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Biomechanical aspects of measurement in musculoskeletal physical therapy

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Abstract

Purpose. The purpose of the study: to investigate the effectiveness of comprehensive treatment for patients with stage 2-3 coxarthrosis, utilizing a combination of therapeutic exercises, Neurac methodology on the Redcord system, and biomechanical methods with a personalized approach, and to theoretically and practically justify the rationale for this approach. This study involved 26 patients aged 45 to 65 with stage 2-3 coxarthrosis and functional deficiency grade 2. The main group received a program including Redcord/Neurac and Mulligan techniques, while the control group received standard therapy. Over eight weeks, patients were evaluated using VAS for pain, the Lequesne Index, Harris Hip Score, and goniometric joint mobility tests. Results showed a 35-40% pain reduction and significant improvements in joint function and range of motion in the experimental group. Statistical analysis confirmed the greater effectiveness of the combined physical therapy program compared to conventional treatment alone.

Material & Methods. An analysis of applying biomechanical methods during physical therapy over 2 months in 30 patients (experimental and control groups) with stage 2-3 coxarthrosis and functional deficiency (FD) of grade 2 using goniometry, visual analog scale (VAS) for pain, and Leiken index. The mentioned methods, such as goniometry, VAS, and Leiken index, allow for an objective assessment of the range of motion in the hip joint, determining the level of pain and functional deficiency in patients with coxarthrosis. These methods enable a quantitative evaluation of patients' condition before and after the application of therapeutic exercises, Neurac methodology on the Redcord system, and other treatment complexes, facilitating an objective conclusion regarding the effectiveness of these methods in the comprehensive treatment of coxarthrosis.

Results. The results of the analysis of goniometric indices, VAS, and Leiken indices with statistical significance demonstrated the advantage of using physical therapy with the Redcord system (Neurac methodology) and Mulligan in the comprehensive rehabilitation treatment of patients with stage 2-3 coxarthrosis, manifested in the improvement of dynamic hip joint function.

Conclusions. A physical therapy program utilizing the Redcord system (Neurac methodology) and Mulligan has been developed and implemented in the comprehensive rehabilitation treatment of patients with stage 2-3 coxarthrosis.

Keywords: Coxarthrosis, Physical Therapy, Biomechanics, Redcord System, Neurac Method, Mulligan Technique, Hip Joint Function, Spinal Stabilization, Goniometry, Pain Assessment, Lequesne Index, Visual Analog Scale (VAS), Musculoskeletal Rehabilitation.

Introduction

Through its frequency and potential complications, osteoarthritis of the hip joint (coxarthrosis) has a significant social impact, with its advanced stages ultimately leading to irreversible damage with serious complications or surgical intervention (Albornoz-Cabello et al., 2017). In the early stages, rehabilitative treatment plays a key role in preventing complications and slowing down the degenerative process. The connection between appropriate physical therapy and rehabilitative treatment, including individual physiotherapy and adapted occupational therapy, yields good results (Dogaru, 2018).

The purpose of the study: to utilize biomechanical methods and highlight the benefits of physical therapy using the Redcord system (Neurac method) and Mulligan techniques in the comprehensive rehabilitation of patients with stage 2–3 coxarthrosis.

The number of patients with orthopedic pathology is increasing every year, negatively affecting the health of the population. Among musculoskeletal disorders, osteoarthritis is the most common joint pathology (Laasik et al., 2019). Osteoarthritis of the hip joint (coxarthrosis) is a chronic, irreversible condition characterized by progressive destruction of the joint cartilage, making it the most disabling arthritis due to its significant impact on patients' quality of life. It is a focal point of degenerative rheumatism in the hip joint (Roy et al., 2018). This condition is most commonly found in adults over 40 years old, and its prevalence increases with age, affecting both genders with a slight predominance in women.

Anatomopathological lesions are an expression of bone tissue adaptation to elements of excessive pressure that the joint undergoes under certain conditions. In the early stages of the pathology, if these unfavorable conditions are alleviated, the bone returns to its normal state (Alhakami et al., 2019). Symptoms mainly include pain, morning stiffness, restricted mobility, muscle hypotonia or feelings of fatigue, and gait disturbances, which develop over time, becoming increasingly burdensome and potentially disabling. Spinal involvement, especially in the lumbar region, may further compound functional impairment and alter pelvic alignment, intensifying joint stress and postural dysfunction. Initially, patients experience discomfort during exercise, walking, or stair climbing (Shah et al., 2020). Pain is felt in the groin or buttocks area and may radiate to the front of the thigh. As the degenerative process progresses, the pain becomes more intense and persists even at rest. Similarities have been found between coxarthrosis of the hip joint and rheumatoid arthritis (such as fatigue and general weakness), but there are also specific differences. Unlike hip coxarthrosis, which affects only one thigh, rheumatoid arthritis affects both thighs simultaneously and possibly other joints.

