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Exploring the relationship between the maximal rate of force development of ankle muscles and the functional ability of patients with knee osteoarthritis

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Abstract

Background and purpose

The impairment of the knee muscles brought on by knee osteoarthritis alters motor function, lowers levels of physical activity, and raises the risk of falling. This study aimed to assess ankle muscle function in individuals with mild to moderate knee osteoarthritis compared to a control group.

Materials and methods

A total of 126 participants aged 30 to 45 were divided into knee osteoarthritis and control groups. The Biodex System 4 isokinetic dynamometer assessed rate of force development of ankle muscles at various speeds, encompassing dynamic contractions at 60°/s and 120°/s, as well as isometric measurements. The dorsi/plantar ratio was calculated at the same speeds. Subjective evaluation employed the Knee Injury and Osteoarthritis Outcome Score, while functional measures included the Forward Step-Down Test and Single-Leg Hop Test to establish the correlations with rate of force development and the dorsi/plantar ratio.

Results

The knee osteoarthritis group exhibited significantly higher rate of force development for both ankle plantar flexors during dynamic contractions at 60°/s and 120°/s, which was observed bilaterally in the knee osteoarthritis group ($p<0.001$). The rate of force development of dorsiflexors is significant greater at 60°/s ($p<0.001$) and 120°/s at 100ms ($p<0.05$). Additionally, insignificant rate of force development in plantar flexors and dorsiflexors during isometric contractions was found compared to controls ($p > 0.05$). At angular velocities of 60°/s and 120°/s, the healthy group exhibited significantly elevated dorsi/plantar ratio in comparison to the knee osteoarthritis group for both right and left ankles ($P<0.05$). There is a significant moderate positive correlation between dynamic rate of force development and Single-Leg Hop Test observed on both the right and left sides ($p<0.05$).

Conclusion

Knee osteoarthritis is associated with neuromuscular alterations manifesting as ankle muscle weakness and elevated dynamic rate of force development, which relate to symptoms and functional deficits. Understanding these secondary neuromuscular effects could guide targeted, multi-joint rehabilitation strategies to enhance outcomes in patients with knee osteoarthritis.

Key words: ankle, knee osteoarthritis, rate of force development, functional measures

Анотація

Меннаталлах Алі Ібрагім Альдесукі Ельшафей, Абір Абдельрахман Шехата Ямані, Мохамед М. Ель Мелігіє, Айя Абдельхамід Мохамед Халіл. Дослідження зв'язку між максимальною швидкістю розвитку сили м'язів гомілковостопного суглоба та функціональною здатністю хворих на артроз колінного суглоба

Обгрунтування і мета

Порушення м'язів колінного суглоба, викликане остеоартритом колінного суглоба, змінює рухову функцію, знижує рівень фізичної активності та підвищує ризик падіння. Це дослідження мало на меті оцінити функцію м'язів гомілковостопного суглоба в осіб з легким або помірним остеоартритом колінного суглоба порівняно з контрольною групою.

Матеріали та методи

Загалом 126 учасників у віці від 30 до 45 років були розділені на остеоартроз колінного суглоба та контрольну групи. Ізокінетичний динамометр Biodex System 4 оцінював швидкість розвитку сили м'язів щиколотки на різних швидкостях, охоплюючи динамічні скорочення при 60°/с і 120°/с, а також ізометричні вимірювання. Співвідношення спини/підошви було розраховано при тих самих швидкостях. Для суб'єктивної оцінки використовувався результат травми коліна та остеоартриту, тоді як функціональні показники включали тест кроку вниз і тест стрибка однією ногою для встановлення кореляції зі швидкістю розвитку сили та співвідношенням спини/підошови.

Результати

Група з остеоартритом колінного суглоба показала значно вищу швидкість розвитку сили для обох підошовних згиначів гомілковостопного суглоба під час динамічних скорочень зі швидкістю 60°/с і 120°/с, що спостерігалося двобічно в групі з остеоартритом колінного суглоба ($p<0,001$). Швидкість розвитку сили тильних згиначів достовірно більша при 60°/с ($p<0,001$) і 120°/с при 100 мс ($p<0,05$). Крім того, була виявлена незначна швидкість розвитку сили підошовних згиначів і тильних згиначів під час ізометричних скорочень порівняно з контролем ($p > 0,05$). При кутових швидкостях 60°/с і 120°/с здорова група демонструвала значно підвищене співвідношення спини/підошовного суглоба порівняно з групою з остеоартритом колінного суглоба як для правої, так і для лівої щиколотки ($P<0,05$). Існує значуща помірна позитивна кореляція між динамічною швидкістю розвитку сили та Single-Leg Hop Test, яка спостерігається як з правого, так і з лівого боків ($p<0,05$).

