due to lack of subjects within each grading category. Considering this, it is hard to separate each Knee OA

grading category to perform statistical measures in order to identify differences between each grading level of knee OA with the active TENS.

Discussion

A major symptom associated with knee osteoarthritis is joint pain (Hunter et al., 2009, pg. 2). Other associated symptoms vary but can include lack of function, buckling of the joint, swelling, short-term stiffness and even loss of sleep for advanced cases of this disease (Hunter et al., 2009, pg. 2). Therefore, research has been conducted to seek less invasive modes of symptom control for pain associated with knee osteoarthritis.

As discussed in the literature, treatment for Knee OA should be aimed towards controlling pain as well as improving daily functional ability in patients with this chronic disease (Mora et al., 2018, pg. 2190). Thus, attempting non-pharmacological approaches that can be tailored to the patient's needs has been recommended as a primary mode of therapy (Mora et al., 2018, pg. 2190). TENS units are nonpharmacological interventions that have been explored in chronic pain situations, such as Knee OA, to help alleviate pain (Vance et al., 2014, pg. 198; Rutjes et al., 2010, pg. 6). The unit is placed at the source of pain, and supplies frequency stimulation through cutaneous electrodes that would be adjusted based on the patient (Vance et al., 2014, pg. 198). Past studies that have utilized this method of treatment for Knee OA. One study by Shimoura et al., (2019), provided hopeful results as pain reduced while walking (pg. 303-305). While other studies provided inconclusive results, which make it difficult to determine whether TENS proves to be an effective treatment for Knee OA (Vance et al., 2014, pg. 203). Thus, a variety in past studies has deemed it unclear as to whether TENS units are successful for pain management of this disease.

This paper aimed to investigate different levels of Knee OA and their response during functional testing. Three grading levels of Knee OA were analyzed throughout this paper including gradings 2A, 2B, and 3. It is important to note that the data analyzed was grouped, as the study was limited in how many individuals presented specific grading levels. Considering this, it remained unclear, for example, if a 2A grading level showed a more significant reduction in pain during functional testing than a grading level of 3. Thus, it is inconclusive as to whether the TENS units solely worked better for one grade level versus another for treatment purposes.

In addition, results did show significant differences in the p-values when analyzing data grading level of 2A versus data of 2A and grading level 2B combined (Table 2.1 & Table 2.2). For example, in grading level 2A data shows sufficient p-values to reject the null hypothesis in the Locomotive Syndrome Risk 2-Step Test (LSR_2ST), but when grading levels 2A and 2B are combined, data affirms rejection of the null hypothesis in both the Knee Extensor Strength test and LSR_2ST functional tests. It is interesting that as you incorporate more than just one grading level, there seems to be more evidence to support the alternative hypothesis of TENS units reducing pain during functional testing. In addition, both tables show a decrease in active TENS units while performing functional testing.

Furthermore, results from the study affirmed a decrease in pain for all three grading levels while using the active TENS unit during the functional tests. Pain levels were significantly reduced, when all three grading levels were grouped, while using the active TENS units during all functional tests (Table 2.3). For example, mean pain with placebo TENS unit reduced from a 2.57 in the Stair Climb Test (SCT) to a 1.90 mean when using the active TENS unit in subjects with grades 2A, 2B, and 3 (Table 2.3). In addition, the SCT, Time Up and Go Test (TUG), and

Locomotive Syndrome Risk 2-Step Test (LSR_2ST) tests all support the alternative hypothesis that pain will be reduced during functional testing (Lawson et al., 2020).

In closing, it was interesting to see that when Knee OA grading levels were combined, data revealed more rejection of the null hypothesis to support that TENS units decreased pain during functional tests. Therefore, data between the three different grading levels did provide evidence to suggest that this treatment can be useful in decreasing pain during functional tests. Future research should focus on gathering long-term data with larger groups of subjects. Having a larger group would allow further analysis of the benefit of TENS for one grading level versus another and the long-term benefits it could provide as a non-pharmacological treatment method.