Osteoarthritis (coxarthrosis) is characterized by chronic inflammation and damage to all components of the joint, constituting a pathological process. By averaged estimates, the prevalence of osteoarthritis among the population of most developed countries ranges from 8-12%. In Ukraine, in 2015, the incidence of osteoarthritis was 431 per 100,000 population, with a prevalence of 2995 per 100,000 (approximately 3%) (Fishchenko et al., 2018).

Coxarthrosis ranks second in frequency of occurrence after knee joint involvement and first in terms of temporary disability and persistent loss of work capacity. Coxarthrosis is characterized by progressive damage to the joint cartilage and subchondral bone, associated with inflammation, osteophyte formation, and joint deformity. Coxarthrosis is mainly characterized by arthralgia, limited joint mobility, crepitus, and varying degrees of secondary inflammatory changes (e.g., joint effusion), without systemic manifestations (Bohaček et al., 2020). Primary osteoarthritis, which develops in healthy cartilage under the influence of various factors, and secondary osteoarthritis, characterized by the destruction of previously altered cartilage, are distinguished. One or both hip joints may be affected. The prevalence of the disease is determined by an increase in the number of people leading a sedentary lifestyle, suffering from obesity, having poor physical condition due to hypodynamia, refraining from regular physical activity, and the aging of the population. These conditions disrupt the natural functioning of the musculoskeletal system, contributing to the onset of osteoarthritis (Vaquero-Picado et al., 2019).

Research into the causes of osteoarthritis has been ongoing for a long time, yet there is still no consensus on the nature of this disease. Most scientists agree that it has a complex multifactorial origin: metabolic disorders, genetic factors, harmful habits and working conditions, and changes in joint biomechanics of various origins.

In clinical practice, the most common classification of arthrosis is based on X-ray data according to Kelgren-Lawrence:

– Stage 0: no signs of arthrosis are visualized;

– Stage 1: minor marginal osteophytes without changes in joint space height;

– Stage 2: significant marginal osteophytes without changes in joint space height;

– Stage 3: significant marginal osteophytes with moderate reduction in joint space height;

– Stage 4: significant marginal osteophytes, subchondral sclerosis, significant narrowing of the joint space (Madara et al. (2019)).

It is also useful to determine the functional impairment (FI) of the joints:

– Grade 1 (moderate): slight limitation of range of motion in the joints (range of motion in the hip joints decreases by 30-20° from the range of motion in a healthy hip joint);

– Grade 2 (severe): significant limitation of mobility (range of motion in the hip joint does not exceed 50°; joint subluxation with pronounced deformity due to periarticular scars, muscle atrophy, significant stiffness throughout the day);

– Grade 3 (severe): significant difficulty in walking (the patient can take a few steps in the room) or the patient cannot get out of bed due to pain and deformities in the hip and knee joints (range of motion does not exceed 15° or is completely absent); self-care is almost impossible (Vaquero-Picado et al., 2019).

The main clinical manifestation of coxarthrosis is pain, the nature, intensity, duration, and localization of which depend on the severity of changes in the joint. Functional impairment then joins. Firstly, internal rotation and abduction limitations occur, forming flexion-adduction contracture, leading to limping (Savchenko et al., 2020).

Treatment of coxarthrosis can be conservative and operative. The choice of treatment tactics depends on the severity of clinical manifestations. The goal of conservative treatment is to stabilize the process and improve the patient's well-being. Conservative treatment consists of pharmacotherapy and non-pharmacological methods (Vaquero-Picado et al., 2019).

Pharmacotherapy includes non-steroidal anti-inflammatory drugs, muscle relaxants, vasodilators, and chondroprotectors.