Висновок

Остеоартрит колінного суглоба пов'язаний із нервово-м'язовими змінами, які проявляються у вигляді слабкості м'язів гомілковостопного суглоба та підвищеної динамічної швидкості розвитку сили, що пов'язано з симптомами та функціональним дефіцитом. Розуміння цих вторинних нервово-м'язових ефектів може скеровувати цілеспрямовані стратегії реабілітації багатьох суглобів для покращення результатів у пацієнтів з остеоартритом колінного суглоба.

Ключові слова: артроз гомілковостопного, колінного суглобів, швидкість розвитку сили, функціональні заходи

Аннотация

Меннаталлах Али Ибрагим Альдесуки Эльшафей, Абир Абдельрахман Шехата Ямани, Мохамед М. Эль Мелигие, Айя Абдельхамид Мохамед Халил. Изучение связи между максимальной скоростью развития силы мышц голеностопного сустава и функциональной способностью пациентов с остеоартрозом коленного сустава

Обоснование и цель

Поражение мышц колена, вызванное остеоартритом коленного сустава, изменяет двигательную функцию, снижает уровень физической активности и повышает риск падения. Целью этого исследования было оценить функцию мышц голеностопного сустава у людей с остеоартритом коленного сустава легкой и средней степени тяжести по сравнению с контрольной группой.

Материалы и методы

Всего 126 участников в возрасте от 30 до 45 лет были разделены на остеоартрит коленного сустава и контрольную группу. Изокинетический динамометр Biodex System 4 оценивал скорость развития силы мышц голеностопного сустава на различных скоростях, включая динамические сокращения со скоростью 60°/с и 120°/с, а также изометрические измерения. Соотношение спина/подошва рассчитывалось на тех же скоростях. Субъективная оценка включала оценку исходов травмы колена и остеоартрита, а функциональные измерения включали тест шага вниз и тест прыжка на одной ноге для установления корреляции со скоростью развития силы и соотношением спины и подошвы.

Результаты

В группе пациентов с остеоартритом коленного сустава наблюдалась значительно более высокая скорость развития силы для обоих подошвенных сгибателей голеностопного сустава во время динамических сокращений со скоростью 60°/с и 120°/с, что наблюдалось билатерально в группе пациентов с остеоартритом коленного сустава ($p<0,001$). Скорость развития силы дорсифлексоров достоверно выше при 60°/с ($p<0,001$) и 120°/с при 100 мс ($p<0,05$). Кроме того, выявлена незначительная скорость развития силы в подошвенных и дорсифлексорах при изометрических сокращениях по сравнению с контролем ($p > 0,05$). При угловых скоростях 60°/с и 120°/с в здоровой группе наблюдалось значительно повышенное соотношение тыльная/подошвенная часть по сравнению с группой с остеоартритом коленного сустава как для правой, так и для левой лодыжки ($P<0,05$). Существует значительная умеренная положительная корреляция между динамической скоростью развития силы и тестом прыжка на одной ноге, наблюдаемая как с правой, так и с левой стороны ($p<0,05$).

Вывод

Остеоартрит коленного сустава связан с нервно-мышечными изменениями, проявляющимися слабостью мышц голеностопного сустава и повышенной динамической скоростью развития силы, что связано с симптомами и функциональными нарушениями. Понимание этих вторичных нервно-мышечных эффектов может помочь в разработке целенаправленных стратегий многосуставной реабилитации для улучшения результатов у пациентов с остеоартритом коленного сустава.

Ключевые слова: голеностопный сустав, остеоартроз коленного сустава, скорость развития силы, функциональные показатели

Introductions

Knee Osteoarthritis osteoarthritis is a chronic degenerative disorder of multifactorial etiology characterized by loss of articular cartilage and perarticular bone remodeling [1]. Knee osteoarthritis of the knee is classified as primary when the cause of articular cartilage degradation is idiopathic typically associated with aging and general wear and tear [2]. In contrast, secondary knee osteoarthritis is attributable to known factors such as previous injury, inflammation, or congenital joint abnormalities [3].

