

Varzar S. O.¹, Babova I. K.^{2,4}, Babov K. D.³

Rehabilitation pathway for patients after core decompression for avascular necrosis: the role of early weight bearing, physiotherapy, and telemonitoring of hip joint function

¹ Municipal Non-Profit Enterprise "City Clinical Hospital No. 11", Odesa, Ukraine

² State Institution "Territorial Medical Association of the Ministry of Internal Affairs of Ukraine in Odesa Region", Odesa, Ukraine

³ State Non-commercial Enterprise "Ukrainian Research Institute of Rehabilitation and Balneology of Ministry of Health of Ukraine", Odesa, Ukraine

⁴ State Institution "Institute of Market and Economic & Ecological Research of the National Academy of Sciences of Ukraine", Odesa, Ukraine

Варзар С. О.¹, Бабова І. К.^{2,4}, Бабов К. Д.³

Реабілітаційний маршрут пацієнтів після декомпресійної тунелізації головки стегнової кістки з приводу аваскулярного некрозу: роль раннього навантаження, фізичної терапії та телемоніторингу функції кульшового суглоба

¹ Комунальне некомерційне підприємство «Міська клінічна лікарня № 11», м. Одеса, Україна

² Державна установа «Територіальне медичне об'єднання Міністерства внутрішніх справ України по Одеській області», м. Одеса, Україна

³ Державне некомерційне товариство «Український науково-дослідний інститут реабілітації та курортології МОЗ України», м. Одеса, Україна

⁴ Державна установа «Інститут ринку і еколого-економічних досліджень Національної академії наук України», м. Одеса, Україна

babovairina@gmail.com

Introduction

Avascular necrosis (AVN) of the femoral head is a progressive condition that leads to loss of weight-bearing capacity of the hip joint and carries a high risk of subchondral collapse [1; 2]. In young and middle-aged patients – particularly military personnel and individuals exposed to high physical demands – joint-preserving treatment strategies are of critical importance [3; 4]. One of the most widely accepted interventions at early stages of the disease is core decompression, which aims to reduce intraosseous pressure, improve microcirculation, and create favorable conditions for bone tissue regeneration [3–5]. However, the clinical success of this procedure depends not only on surgical technique but also, to a large extent, on a carefully tailored postoperative rehabilitation program.

Current evidence indicates that functional recovery of the hip joint after core decompression requires a well-balanced combination of early, controlled loading, targeted physiotherapeutic interventions, and structured postoperative supervision [6–8]. Early partial weight bearing, when combined with appropriate biomechanical control, provides an optimal stimulus for trabecular remodeling while helping to prevent muscular and periarticular atrophy. Physiotherapeutic modalities, including proprioceptive training, therapeutic exercise, and techniques aimed at enhancing microcirculation, play a key role in accelerating recovery and stabilizing joint function [6]. At the same time, the integration of telemonitoring technologies offers new

opportunities for continuous assessment of physical activity, load control, timely adjustment of rehabilitation protocols, and improved patient adherence [9].

Despite the growing number of studies reporting outcomes of core decompression in AVN, the optimal rehabilitation pathway remains insufficiently standardized [3–6; 10]. There is a lack of unified protocols that take into account disease stage, individual biomechanical profiles, the location of the necrotic segment, the pace of recovery, and the availability of remote monitoring tools. This underscores the need for the development of a comprehensive, evidence-based rehabilitation framework capable of defining an optimal postoperative algorithm after core decompression and ensuring maximal preservation of hip joint function.

The aim of the study was to determine the optimal rehabilitation pathway for patients after core decompression in avascular necrosis of the femoral head. Particular attention was paid to the role of early graded weight bearing, physiotherapeutic interventions, and telemonitoring technologies in improving functional recovery, gait biomechanics, and long-term preservation of hip joint function.

Object, materials and research methods

Object of the study was the postoperative rehabilitation process and functional recovery of patients with early-stage AVN of the femoral head after core

decompression, including gait biomechanics, weight-bearing dynamics, pain intensity, and hip joint function under telemonitoring-guided rehabilitation. The study was conducted as a prospective-retrospective cohort analysis and included patients with AVN of the femoral head who underwent core decompression between 2020 and 2025 in specialized orthopedic centers in Odesa and Kyiv. The total number of patients treated with core decompression was 51, as confirmed by multicenter data. Patients aged 18–60 years with diagnosed AVN stages ARCO I–II and Ficat I–II [11; 12], without signs of structural collapse exceeding 2 mm, were eligible for inclusion. Mandatory inclusion criteria were the availability of preoperative and postoperative MRI examinations and informed consent to participate in a structured rehabilitation and telemonitoring program.