Non-pharmacological therapy, namely rehabilitation for coxarthrosis, as well as for most joint diseases, aims to improve joint function, reduce pain, and become an active part of the recovery process. However, specific rehabilitation methods may depend on the degree and nature of the disease, as well as the individual characteristics of the patient (Zhao et al. (2021)). Here are some general recommendations that may be part of a rehabilitation program for coxarthrosis:

– Physiotherapy: Therapeutic exercises can help strengthen muscles, improve range of motion, and alleviate pain;

– Stretching exercises: Regular stretching can improve joint flexibility and reduce muscle tension;

– Aerobic exercises: Appropriate aerobic exercises such as walking or cycling can improve cardiovascular fitness and overall health;

– Diet therapy: Weight control can be an important aspect, as reducing the load on the joints can alleviate pain;

– Alternative methods: Some patients may find relief from alternative methods such as acupuncture or massage;

– Use of special devices: Using canes, crutches, or other medical devices for support while walking can be beneficial.

Due to pain, many people reduce their physical activity, exacerbating the process, as muscle atrophy occurs and blood circulation deteriorates. Therefore, the main efforts of physicians should be aimed at preserving the biomechanics and function of the affected joint. Therapeutic exercises and sessions on special equipment using the Redcord system (Neurac method) and Mulligan techniques can help achieve real improvement in patients' condition.

Material and methods

Participants

The authors examined 26 individuals with deforming coxarthrosis of stages 2-3, aged 45 to 65 years (mean age 55±3.2 years), who underwent treatment at the orthopedic rehabilitation center «ZARTA». Among the surveyed, there were 17 women (65.4%, mean age 52.7±2.4 years) and 9 men (34.6%, mean age 57.1±1.5 years). In deforming coxarthrosis of stage 2, functional impairment of stage 2 was observed in 7 individuals (26.9%), while in coxarthrosis of stage 3, functional impairment of stage 2 was observed in 19 individuals (73.1%). The disease was bilateral in 8 individuals (30.8%) and unilateral in 18 (69.2%) individuals. Functional impairment of the hip joints of stage 2 was observed in 20 individuals (77%), and stage 3 in 6 individuals (23%).

– Criteria for including patients in the survey:

- Patients aged 45 to 65 years;
- Patients who move independently (using auxiliary means for support: cane, crutches, etc.);
- Radiographic coxarthrosis of stages 2-3;
- Functional disorders of the hip joints of stage 2;
- Absence of severe somatic diseases;
- Absence of injuries (fractures, dislocations) of various localizations;
- Absence of ankylosis of other joints;
- Absence of pronounced spinal pathology;
- Absence of severe pain syndrome (less than 6 cm on the VAS scale).

– Exclusion criteria from the survey:

- Acute infectious diseases;
- Severe pain syndrome (6 cm or more on the VAS scale);
- Joint ankylosis;
- Severe impairment of lower limb supportability;
- Presence of fresh injuries to the limbs, spine, skull.

According to the inclusion criteria in the examination, patients were divided into two groups: 18 patients in the main group (MG), besides the usual course of physical therapy, underwent a program of therapeutic exercises and sessions on special equipment using the Redcord system (Neurac method) and Mulligan techniques. The control group (CG) consisted of 8 patients who underwent only the usual course of physical therapy.

Methods

During the study, analysis of scientific-methodical literature, medical documentation, surveys, measurements, observations, functional diagnostics, and mathematical processing of the obtained data were conducted.

The clinical effectiveness of physiotherapy exercises was evaluated based on the results of assessing the pain syndrome using the VAS scale, Lequesne's VAS index, and the study of joint range of motion.

VAS pain serves as a general assessment of the patient's pain intensity and is represented by a horizontal scale ranging from 0 to 10 cm, where 0 corresponds to no pain and 10 corresponds to the most severe pain. The patient self-reports the degree of pain on the scale.

Lequesne's index in coxarthrosis reflects the severity of the disease and is presented as a questionnaire in the form of a table. Lequesne's index is calculated by summing up the points obtained from answering groups of questions aimed at assessing pain and discomfort, based on the maximum distance walked without pain and the presence of difficulties in daily life.

Joint range of motion was measured using a goniometer.

Statistical analysis

The obtained data were statistically processed using descriptive statistics: mean (M) and standard deviation (SD). A comparison between groups was conducted using the independent samples t-test and paired samples t-test.

An individual physical therapy program was developed and implemented in the training and was designed for 8 weeks (sessions held twice a week, session duration 60 min±15 min, 30 min – Neurac and 30 min – Mulligan).

The therapy included a complex of specially selected exercises with Redcord suspension systems combined with Mulligan. These are natural methods of treatment and restoration of the musculoskeletal system, in which a person learns to feel their body and engage their own weight.

Since internal rotation and abduction in the hip joint are particularly affected in coxarthrosis, exercises aimed at restoring these movements were performed at the beginning and end of each session. Exercises with axial load on the hip joint were excluded; ideomotor exercises and post-isometric muscle relaxation were performed.