Modifiable and non-modifiable risk factors exist for knee osteoarthritis. Modifiable factors are (articular trauma, due to occupation for instance prolonged standing and repetitive knee bending, muscle weakness or imbalance, obesity, and health such as metabolic syndrome). It was assumed that the degeneration of knee osteoarthritis was caused by wear and tear. Non-modifiable factors are as follows: gender (it's been noticed that females are more common than males), age, genetics, and race [4]. Ankle joint biomechanical alterations are linked to knee osteoarthritis [5]. Ankle proprioceptive input is impacted by lower extremity mechanical changes in knee osteoarthritis, which in turn alters ankle joint position sensation [6].When individuals were confronted with knee osteoarthritis; it leads to change in the moment of the hip and ankle joints [7].

The gait pattern associated with knee osteoarthritis is characterized by reduced walking speed, shortened strides, and greater ground reaction force. Furthermore, patients with knee osteoarthritis exhibit a greater knee adduction moment (KAM) in their stride. It may have an impact on neighboring weight-bearing joints, such as the ankle and hip joints, either directly or indirectly. By limiting the force on their knees, patients try to lessen their pain [7]. Furthermore, during a late stance during gait, patients with knee osteoarthritis showed increased ankle dorsiflexion. According to Levinger et al. (2013), it was seen as a compensating reaction to encourage enough power generation at the ankle during propulsion [8]. During the toe-off and swing phases, patients with mild knee osteoarthritis showed increased hamstring activity and higher plantar flexion compared to the controls [9].

The impairment of the knee muscles brought on by knee osteoarthritis alters motor function, lowers levels of physical activity, and raises the risk of falling [10]. Ankle and knee stability during gait is linked to the ankle plantar flexor [11]. In order to prevent increasing weight bearing on the medial knee joint during the stance phase of locomotion, the quadriceps and gastrocnemius muscles resist the knee adduction moment in the frontal plane, which helps to maintain knee stability [12, 13]. Patients with knee osteoarthritis experience altered muscle activation and neuro-muscular control, which impedes normal load distribution around the knee and speeds up the course of the disease. Individuals with knee osteoarthritis gait have decreased quadriceps activation and greater hamstring muscle activity during late stance and early swing phase [14].

The rate of force development is quantitatively assessed as the slope of the force-time curve during the initial phase of muscle contraction, typically between 0 and 200 milliseconds after contraction onset. This measure reflects the explosive strength capacity of a muscle, indicating how quickly force can be generated. Maximum strength may not be as closely correlated with everyday activities as the rate of force development. Furthermore, research has shown a correlation between the rate of force development of quadriceps muscle in patients with knee osteoarthritis and Knee Outcome Survey Activities of Daily Living Scale [15] as well as biomechanical gait factors including power absorption and generation during free and fast walking [16]. The early identification of the development of severe knee osteoarthritis may be associated with weakness in the quadriceps rate of force development, suggesting that impairments in rate of force development could serve as an early indicator of disease progression [17].

Previous research has not assessed rate of force development in ankle muscles for individuals with knee osteoarthritis. Additionally, there is a gap in studies examining the correlation between rate of force development and functional measures in knee osteoarthritis. This study's primary aim was to explore rate of force development across ankle muscles in individuals with mild to moderate knee osteoarthritis and. The secondary aim was to establish correlations between deficits in rate of force development and impairments in functional measures. We hypothesized that deficits in rate of force development may be associated with observed impairments in functional measures among these patients. Clarifying the relationship between rate of force development and knee osteoarthritis progression would hold the potential to unveil therapeutic targets and intervention strategies.

Materials and methods

Study design

A cross sectional study was conducted to assess the maximal rate of force development in dorsiflexor and plantar flexor muscles in individuals with mild to moderate knee osteoarthritis compared to a control group along with the ankle dorsi/plantar ratio. Additionally, the relationship between rate of force development and functional measures in knee osteoarthritis patients was investigated in knee osteoarthritis patients.

Ethical approval

The study was approved by the local Ethical Committee of Faculty of Physical Therapy, Cairo University (P.T.REC/012/004656). This study was registered on clinicaltrials.gov with registration number NCT06063889.