Exclusion criteria comprised rheumatologic pathology of the hip joint, post-traumatic deformities of the femoral neck, infectious lesions, previous surgical interventions on the hip joint, lack of access to telemetric monitoring, and non-compliance during the rehabilitation program.

All patients provided written informed consent. The study was approved by the local Bioethics Committee (protocol No. 3 dated 11.09.2023) and conducted in accordance with the Declaration of Helsinki (rev. 2024) and national bioethical standards [13].

The core decompression technique was standardized across all participating centers and involved the creation of one or more decompression channels under fluoroscopic guidance. The postoperative rehabilitation protocol consisted of three consecutive stages: (1) early graded loading with partial weight bearing during the first 2–4 weeks; (2) kinesitherapy and proprioceptive training with gradual progression of functional load; and (3) physiotherapeutic interventions aimed at restoring microcirculation, muscular balance, and physiological movement patterns [6; 14]. All patients were enrolled in a hip function telemonitoring system, which included inertial gait analysis sensors (WitMotion WT901, China) [15], a digital pain scale [16], daily functional questionnaires [17], and weekly remote supervision by a physical therapist.

Functional outcomes were assessed using the Harris Hip Score (HHS) [18], the visual analogue scale (VAS) for pain [16], limping index [19], and dynamic load parameters obtained from telemetric sensors. Radiological evaluation was performed according to the ARCO (2019) [11] and Ficat–Arlet [12] classifications, as well as the JIC classification [20] to determine the localization of the necrotic segment.

To validate the proposed rehabilitation scale, internal consistency (Cronbach's α), interobserver reliability (intraclass correlation coefficient, ICC), and convergent validity were assessed through comparison with HHS, VAS, and objective biomechanical parameters. Between-group comparisons were performed using ANOVA, the Mann–Whitney U test, and Spearman correlation analysis, with a significance threshold set at $p < 0.05$ [21].

Research results

The patient cohort was predominantly composed of young and middle-aged men (mean age 34.8 ± 7.1 years), with high-dose or prolonged glucocorticoid therapy identified as the leading etiological factor in 64.7% of cases. According to the JIC classification, lesion localization corresponded to types B–C in 58.8% of patients, indicating a moderate to high risk of biomechanical vulnerability of the necrotic segment.

Postoperative management followed a three-stage rehabilitation pathway comprising early graded weight bearing (weeks 1–4), targeted kinesitherapy (weeks 4–12), and physiotherapeutic interventions combined with telemonitoring (up to 6 months). By week 4, 82.3% of patients were able to tolerate partial weight bearing without exacerbation of pain. Improvements in proprioception and muscular coordination during the second stage were reflected in a progressive increase in functional outcomes: the mean Harris Hip Score (HHS) improved from 64.2 ± 5.9 to 78.5 ± 6.3 points ($p < 0.01$), while pain intensity on the VAS decreased from 5.2 ± 1.3 to 2.8 ± 0.9 ($p < 0.001$).

Telemonitoring enabled objective assessment of gait mechanics and load distribution on the operated limb. Gait asymmetry during the stance phase was detected in 41 patients (80.4%) and decreased by an average of 22% by week 12. Data from inertial sensors demonstrated restoration of hip flexion amplitude to the physiological range in 74.5% of patients; however, among those with larger necrotic lesions (Steinberg stage II), normalization was achieved in only 51.8% of cases.

Over the 6-month follow-up period, radiologically confirmed progression to femoral head collapse was observed in 4 patients (7.8%). All such cases were classified as JIC types C–D and involved lesion volumes exceeding 30%. In patients without progression, MRI findings indicated stable trabecular remodeling, including a reduction in bone marrow edema intensity and attenuation of the double-line sign.