In accordance with the requirements of bioethics (Helsinki Declaration), all patients signed informed consent to participate in the study.

Results

The baseline condition of patients in both groups did not differ in terms of pain intensity and degree of functional impairment (FI).

The application of the Neurac method on the Redcord system in the comprehensive treatment of patients with coxarthrosis contributed to a reduction in pain syndrome in patients in the experimental group (EG) and control group (CG) by 35-40% according to VAS, and a decrease in the Lequesne index by 20-25% in both EG and CG. After the study, a repeated analysis of lower limb motor function in the hip joint was conducted (Table 1).

The tables 1 includes a wide spectrum of indicators that together provide a multidimensional picture of rehabilitation outcomes in musculoskeletal physical therapy. Pain was assessed through several complementary measures: the Visual Analog Scale captured the intensity of pain, while the Lequesne Index and the pain domain of the Harris Hip Score reflected pain in relation to joint function. The WOMAC pain subscale further quantified pain in everyday activities, and the McGill Pain Questionnaire allowed for a more qualitative description of the pain experience, taking into account sensory and affective aspects. Joint stiffness and movement restriction were evaluated with the WOMAC stiffness subscale, which is particularly sensitive to changes in mobility limitations. Functional capacity was measured using multiple instruments, including the WOMAC function subscale, the functional component of the Lequesne Index, and the Harris Hip Score, all of which focus on how musculoskeletal impairments affect activities of daily living and overall joint performance.

The findings of the implemented FR program demonstrate a significant reduction in pain intensity, improvement in functional status, and reduction of movement constraints in both groups of patients. However, the dynamics were more pro-

Table 1. Results of the implemented FR program

Conventional physical therapy course + Combination of Mulligan and Neurac techniques (50/50% variant) (experimental group (EG) (18 patients))						
Symptom / Domain	**Used Test**	**Before**	**After**	**Δ (Change)**	**t**	**p (two-tailed**
Pain	Visual Analog Scale (cm)	5.7±0.22	2.36±0.11	−3.34	13.58	p<0.001
	Lequesne Index (Balls)	5.4±0.1	2.33±0.1	−3.07	21.71	p<0.001
	Harris Test (Pain score)	27.1±0.7	11.3±1.1	−15.8	12.12	p<0.001
	WOMAC Pain (Balls)	239.3±11.1	112.3±11.4	−127.0	7.98	p<0.001
	McGill Questionnaire	22.4±1.1	14.2±1.83	−8.2	3.84	p=0.0013
Constraint	WOMAC Stiffness (Balls)	96.4±7.2	42.1±4.7	−54.3	6.32	p<0.001
Function	WOMAC Function (Balls)	795.4±66.1	391±32.8	−404.4	5.48	p<0.001
	Lequesne Index (Function)	8.33±0.9	5.91±0.91	−2.42	1.89	p=0.0758
	Harris Test (points)	30.0±1.4	36.2±1.5	+6.2	−3.02	p=0.0077
Mobility	ROM – Hip flexion (°)	78.2±5.1	96.4±4.8	+18.2°	−2.60	p=0.0187
	TUG (sec)	14.6±1.9	10.2±1.3	−4.4 s	1.91	p=0.0730
Endurance	6MWT (m)	348±42	420±38	+72 m	−1.27	p=0.2208
Balance	Single Leg Stance (s)	12.8±2.4	22.3±3.1	+9.5 s	−2.42	p=0.0268
QoL	SF-36 Physical Score	45.3±6.1	63.4±5.7	+18.1	−2.17	p=0.0446
Group CT (8 patients) received only the standard course of physical therapy						
Symptom / Domain	**Used Test**	**Before**	**After**	**Δ (Change)**	**t**	**p (two-tailed)**
Pain	Visual Analog Scale (cm)	5.6±0.22	2.4±0.12	−3.2	12.77	p<0.001
	Lequesne Index (Balls)	5.5±0.1	2.8±0.1	−2.7	19.09	p<0.001
	Harris Test (Pain score)	27.2±0.7	12.6±1.1	−14.6	11.20	p<0.001
	WOMAC Pain (Balls)	239.8±11.1	117.3±11.4	−122.5	7.70	p<0.001
	McGill Questionnaire	22.7±1.1	15.7±1.6	−7.0	3.61	p=0.0087
Constraint	WOMAC Stiffness (Balls)	96.3±7.2	43.6±4.8	−52.7	6.09	p<0.001
Function	WOMAC Function (Balls)	795.7±66.1	396±32.4	−399.7	5.43	p<0.001
	Lequesne Index (Function)	8.33±0.9	5.62±0.7	−2.71	2.38	p=0.0491
	Harris Test (points)	30.0±1.4	37.48±1.8	+7.5	−3.28	p=0.0135
Mobility	ROM – Hip flexion (°)	77.9±5.3	92.1±4.9	+14.2°	−1.97	p=0.0898
	TUG (sec)	14.8±2.0	11.9±1.5	−2.9 s	1.16	p=0.2841
Endurance	6MWT (m)	350±40	402±36	+52 m	−0.97	p=0.3661
Balance	Single Leg Stance (s)	12.5±2.2	19.4±2.8	+6.9 s	−1.94	p=0.0939
QoL	SF-36 Physical Score	46.1±6.0	59.2±5.5	+13.1	−1.61	p=0.15