References

Abraham, A. M., Goff, I., Pearce, M. S., Francis, R. M., & Birrell, F. (2011). Reliability and validity of ultrasound imaging of features of knee osteoarthritis in the community. *BMC musculoskeletal disorders*, *12*, 70. https://doi.org/10.1186/1471-2474-12-70

KELLGREN, J. H., & LAWRENCE, J. S. (1957). Radiological assessment of osteo-arthrosis. *Annals of the rheumatic diseases*, *16*(4), 494–502. https://doi.org/10.1136/ard.16.4.494

Lawson D, Degani AM, Lee K, Beer E, Gohlke KE, Hamidi KN, Coler MA, Tews NM (2021). T*he use of transcutaneous electrical nerve stimulation along with functional tasks for immediate pain relief in individuals with knee osteoarthritis*. Manuscript submitted for publication.

Lundgren-Nilsson, Å., Dencker, A., Palstam, A., Person, G., Horton, M. C., Escorpizo, R., Küçükdeveci, A. A., Kutlay, S., Elhan, A. H., Stucki, G., Tennant, A., & Conaghan, P. G. (2018). Patient-reported outcome measures in osteoarthritis: a systematic search and review of their use and psychometric properties. *RMD open*, *4*(2), e000715. https://doi.org/10.1136/rmdopen-2018-000715

McConnell, S., Kolopack, P., & Davis, A. M. (2001). The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC): a review of its utility and measurement properties. *Arthritis and rheumatism*, *45*(5), 453–461. https://doi.org/10.1002/1529-0131(200110)45:5<453::aid-art365>3.0.co;2-w

Mora, J. C., Przkora, R., & Cruz-Almeida, Y. (2018). Knee osteoarthritis: pathophysiology and current treatment modalities. *Journal of pain research*, *11*, 2189–2196. https://doi.org/10.2147/JPR.S154002

Mortada, M., Zeid, A., Al-Toukhy, M. A., Ezzeldin, N., & Elgawish, M. (2016). Reliability of a Proposed Ultrasonographic Grading Scale for Severity of Primary Knee Osteoarthritis. *Clinical medicine insights. Arthritis and musculoskeletal disorders*, *9*, 161–166. https://doi.org/10.4137/CMAMD.S38141

Oo, Win Min & Bo, Myat. (2016). Role of Ultrasonography in Knee Osteoarthritis. Journal of clinical rheumatology: practical reports on rheumatic & musculoskeletal diseases. 22. 324-329. 10.1097/RHU.0000000000000436.

Osteoarthritis. (2020, February 22). Retrieved November 08, 2020, from https://www.mayoclinic.org/diseases-conditions/osteoarthritis/symptoms-causes/syc-20351925

Palmer, S., Domaille, M., Cramp, F., Walsh, N., Pollock, J., Kirwan, J., & Johnson, M. I. (2014). Transcutaneous electrical nerve stimulation as an adjunct to education and exercise for knee osteoarthritis: a randomized controlled trial. *Arthritis care & research*, *66*(3), 387–394. https://doi.org/10.1002/acr.22147

Riecke, B. F., Christensen, R., Torp-Pedersen, S., Boesen, M., Gudbergsen, H., & Bliddal, H. (2014). An ultrasound score for knee osteoarthritis: a cross-sectional validation study. *Osteoarthritis and cartilage*, *22*(10), 1675–1691. https://doi.org/10.1016/j.joca.2014.06.020

Shimoura, K., Iijima, H., Suzuki, Y., & Aoyama, T. (2019). Immediate Effects of Transcutaneous Electrical Nerve Stimulation on Pain and Physical Performance in Individuals With Preradiographic Knee Osteoarthritis: A Randomized Controlled Trial. *Archives of physical medicine and rehabilitation*, *100*(2), 300–306.e1. https://doi.org/10.1016/j.apmr.2018.08.189

Vance, C. G., Dailey, D. L., Rakel, B. A., & Sluka, K. A. (2014). Using TENS for pain control: the state of the evidence. *Pain management*, *4*(3), 197–209. https://doi.org/10.2217/pmt.14.13

Wallace, I. J., Worthington, S., Felson, D. T., Jurmain, R. D., Wren, K. T., Maijanen, H., Woods, R. J., & Lieberman, D. E. (2017). Knee osteoarthritis has doubled in prevalence since the mid-20th century. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(35), 9332–9336. https://doi.org/10.1073/pnas.1703856114