Participants

The study recruited 126 participants from the Ahram Canadian University clinic and its associated worker population. The cohort was divided into two distinct groups: the Knee osteoarthritis group and the healthy control group, with 63 individuals in each. The age range of the participants was 30 to 45 years old.

In the knee osteoarthritis group, inclusion criteria were based on a diagnosis of knee osteoarthritis according to the 2018 classification criteria for early-stage Knee osteoarthritis derived from data in the Osteoarthritis Initiative (OAI) as described by Leung et al., 2020. Only individuals with a Kellgren-Lawrence classification of Grade 2-3 Knee osteoarthritis, who had been experiencing knee pain for at least six months, and with a visual analog scale pain score of 3 or more, were enrolled [17]. The healthy control group consisted of individuals without signs or symptoms of knee osteoarthritis or other neurological or musculoskeletal conditions [18].

Exclusion criteria for the study were comprehensive to ensure the integrity of the results. Individuals with patellar subluxation, a history of surgery on any joint of the lower limb, meniscal injury, ligament instability, or those who had received intra-articular injections in the knee in the last six months were excluded [19]. Additionally, potential participants with hip or ankle problems that could interfere with the outcome measures, or those who had participated in another physical therapy program in the last three months, were not included in the study [20].

Procedure

The study's purposes and procedures were thoroughly explained to all the participants. An informed consent was obtained, ensuring participants were aware of their right to withdraw from the study at any time without facing any repercussions. The study spanned from April 2023 through September 2023.

Instrumentation

The Biodex Medical System 4® dynamometer (850-000 System 4 Pro) was used for isokinetic testing. The isokinetic dynamometer provided mechanically reliable measures of torque, position and velocity on repeated trials performed on the same day as well as on different days [21]. Sole et al. (2007) reported "very high" relative reliability with an Intraclass Correlation Coefficient (ICC) 0.90 for isokinetic dynamometer measurements [22]. The system was powered on, initialized, and calibrated before use. The application and procedure done as mentioned in [23]. The Rate of rate of force development of the ankle plantar flexor and dorsiflexor muscles was measured 60°/s and 120°/s, and isometrically, by recording the torque at 0-100-200 milliseconds. There was a 60 sec rest between velocities. Participants performed submaximal warm-up trials and were familiarized to the protocol during a separate orientation session. Muscle torque was sampled at 100 Hz by the Biodex software. Torque signals were filtered with a 15 Hz low-pass Butterworth filter. Peak torque was calculated as the maximum value during the concentric phase. Rate of force development was derived as the slope of the torque-time curve [24] at 0-100 ms and 0-200 ms using custom functions in Microsoft Excel.

The subjective tests employed were the Knee Injury and Osteoarthritis Outcome Score (KOOS), a patient-reported outcome measure that assesses people's opinions about their knee and associated

problems. The KOOS consists of five subscales: Pain, Symptoms, Activities of Daily Living (ADL), Sport and Recreation Function, and knee-related Quality of Life (QoL). Each subscale is scored separately on a scale from 0 (extreme knee problems) to 100 (no knee problems) [25]. The functional measure tests used in the current study were the Forward Step-Down Test (FSDT) and the Single Leg Hop Test (SLHT). The FSDT is a functional activity that requires dynamic muscle control and weight-bearing stress at varying degrees of knee flexion, similar to descending stairs [26]. The FSDT can serve as both a knee rehabilitation exercise and a screening tool, given the substantial loads it imposes on the knee joints (Sanchez et al., 2016). The forward step-down test results were categorized as good (0–1), moderate (2–3), or poor (≥4 points) based on the observed movement quality of participants [26]. The SLHT is a performance-based test that evaluates muscle strength, neuromuscular control, limb confidence, and the ability to withstand sports-specific activities [27,28]. It is a valid and reliable test for assessing treatments in patients with knee injuries and osteoarthritis, as demonstrated by good test–retest reliability (ICC 0.92, 95% CI 0.86–0.96 and 0.93, 95% CI 0.87–0.97) [29]. Each leg underwent three valid repetitions of the step hop test, and the hop index was determined using the average value.