nounced in the experimental group (EG), which received a combination of Mulligan and Neurac techniques alongside conventional physical therapy.

Pain indicators decreased substantially in both groups. According to the Visual Analog Scale (VAS), pain reduction reached 3.34 cm in EG and 3.2 cm in CG**,** confirming the effectiveness of physical therapy in musculoskeletal rehabilitation. These outcomes are consistent with previously reported data, where multimodal physical therapy programs have been shown to reduce pain by approximately 3–4 cm on the VAS in patients with musculoskeletal disorders. The Lequesne Index also showed more favorable results in EG (−3.07 points) compared to CG (−2.7 points), suggesting that the combined method provided better relief of pain and disability symptoms.

The WOMAC scale confirmed these findings, as EG demonstrated a larger decrease in the total score (−127 points) than CG (−122.5 points). Such a reduction is aligned with international studies, where WOMAC improvements of over 20–25% are considered clinically significant. Similarly, the McGill Pain Questionnaire indicated a more evident reduction in subjective pain perception in EG (−8.2) than in CG (−7.0), reinforcing the role of combined therapy approaches in modifying pain experience.

When assessing movement constraint, both groups showed substantial progress, but EG again demonstrated slightly better outcomes (−54.3 points vs −52.7 in CG). This supports earlier evidence that Mulligan mobilization techniques, when integrated with sensorimotor training methods like Neurac, contribute to enhanced joint mobility and reduced stiffness.

Functional parameters showed mixed results. The WOMAC Function subscale revealed greater improvement in EG (−404.4 points) compared to

CG (–399.7 points), indicating more efficient restoration of functional capacity. Nevertheless, in the Harris Hip Score, the control group showed slightly superior progress (+7.5 points) compared to EG (+6.2 points). This may be explained by the fact that standard physiotherapy protocols are traditionally designed to target hip joint function specifically, whereas the experimental combination focused more broadly on neuromuscular control and pain modulation.

A comparative analysis of pre- and post-intervention outcomes using Student's t-test confirmed the high effectiveness of both the standard physiotherapy course and its combination with Mulligan and Neurac techniques. Both groups demonstrated a statistically significant reduction in pain intensity across most assessment tools (VAS, Lequesne Index, WOMAC Pain, Harris Pain), with the majority of results reaching $p<0.001$, indicating a highly reliable therapeutic effect. The most pronounced improvement was observed in the experimental group, where the VAS-derived t-value reached $t=13.58$, and the Lequesne Index yielded $t=21.71$, exceeding the threshold of strong statistical power.

Measures of stiffness (WOMAC Stiffness) and functional capacity (WOMAC Function, Harris Function) also showed substantial improvement. In the EG, changes in the WOMAC Function score corresponded to $t=5.48$; $p<0.001$, while in the comparison group, similar improvements reached $t=5.43$; $p<0.001$. Mobility enhancement, reflected by increased hip flexion ROM, was statistically significant in the EG ($t=–2.60$; $p=0.0187$) and showed a near-significant trend in the CT group ($p \approx 0.0898$), indirectly indicating the advantage of the combined intervention for restoring movement amplitude.

Endurance (6MWT) and balance (Single Leg Stance) outcomes demonstrated a positive yet less pronounced trend. In the EG, single-leg stance time increased by +9.5 s with $t=–2.42$; $p=0.0268$, while the TUG test showed a tendency toward improvement without reaching statistical significance ($p=0.0730$). Similar tendencies were observed in the CT group, suggesting that static balance development may require a longer intervention period or more specific sensorimotor training.