At completion of the 6-month rehabilitation pathway, full functional recovery (HHS ≥ 85) was achieved in 72.5% of patients, moderate recovery (HHS 70–84) in 21.6%, and clinically significant functional limitations persisted in 5.9%. The most favorable outcomes were associated with early partial weight bearing, high adherence to telemonitoring protocols, and the absence of biomechanically unfavorable lesion localization (JIC A–B).

The proposed rehabilitation pathway represents a staged, biomechanically grounded management strategy for patients after core decompression. It is based on objective load assessment, structural stability of the femoral head, and integration of telemonitoring technologies (Figure 1). Unlike traditional approaches relying on generalized recommendations such as “partial weight bearing” or “movement restriction,” this system provides a personalized protocol that accounts for necrotic

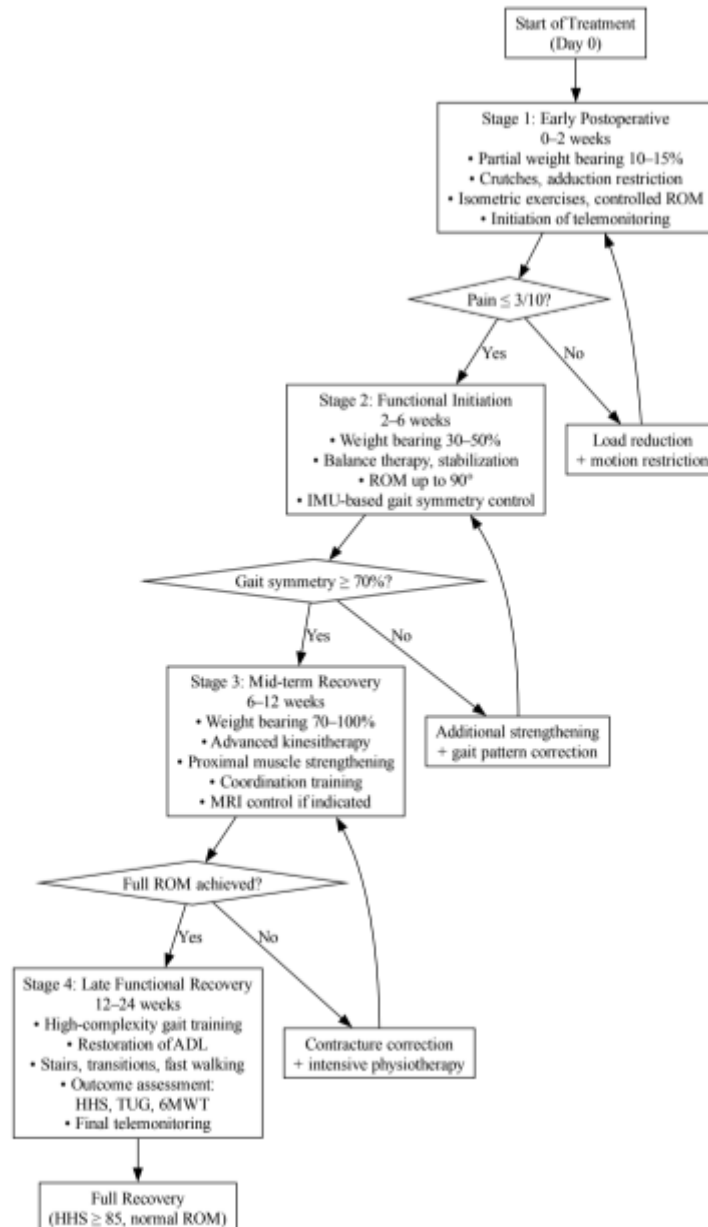


Fig. 1. Rehabilitation pathway after core decompression

lesion localization (JIC), lesion extent (Steinberg), MRI morphology, and the dynamic evolution of gait biomechanics.

Let's consider the stages of rehabilitation in more detail.

Stage 1. Early postoperative period (0–2 weeks)

Goal: to support reperfusion, prevent an increase in intraosseous pressure, and avoid overload of the weakened subchondral plate.

Stage characteristics:

1. Partial axial weight bearing limited to 10–15% of body weight using two crutches.

2. Positional therapy avoiding adduction and rotational movements that generate shear stress.

3. Isometric exercises for the quadriceps and gluteal muscles, with core muscle activation.

4. Lymphatic drainage and microcirculatory modalities (electrical stimulation, magnetotherapy).

5. Initiation of digital monitoring: daily VAS pain scores and remote consultations.

Distinctive features of the approach: Most conventional protocols recommend fixed load restriction (up to 6 weeks). In the proposed algorithm, decisions are made dynamically based on the patient's biomechanical profile.