Statistical analysis

Data analysis was performed using SPSS Statistics Version 27 and Python 3.8. Assessments of normality and homogeneity of variance were executed through Shapiro-Wilk tests in SPSS (Table1). Descriptive statistics were generated in SPSS, and Cohen's d was employed for effect size calculations. The analysis of Rate of Force Development was conducted using Python. Between-subjects univariate ANOVA was implemented with statsmodels.api after confirming assumptions with scipy.stats. Bivariate Pearson's correlations between Rate of Force Development and outcomes were computed using scipy.stats.pearsonr. For data visualization, matplotlib and seaborn Python packages were utilized. All statistical tests maintained a significance level of $p < 0.05$. The interpretation of effects considered mean differences, confidence intervals, F-statistics, and effect sizes, including partial eta squared and Cohen's d.

Table 1
Table showing the results of normal distribution for all indicators

Outcome Indicator	Shapiro-Wilk Statistic (W)	p-value	Conclusion
Ankle D/P ratio	0.967	0.204	Normal
RFD at 100 ms	0.978	0.305	Normal
RFD at 200 ms	0.989	0.560	Normal

Shapiro-Wilk Statistic (W) is the test statistic, where values closer to 1 suggest that the data is normally distributed; p-value is used to determine the significance of the test result. A common threshold for significance is 0.05.

Results

Participant characteristics

The study included 126 participants based on sample size calculation divided into a knee osteoarthritis (OA) group (n=63) and a healthy control group (n=63). There were no significant between-group differences in age (p=0.94), BMI (p=0.90), height (p=0.72), or weight (p=0.97((P >0.05) (Table 2). Hence, the groups were well matched at the entry level.

Table 2
Demographic characteristics of the patients

Variable	Control Group A (n=63)	Knee osteoarthritis Group B (n=63)	t-value	p-value
Age (years)	30.07 ± 4.48	30.00 ± 3.15	0.074	0.944
BMI (kg/m2)	26.07 ± 1.46	26.03 ± 1.08	0.118	0.907

Height (cm)	168.63 ± 6.51	169.26 ± 6.18	-0.363	0.717
Weight (kg)	74.67 ± 8.25	74.59 ± 5.53	0.038	0.969
Sex				
Female	44 (69.8%)	43 (68.3%)		
Male	19 (30.2%)	20 (31.7%)		

OA: osteoarthritis

Ankle strength ratiosw

A multivariate ANOVA found a significant interaction between group (knee osteoarthritis vs control) and contraction setting (60°/sec, 120°/sec, isometric) on ankle dorsiflexion/plantar flexion strength ratios (Pillai's Trace = 0.34, F (6.94) = 5.60, $p < 0.001$). Pillai's Trace represents the proportion of variance in D/P ratios explained by the interaction effect.

For dynamic contractions at 60°/sec and 120°/sec, the knee osteoarthritis group exhibited significantly lower D/P ratios than controls for both right and left ankles ($p < 0.01$), with moderate to large effect sizes (Cohen's d = 0.73 to 1.19) (Table 3). However, there were insignificant between-group differences in D/P ratios during isometric contractions (right p=0.42; left p= 0.45).

Table 3

Final between-group comparison after experiment on ankle dorsiflexion/plantar-flexion strength ratio

Setting	Healthy Group	Knee Osteoarthritis Group	F- value	Partial Eta Square	p-value
P/D ratio 60 D/s rt	Mean: 124.99, SD: 70.31	Mean: 64.62, SD: 23.82	29.939	0.194	(p < 0.001)
P/D ratio 60 D/s lt	Mean: 210.41, SD: 359.08	Mean: 66.88, SD: 29.29	22.887	0.156	(p = 0.002)
P/D ratio 120 D/s rt	Mean: 149.10, SD: 106.26	Mean: 82.34, SD: 37.60	47.207	0.276	(p < 0.001)
P/D ratio 120 D/s lt	Mean: 147.14, SD: 69.46	Mean: 87.36, SD: 37.80	55.125	0.308	(p < 0.001)
P/D ratio ISOM D/s rt	Mean: 182.97, SD: 86.45	Mean: 203.27, SD: 181.13	.645	0.005	(p = 0.424)
P/D ratio ISOM D/s lt	Mean: 181.49, SD: 72.98	Mean: 193.84, SD: 107.41	.570	0.005	(p = 0.452)

P/D ratio: dorsiflexion/plantar-flexion strength ratio

Rate of Force Development of Ankle Muscles

Regarding the plantar flexors (PF), the knee osteoarthritis group showed significantly higher Rate of Force Development at 100ms and 200ms bilaterally during dynamic contractions at 60°/sec and 120°/sec compared to controls ($p < 0.001$), with very large effect sizes (Cohen's d ranged from 1.34 to 1.87) (Table 4).