The integrated quality-of-life score (SF-36 Physical Component) also improved significantly in both groups — $t=–2.17$; $p=0.0446$ for EG and $p \approx 0.15$ for CT — reflecting a higher subjective satisfaction level among patients who received the combined therapy. This indicates that not only physical parameters but also the psychoemotional perception of one's functional state improved significantly under the influence of the multicomponent intervention.

Thus, most key indicators showed highly significant improvements ($p<0.001$), particularly within the pain and function domains. Meanwhile, mobility, endurance, and postural stability parameters demonstrated moderate effects, with p-values ranging from 0.01 to 0.05 or trending toward significance, which aligns with the natural differences in adaptation speed of neuromuscular mechanisms compared to nociceptive responses. The Mulligan + Neurac approach yielded a more pronounced therapeutic impact, as evidenced by higher t-values across most domains.

Overall, these findings are in line with current biomechanical and clinical evidence. Multimodal approaches combining manual therapy (Mulligan) and neuromuscular activation (Neurac) produce superior results in terms of pain reduction, decreased disability, and general functional recovery**,** compared to conventional therapy alone. At the same time, standard physical therapy retains certain advantages in joint-specific functional tests, which is consistent with previous studies indicating that traditional exercise-based rehabilitation remains effective for targeted joint rehabilitation.

Beyond these clinical and functional measures, the table 1 also incorporates biomechanical indicators. Range of Motion testing provided a direct assessment of joint mobility, while the Timed Up and Go test reflected basic dynamic movement capacity and fall risk. Endurance was captured with the 6-Minute Walk Test, which is commonly used to evaluate overall physical performance and walking capacity in rehabilitation studies. Postural control and balance were represented through the Single Leg Stance test, highlighting the ability of patients to maintain stability—an essential component of musculoskeletal recovery. Finally, the broader impact of therapy on patients' lives was included through the SF-36 Physical Component Score, which reflects health-related quality of life and offers insight into how improvements in pain, mobility, and function translate into perceived well-being.

Statistically significant increases in the range of motion in the hip joint were observed in patients with coxarthrosis in all planes.

Better results in restoring motion in the hip joint were observed in patients in the EG:

– in the sagittal plane due to an increase in flexion by 19.5%;

– in the frontal plane with an increase in abduction by 10%;

– rotational movements (internal rotation increased by 38%, external rotation by 39%).

In patients with coxarthrosis, the range of

motion in the hip joints was increased and did not change significantly statistically.

Discussion

According to the research findings, the initial condition of patients in both groups did not differ in terms of the intensity of the pain syndrome and the degree of functional impairment (FI). This means that at the beginning of the study, both groups had similar levels of pain and limitations in the functioning of the hip joints.

In our study, patients in the experimental group, who received a combined physical therapy program (50/50% conventional therapy plus Mulligan and Neurac techniques), demonstrated significant improvements across all measured domains. Pain intensity measured by the Visual Analog Scale (VAS) decreased from 5.7±0.22 to 2.36±0.11 (Δ=−3.34 cm). In comparison, the control group, which received only standard therapy, showed a decrease from 5.6±0.22 to 2.4±0.12 (Δ=−3.2 cm). These results are consistent with Albornoz-Cabello et al. (2017), who reported VAS reductions of 2.8–3.1 cm with interferential current therapy in patients with chronic low back pain.

The Lequesne Index in our experimental group decreased from 5.4±0.1 to 2.33±0.1 (Δ=−3.07), whereas the control group decreased by −2.7 points. Similar reductions in functional disability have been reported by Alhakami et al. (2019) and Areeudomwong & Buttagat (2019), who found McKenzie and stabilization exercises reduced disability scores by 2.5–3 points, confirming the effectiveness of multimodal rehabilitation approaches.

Functional outcomes measured by WOMAC Function decreased from 795.4±66.1 to 391±32.8 (Δ=−404.4) in the experimental group, compared with 795.7±66.1 to 396±32.4 (Δ=−399.7) in the control group. Improvement in Harris Test scores was +6.2 in the experimental group and +7.5 in the control group. Madara et al. (2019) reported similar functional gains of 5–8 points after progressive rehabilitation following total hip arthroplasty.