Stage 2. Early functional recovery (2–6 weeks)

Goal: to stimulate trabecular remodeling, restore proprioception, and normalize muscle balance.

Stage characteristics:

1. Gradual increase in load to 30–50% of body weight provided pain dynamics remain stable.

2. Exercises in closed kinetic chains, use of stabilization platforms, and balance therapy.

3. Range-of-motion exercises within the comfort zone: hip flexion up to 90° with minimal rotation.

4. Proprioceptive techniques using IMU sensors to monitor axial deviations.

5. Telemonitoring of gait parameters (stance phase, step symmetry).

Distinctive features of the approach: For the first time, load progression is guided by sensor-based data rather than solely by subjective pain assessment.

Stage 3. Mid-term recovery (6–12 weeks)

Goal: to restore full motor control and optimize gait biomechanics.

Stage characteristics:

1. Transition to full or near-full weight bearing (70–100%) once IMU sensors confirm movement symmetry.

2. Kinesitherapy incorporating open kinetic chains and strength training of proximal muscle groups.

3. Restoration of full range of motion, including rotational components.

4. Biomechanical correction of gait patterns (reduction of pelvic drop, normalization of contact phases).

5. Regular MRI follow-up as indicated (presence of bone marrow edema, double-line sign).

Distinctive features of the approach: Traditional protocols do not apply quantitative gait pattern correction. In the proposed algorithm, telemonitoring provides objective metrics, replacing purely observational assessment by the rehabilitation specialist.

Stage 4. Late functional phase (12–24 weeks)

Goal: to achieve full functional recovery and prevent secondary disorders.

Stage characteristics:

1. Functional training including fast walking, transitions, and stair negotiation.

2. Gradual return to professional or military activity.

3. Outcome testing: Harris Hip Score (HHS), 6-minute walk test, Timed Up and Go, and load symmetry analysis.

4. Final telemonitoring phase focusing on assessment of load cyclicality.

Distinctive features of the approach: Instead of linear rehabilitation, the pathway allows staged reassessment with the option to revert to a previous level in case of unfavorable dynamics.

The proposed rehabilitation pathway differs from conventional protocols in several important ways. First, load progression is individualized and guided by data obtained from IMU sensors, rather than being determined solely by fixed time frames. Each rehabilitation stage is built on a clear biomechanical rationale that takes into account the localization of the necrotic lesion according to the JIC classification and the structural vulnerability of the subchondral plate. Telemonitoring is integrated as a mandatory element of patient management, not merely an optional add-on, allowing continuous supervision beyond in-person visits. The pathway is designed to be clinically adaptive, with the possibility to modify or repeat stages depending on pain intensity, range of motion, and gait characteristics. Unlike traditional

approaches, which often rely on subjective or visual assessment, this protocol incorporates continuous monitoring of kinematic phase symmetry, a parameter that is rarely addressed in standard rehabilitation schemes. Finally, particular emphasis is placed on the restoration of proprioception, which is considered a key protective mechanism against secondary collapse and long-term functional deterioration.

Discussion of research results

The proposed rehabilitation algorithm following core decompression for avascular necrosis of the femoral head reflects current understanding of the disease's pathobiomechanics and the principles of bone tissue recovery after decompressive interventions. Unlike traditional protocols, which are largely based on fixed time restrictions and do not account for individual structural characteristics of the joint, the proposed pathway allows for dynamic load adjustment guided by objective data obtained through telemonitoring technologies and inertial motion sensors. This approach is consistent with the ongoing shift in modern orthopedics toward personalized treatment and biomechanically grounded functional recovery.

Clinical outcomes demonstrated that early, carefully dosed weight bearing, when combined with algorithm-guided control of gait symmetry, creates favorable conditions for trabecular remodeling without increasing the risk of subchondral collapse. These findings are in line with emerging experimental evidence suggesting that complete immobilization may slow reperfusion processes, whereas controlled mechanical loading stimulates osteoblastic activity and contributes to normalization of intraosseous pressure. In this context, the proposed protocol achieves a balance between safety and functional stimulation, which is particularly important in patients with early-stage AVN.