Table 4
Final between-group comparisons of rate of force development

Setting	Healthy Group	Knee OA Group (Mean±SD)	F-value (Mean±SD)	Partial Eta Squared	p-value
RFD 60°/s (100 msec) right PF	0.049± 0.053	0.154± 0.104	49.661	0.289	p < 0.001
RFD 60°/s (100 msec) left PF	0.043±0.044	0.139±0.102	46.732	0.277	p < 0.001
RFD 60°/s (200 msec) right PF	0.044±0.039	0.112±0.062	53.611	0.305	p < 0.001
RFD 60°/s (200 msec) left PF	0.038±0.037	0.106±0.071	44.840	0.269	p < 0.001
RFD 120°/s (100 msec) right PF	0.050±0.047	0.109±0.084	23.375	0.161	p < 0.001
RFD 120°/s (100 msec) left PF	0.043±0.056	0.112±0.088	27.137	0.182	p < 0.001
RFD 120°/s (200 msec) right PF	0.035±0.028	0.069±0.058	16.627	0.120	p < 0.001
RFD 120°/s (200 msec) left PF	0.029±0.032	0.063±0.057	15.852	0.115	p < 0.001
RFD isom (100 msec) right PF	0.029± 0.029	0.023±0.038	1.022	0.008	p = 0.314
RFD isom (100 msec) left PF	0.023±0.027	0.033± 0.034	3.409	0.027	p = 0.067
RFD isom (200 msec) right PF	0.017±0.017	0.016±0.027	0.054	0.000	p = 0.816
RFD isom (200 msec) left PF	0.014±0.016	0.020± 0.022	2.728	0.022	p = 0.101

RFD: Rate of Force Development; OA: osteoarthritis

For dorsiflexors, the knee osteoarthritis group had significantly greater Rate of Force Development at 100ms bilaterally at 60°/sec (right p<0.001, d=0.99; dorsiflexors p<0.001, d=1.37). The knee osteoarthritis group had significantly greater Rate of Force Development for the left dorsiflexors (p=0.05) not the right dorsiflexors (p=0.046) at 120°/sec. At 200 ms, Rate of Force Development was significantly greater in the knee osteoarthritis group for the left dorsiflexors (p = 0.001) but not the right dorsiflexors (p =0.072) at 6120°/sec. Rate of Force Development was significantly greater in the knee osteoarthritis group for right dorsiflexors (p = 0.046) but not left dorsiflexors (p =0.152) at 120°/ sec. At 100ms and 2oo ms, there were insignificant between-group differences in isometric Rate of Force Development for either PF or dorsiflexors (p > 0.05) (Table 5).

A multivariate ANOVA found an overall significant Rate of Force Development difference between groups across settings (Pillai's Trace = 0.410, F (12,111) = 6.436, p < 0.001). Pillai's Trace indicates the knee osteoarthritis group accounted for 41.0% of the variance in RFD measures.

Table 5
Final between-group comparisons of rate of force development for dorsi-flexors

Setting	Healthy Group (Mean±SD)	Knee OA Group (Mean±SD)	F-value	Partial Eta Squared	p-value
RFD 60°/s (100 msec) right DF	0.052± 0.025	0.074± 0.039	16.045	0.115	p < 0.001
RFD 60°/s (100 msec) left DF	0.053± 0.027	0.084±0.041	25.479	0.170	p < 0.001
RFD 60°/s (200 msec) right DF	0.037± 0.017	0.048±0.044	3.293	0.026	p = 0.072
RFD 60°/s (200 msec) left DF	0.035± 0.020	0.051±0.030	11.085	0.082	p = 0.001
RFD 120°/s (100 msec) right DF	0.034± 0.026	0.045±0.0367	3.151	0.025	p = 0.078
RFD 120°/s (100 msec) left DF	0.039± 0.028	0.050±0.035	3.765	0.029	p = 0.055
RFD 120°/s (200 msec) right DF	0.022± 0.017	0.042 0.080	4.053	0.032	p = 0.046
RFD 120°/s (200 msec) left DF	0.022± 0.022	0.028± 0.022	2.073	0.016	p = 0.152
RFD isom (100 msec) right DF	0.021± 0.023	0.022± 0.012	0.126	0.001	p = 0.724
RFD isom (100 msec) left DF	0.022± 0.023	0.019± 0.007	0.414	0.003	p = 0.521
RFD isom (200 msec) right DF	0.009± 0.005	0.013±0.0103	5.000	0.039	p = 0.027
RFD isom (200 msec) left DF	0.009± 0.005	0.010± 0.040	0.011	0.000	p = 0.918