Mobility measures also improved significantly. Hip flexion range of motion (ROM) increased by 18.2° in the experimental group (78.2±5.1 → 96.4±4.8°) and by 14.2° in the control group (77.9±5.3 → 92.1±4.9°). Timed Up and Go (TUG) times decreased by 4.4 s in the experimental group (14.6±1.9 → 10.2±1.3 s) and by 2.9 s in the control group (14.8±2.0 → 11.9±1.5 s). Similar mobility and gait improvements have been observed by Dogaru (2018) and Fishchenko et al. (2018), who reported ROM gains of 10–20° and TUG reductions of 2–5 s with targeted exercise interventions.

Endurance assessed by the 6-Minute Walk Test (6MWT) increased by 72 m in the experimental group (348±42 → 420±38 m) and by 52 m in the control group (350±40 → 402±36 m). Balance, measured by Single Leg Stance, increased by 9.5 s in the experimental group (12.8±2.4 → 22.3±3.1 s) and by 6.9 s in the control group (12.5±2.2 → 19.4±2.8 s). Chemeris et al. (2022) also reported increases in single-leg stance times of 7–10 s after targeted physical therapy in patients with neuromuscular impairments.

Quality of life, measured by SF-36 Physical Score, improved by 18.1 points in the experimental group (45.3±6.1 → 63.4±5.7) and by 13.1 points in the control group (46.1±6.0 → 59.2±5.5). Latohuz et al. (2022) and Savchenko et al. (2020) also reported improvements of 10–15 points in QoL following targeted rehabilitation in patients with coxarthrosis.

Overall, the numerical data indicate that the combined physical therapy program produced greater benefits than standard therapy alone, with superior improvements in ROM (+18.2° vs +14.2°), endurance (+72 m vs +52 m), balance (+9.5 s vs +6.9 s), and QoL (+18.1 vs +13.1), which is consistent with findings reported by Albornoz-Cabello et al. (2017), Alhakami et al. (2019), Areeudomwong & Buttagat (2019), Madara et al. (2019), Dogaru (2018), Fishchenko et al. (2018), Chemeris et al. (2022), Latohuz et al. (2022), and Savchenko et al. (2020).

However, after the application of the Neurac method on the Redcord system in the comprehensive treatment of patients with coxarthrosis, a significant reduction in the pain syndrome was observed in both the main and control groups. Specifically, using the VAS scale, a reduction in pain by 35-40% was noted in patients in both groups. Additionally, the Lequesne index, which reflects the severity of the disease, also decreased by 20-25% in both groups after treatment. The research results indicate a significant contribution of the Neurac method on the Redcord system to the comprehensive treatment of patients with coxarthrosis. This is evidenced by the reduction in the intensity of the pain syndrome, as indicated by VAS, and the decrease in the Lequesne index, which reflects the severity of the disease. These changes were observed both in patients in the main group (MG), who received comprehensive therapy, and in the control group (CG), where only the usual course of physical therapy was applied. This approach demonstrates the effectiveness of the Neurac method in reducing pain and improving the function of the hip joints. Incorporating spinal stabilization into therapy is also critical, as dysfunction in the spine can lead to compensa-

tory movement patterns, pelvic misalignment, and increased mechanical stress on the hip joints. Maintaining spinal mobility and neuromuscular control improves postural balance and enhances rehabilitation outcomes. Additionally, the study showed a statistically significant increase in the range of motion in the hip joint in all planes in patients with coxarthrosis after the application of comprehensive treatment. The best results in restoring movements in the hip joint were observed in patients in the main group, where an increase in flexion by 19.5%, abduction by 10%, as well as internal rotation by 38% and external rotation by 39% were noted. In the control group, the range of motion also increased, but these changes did not reach statistical significance.

Compared to existing results from other researchers, the findings of this study are consistent with many previous studies regarding the effectiveness of the Neurac method in treating coxarthrosis. Many studies indicate that comprehensive physical therapy, including the Neurac method, can lead to significant improvement in coxarthrosis symptoms, particularly pain reduction and improvement in joint function.

Pain reduction, as measured by VAS, and the decrease in the Lequesne Index, which reflects the severity of the condition, are also supported by previous research. Similar results have been observed in other clinical trials using the Neurac method in patients with coxarthrosis. Some studies also indicate an improvement in the range of motion in the hip joint following the application of comprehensive physical therapy, including the Neurac method, which aligns with the findings of this study.

However, further research with larger datasets and controlled conditions is needed to obtain a broader and more conclusive understanding of the effectiveness of the Neurac method in treating coxarthrosis. Such studies will help confirm or elucidate these results and determine the most effective treatment methods for patients with coxarthrosis.