A key strength of the pathway is the integration of telemonitoring, which makes it possible to track the true dynamics of recovery outside the clinical setting. Compared with conventional follow-up based on periodic in-person visits, remote assessment of gait phases, range of motion, and load symmetry provides more precise data, enables early detection of deviations, and supports timely adjustment of the rehabilitation plan. This approach substantially improves patient adherence and reduces the risk of chronic functional impairment.

At the same time, several limitations of the algorithm warrant consideration. First, although the sample size was sufficient for an initial analysis, it does not allow definitive conclusions regarding effectiveness in specific subgroups, particularly patients with JIC type D lesions or necrotic involvement exceeding 30%. Second, reliance on telemonitoring introduces technical requirements that may limit implementation in settings where IMU sensors or remote monitoring platforms are not readily available. In addition, the algorithm does not account for variations in surgical technique (single-versus multi-channel

decompression, use of mesenchymal stem cells, etc.), which may influence the rate of bone remodeling.

Despite these limitations, the proposed model has the potential to become a new standard for postoperative management of patients with AVN, as it addresses key shortcomings of traditional schemes – namely, the lack of biomechanical rationale and objective monitoring. Its implementation may reduce progression to collapse, shorten recovery time, and improve return to physical or occupational activity. Compared with existing protocols, the model combines an evidence-based framework, technological support, and clinical flexibility, making it suitable for broader application and further multifactorial validation.

Prospects for further research

Future research should focus on optimizing load progression for different morphotypes of necrotic involvement and exploring the integration of this algorithm into comprehensive telerehabilitation programs. Another important direction is the development of predictive mathematical models to estimate collapse risk based on biomechanical data collected through telemonitoring.

In summary, the proposed rehabilitation pathway demonstrates good clinical effectiveness, high adaptability, and solid scientific rationale, and may serve as a platform for the development of personalized recovery protocols following joint-preserving interventions for avascular necrosis.

Conclusions

1. The proposed rehabilitation algorithm following core decompression for avascular necrosis provides a biomechanically grounded, stepwise recovery strategy

based on individual clinical and functional criteria, including pain intensity, gait symmetry, and range of motion. This personalized approach allowed early graded weight bearing to be safely implemented, with 82.3% of patients tolerating partial load by week 4 without pain escalation. Importantly, during the 6-month follow-up, radiologically confirmed progression to subchondral collapse was observed in only 7.8% of cases, all of which were associated with unfavorable lesion localization (JIC C–D) and necrotic volume >30%, supporting the protective role of controlled, criteria-driven loading in early-stage AVN.

2. The integration of telemonitoring and inertial motion sensors enabled objective quantification of recovery dynamics and continuous monitoring of gait mechanics and load distribution. Gait asymmetry during the stance phase was initially detected in 80.4% of patients, but decreased by an average of 22% by week 12, reflecting progressive biomechanical normalization. Sensor-based feedback facilitated timely modification of rehabilitation intensity and was associated with high patient adherence, contributing to more consistent execution of the rehabilitation program and early identification of maladaptive movement patterns.

3. Compared with conventional time-based rehabilitation protocols, the algorithm demonstrated superior functional outcomes. Mean Harris Hip Score improved from 64.2 ± 5.9 preoperatively to 78.5 ± 6.3 by week 12 ($p < 0.01$), with further gains observed by sixth month. By the end of the rehabilitation pathway, 72.5% of patients achieved full functional recovery ($\text{HHS} \geq 85$), while an additional 21.6% reached moderate functional restoration ($\text{HHS } 70\text{--}84$). Pain intensity decreased significantly (VAS from 5.2 ± 1.3 to 2.8 ± 0.9 , $p < 0.001$), and the need for unscheduled follow-up visits was reduced, indicating a more efficient and predictable recovery trajectory.