RFD: Rate of Force Development

Correlation between ankle rate of force development and function

Dynamic Rate of Force Development showed significant moderate positive correlations with Knee Injury and Osteoarthritis Outcome Score symptom (r = 0.23 to 0.45), pain (r = 0.23 to 0.44), and function (r =0 .23 to 0.36) scores (p < 0.01). Higher (worse) Knee Injury and Osteoarthritis Outcome Score scores were associated with lower dynamic Rate of Force Development. Dynamic Rate of Force Development at 60 ,120 °/sec demonstrated significant moderate negative correlations with Forward Step-Down Test (r = -0.28 to -0.52, p < 0.01), indicating worse Forward Step-Down Test performance was linked to reduced Rate of Force Development. There were significant moderate positive correlations between dynamic Rate of Force Development and Single Leg Hop Test (r = 0.34 to 0.50, p <0 .001), showing higher Single Leg Hop Test scores (poorer performance) related to lower Rate of Force Development. Insignificant correlations were found between isometric Rate of Force Development and functional measures (p > 0.05) as shown in (Table 6).

Table 6
Correlation Strength for RFD 60°/s DF, 120°/s, and Isometric with functional measures

RFD Measure	Outcome r (p value)							
	Symptoms	Pain	ADL	Sports	QOL	FSD	SHLT	Hop Index
RFD 60°/s PF	0.23 to 0.45 (< 0.01)	0.23 to 0.44 (< 0.01)	0.23 to 0.30 (< 0.01)	0.29 to 0.36 (< 0.001)	0.25 to 0.29 (< 0.01)	-0.28 to -0.52 (< 0.01)	0.34 to 0.50 (< 0.001)	NSC
RFD 120°/s PF	0.23 to 0.44 (< 0.01)	0.23 to 0.44 (< 0.01)	0.23 to 0.30 (< 0.01)	0.29 to 0.36 (< 0.001)	0.25 to 0.29 (< 0.01)	-0.28 to -0.52 (< 0.01)	0.34 to 0.50 (< 0.001)	NSC
RFD 60°/s DF	0.26 to 0.32 (< 0.01)	0.26 to 0.32 (< 0.01)	0.27 to 0.32 (< 0.01)	0.32 (< 0.001)	0.26 to 0.30 (< 0.01)	-0.33 to -0.42 (< 0.001)	0.33 (< 0.001)	NSC
RFD 120°/s DF	0.24 to 0.28 (< 0.01)	0.24 to 0.31 (< 0.01)	0.23 to 0.29 (< 0.01)	0.22 (< 0.05)	0.25 (< 0.01)	-0.23 to -0.18 (< 0.05)	0.30 (= 0.001)	NSC
Isometric RFD	NSC	NSC	NSC	NSC	NSC	NSC	NSC	NSC

NSC: No significant correlations; RFD: Rate of Force Development

Discussion

Knee osteoarthritis (OA) is a prevalent condition with significant implications for patients' quality of life and mobility. Understanding the neuromuscular alterations associated with knee OA, in particular, the function of ankle muscles, could provide crucial insights for developing effective therapeutic interventions. This was the driving force behind our study. Our main findings were that the knee OA group exhibited significantly lower dorsiflexion/plantarflexion (D/P) strength ratios bilaterally during dynamic contractions compared to controls. However, no between-group differences in D/P ratios were seen during isometric contraction.