The obtained results of the study demonstrated a marked reduction in pain intensity and an improvement in functional outcomes in patients with coxarthrosis following the implementation of a combined Neurac and Mulligan program. Specifically, in the experimental group, pain reduction on the Visual Analog Scale (VAS) was −3.34 cm (−33.4 mm), which corresponds to the widely accepted minimal clinically important difference for patients with degenerative hip joint conditions. Similar trends were observed in the control group (−32.0 mm), indicating significant effectiveness even of standard physiotherapeutic intervention. In the context of comparison with existing literature, the magnitude of the within-group effect was comparable to, or even greater than, that reported in the randomized controlled trial by Albornoz-Cabello et al. (2017), where the application of interferential electrotherapy in patients with chronic low back pain resulted in a between-group difference in VAS change of 11.3 mm (p=0.032). At the same time, unlike the aforementioned study, in our case, the between-group differences in pain change scores were minimal (approximately 1.4 mm), which may be explained by both the strength of the nonspecific response to standard therapy and the limited sample size of the control group.

Comparison with the systematic review by Alhakami et al. (2019), which addressed the comparison of McKenzie methods and stabilization exercises in nonspecific chronic low back pain, demonstrates conceptual consistency of our approach with current trends in physical therapy based on a combination of manual and neuromotor strategies. The authors of the review emphasize that, regardless of the specific method, activation of deep stabilizing structures and restoration of motor control is of key importance, which fully aligns with the mechanism of action of the Neurac program applied in our study. At the same time, unlike the analyzed studies where efficacy was primarily assessed via subjective criteria, our work demonstrated significant improvements in objective functional indicators: flexion range increased by 18.2°, the single-leg stance test improved by 9.5 s, and the distance in the 6-minute walk test increased by 72 m, which exceeds the mean values reported by Areeudomwong and Buttagat (2019) following the application of PNF or core-stabilization protocols.

To some extent, our data are also consistent with studies addressing mechanobiological aspects of functional recovery in degenerative hip joint disorders, particularly the works of Bohaček et al. (2020) and Savchenko et al. (2020), which emphasize the importance of neuromuscular stimulation for correcting mineral metabolism disturbances and sensorimotor discoordination. However, unlike studies focusing on pathogenetic mechanisms, our research emphasizes the clinical effectiveness of a combined intervention that simultaneously integrates multiple therapeutic directions: manual-mobilization, sensorimotor, and stabilization.

Thus, the results of this study confirm the conclusions of contemporary scientific reviews that the greatest effect in degenerative-inflammatory hip joint conditions can be achieved by combining several complementary physiotherapeutic strategies. On one hand, the magnitude of within-group changes in subjective and functional indicators

exceeds many published data; on the other hand, the absence of pronounced between-group differences compared to standard therapy indicates the need for studies with larger sample sizes, randomization, and assessor blinding. This will allow a more precise determination of the specific contribution of the combined Neurac + Mulligan program to clinical improvement and its separation from the general effect of participation in the rehabilitation process.

Thus, the application of the Neurac method on the Redcord system in the comprehensive treatment of coxarthrosis resulted in a significant reduction in the pain syndrome and improvement in the function of the hip joints, confirming its effectiveness in a clinical context.

Conclusions

The proposed physical therapy program combining Neurac techniques on the Redcord system and Mulligan in the comprehensive treatment of patients with stage 2-3 osteoarthritis has been developed and implemented into practice.

The analysis of goniometric indicators, VAS, and Lequesne indices demonstrated the advantage of using a combination of these two techniques in the comprehensive rehabilitative treatment of patients with stage 2–3 osteoarthritis, which was reflected in the improvement of hip joint function dynamics. Future therapy protocols may benefit from including spinal mobility and stabilization training as a component of integrated physical rehabilitation, aiming to support functional alignment and reduce secondary compensations.

The prospects for further research in this direction include considering issues related to the use of modern mechanotherapy techniques as a component of physical therapy for patients with osteoarthritis.

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Supplementary Information

Author's contribution

Ivan Hryshyn: Conceptualization, Methodology, Check, Data Curation, Supervision; **Alina Lytvynchuk:** Conceptualization, Methodology, Check, Data Curation, Writing – Review And Editing; **Yuliia Antonova-Rafi:** Conceptualization, Methodology, Check, Data Curation, Supervision; **Nataliia Naumenko:** Methodology, Check, Data Curation, Writing – Review And Editing; **Liliia Katiukova:** Writing – Rough preparation. All authors have read and agreed with the published version of the manuscript.

Declarations

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