The knee OA group also showed greater RFD of the plantar flexors at 100–200 ms during dynamic contractions (60°/sec, 120°/sec). During dynamic contraction at 60°/sec, the knee OA group exhibited significantly greater RFD of the dorsiflexor (DF) at 100 msec bilaterally at 60°/sec. At 200 msec, RFD of DF was significantly higher in the knee OA group for the left DF but insignificant in the right compared to control. During dynamic contraction at 120°/sec, the knee OA group showed significantly higher RFD of the left DF at 100 relative to controls. However, at 200 msec, RFD was significantly greater in the knee OA group for the right DF but insignificant in the left DF, with no differences in isometric RFD. Finally, we found moderate positive correlations between dynamic RFD and functional measures including symptoms, pain, ADLs, and physical performance. No associations were seen between isometric RFD and function. While there is a lack of studies addressing the dorsi/plantar ratio in knee osteoarthritis (OA), a recent investigation by Tapanya et al. (2023) consistently highlighted the predominant role of plantarflexors in torque-muscle density interactions [30]. The observed dorsiflexion-to-plantarflexion ratios, aligning with prior research (e.g., D/P ratio <1.0), revealed a correlation between lower ratios and shorter mean step duration, emphasizing the importance of robust plantar flexion during adjustments in shaping a balanced step, which, in turn, influences the kinetics of the stance.

Regarding the lower P/D strength ratio, it was attributed to weakness of both plantar flexors and dorsiflexors. The dorsiflexor weakness observed in the knee OA group might be due to Arthrogenic muscle inhibition (AMI), a neural protective mechanism that can reflexively limit voluntary activation of muscles crossing injured joints like the knee [31]. Arthrogenic muscle inhibition from knee OA could potentially inhibit dorsiflexors due to

shared spinal circuitry between the knee and ankle. Additionally, disuse from knee OA-related pain and mobility limitations could induce preferential atrophy of type II fibers in dorsiflexors, further reducing strength [32].

Previous studies reported moderate ankle plantar flexor weakness in patients with knee OA. There was significant weakness in concentric peak torque plantar flexors compared to controls [33]. The impact of plantar flexor weakness on knee OA affects gait, stability, and function. The increase in RFD in patients with knee OA likely represents compensatory neuromuscular adaptations to maintain gait stability and reduce knee loading. Patients may increase reliance on ankle musculature for propulsion and stability as knee OA progresses, requiring rapid force generation to control moments during gait [34]. This motor control recalibration could manifest as increased dynamic RFD. However, such compensations may increase joint stresses, contributing to fatigue and secondary injuries at ankle joint. The correlations between diminished dynamic RFD and worse symptoms, pain, and function align with previous research showing knee extensor RFD impacts function and predicts OA severity [16]. Our study expands on this by demonstrating associations between ankle muscle RFD and patient-reported outcomes. This highlights the potential utility of dynamic RFD for assessing functional deficits in knee OA.

Regarding isometric RFD findings, there were inconsistent results between previous studies. A study by Winter et al. (2014) found that RFD was not different between knee OA and healthy subjects, but the knee OA subjects generated the highest peak RFD at a lower percentage of their maximal voluntary isometric strength (MVIC) [35]. They also found that RFD was related to knee joint power and functional outcomes in the knee OA subjects. In contrast, a different study found a significant association between lower quadriceps RFD and worsening physical function in adults with or at risk for knee osteoarthritis [36]. This discrepancy may stem from distinct testing procedures and muscles examined. Standardizing RFD assessment protocols could improve consistency across studies. Joint-specific neuromuscular changes may occur, warranting further investigation.

This study had limitations including a homogenous sample, which could restrict generalizability. Additionally, our laboratory measurements may not fully capture real-world muscle function. We did not radiographically confirm knee OA, which could limit accuracy of comparisons by disease severity. The cross-sectional design also precludes determining causality between knee OA and neuromuscular changes.

Future studies should examine ankle muscle RFD across a broader range of demographics and OA severities using radiographic grading. Longitudinal analyses could help establish temporal relationships between knee OA progression and RFD changes. Examining associations between dynamic RFD and other functional measure tests would be beneficial. Clinically, interventions aimed at improving ankle strength and neuromuscular function should be studied as rehabilitation strategies for knee OA patients.

Conclusion

Knee OA is associated with neuromuscular alterations manifesting as ankle muscle weakness and elevated dynamic RFD, which relate to symptoms and functional deficits. Understanding these secondary neuromuscular effects could guide targeted, multi-joint rehabilitation strategies to enhance outcomes in patients with knee OA.

Conflict of interest

The authors declare that there is no conflict of interest.

Author disclosures

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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