Bibliography

1. Pijnenburg L, Felten R, Javier RM. Ostéonécroses aseptiques, une revue générale des ostéonécroses de la hanche, et au-delà [A review of avascular necrosis, of the hip and beyond]. *Rev Med Interne*. 2020 Jan;41(1):27–36. French. DOI: 10.1016/j.revmed.2019.10.332. Epub 2019 Nov 10. PMID: 31722835.
2. Massin P. Treatments of avascular osteonecrosis of the hip: Current treatments. *Morphologie*. 2021 Jun;105(349):120–126. DOI: 10.1016/j.morpho.2020.06.003. Epub 2020 Jul 8. PMID: 32653168.
3. Atilla B, Bakircioğlu S, Shope AJ, Parvizi J. Joint-preserving procedures for osteonecrosis of the femoral head. *EFORT Open Rev*. 2020 Jan 28;4(12):647–658. DOI: 10.1302/2058-5241.4.180073. PMID: 32010453; PMCID: PMC6986391.
4. Kunze KN, Sullivan SW, Nwachukwu BU. Updates on Management of Avascular Necrosis Using Hip Arthroscopy for Core Decompression. *Front Surg*. 2022 Apr 8;9:662722. DOI: 10.3389/fsurg.2022.662722. PMID: 35465433; PMCID: PMC9024040.
5. Kumar P, Shetty VD, Dhillon MS. Efficacy of orthobiologic adjuvants to core decompression for hip preservation in avascular necrosis hip. *J Hip Preserv Surg*. 2020 Nov 22;7(3):423–438. DOI: 10.1093/jhps/hnaa051. PMID: 33948198; PMCID: PMC8081433.
6. Gökmen MY, Gökmen HS, Uluöz M, Pazarcı Ö, Özgözen AL, Uluç EA, Çiloğlu O. Healing beyond bone: a qualitative study of the core decompression experience of physically active patients with stage II hip avascular necrosis. *J Orthop Surg Res*. 2025 Jan 24;20(1):93. DOI: 10.1186/s13018-025-05497-6. PMID: 39849561; PMCID: PMC11761184.
7. Pakhan AA, Phansopkar P, Boob MA. Rehabilitation to Complement Unique Single-Stage Core Decompression and Total Hip Arthroplasty in Bilateral Avascular Necrosis: A Case Report. *Cureus*. 2024 Jan 25;16(1):e52914. DOI: 10.7759/cureus.52914. PMID: 38406129; PMCID: PMC10893823.
8. Gabada R, Jawade S, Tikhile P. Proprioceptive Neuromuscular Facilitation (PNF)-Integrated Gait Rehabilitation Following Total Hip Arthroplasty. *Cureus*. 2024 Apr 8;16(4):e57854. DOI: 10.7759/cureus.57854. PMID: 38721165; PMCID: PMC11078558.
9. Tenforde AS, Hefner JE, Kodish-Wachs JE, Iaccarino MA, Paganoni S. Telehealth in Physical Medicine and Rehabilitation: A Narrative Review. *PM R*. 2017 May;9(5S):S51–S58. DOI: 10.1016/j.pmrj.2017.02.013. PMID: 28527504.

10. Lohiya A Jr, Dhaniwala N, Dudhekar U, Goyal S, Patel SK. A Comprehensive Review of Treatment Strategies for Early Avascular Necrosis. *Cureus*. 2023 Dec 14;15(12):e50510. DOI: 10.7759/cureus.50510. PMID: 38226130; PMCID: PMC10788237.
11. Yavuz Sarsam B, Cankurtaran T, Haberal B, Çakmak E. Avascular necrosis of the femoral head: which MRI parameters or findings are more decisive for determining the prognosis? *Radiologie (Heidelb)*. 2024 Nov;64(Suppl 1):145–152. English. DOI: 10.1007/s00117-024-01359-0. Epub 2024 Sep 5. PMID: 39235473.
12. Kalekar T, Bothara K, Lamghare P. The Application of Magnetic Resonance Imaging in the Early and Accurate Diagnosis of Hip Joint Avascular Necrosis. *Cureus*. 2024 Sep 7;16(9):e68888. DOI: 10.7759/cureus.68888. PMID: 39376854; PMCID: PMC11458061.
13. Beauchamp TL, Childress JF. Principles of biomedical ethics. 9th ed. Oxford: Oxford University Press; 2026. 528 p.
14. Sai Krishna MLV, Kar S, Kumar R, Singh H, Mittal R, Digge VK. The Role of Conservative Management in the Avascular Necrosis of the Femoral Head: A Review of Systematic Reviews. *Indian J Orthop*. 2023 Feb 3;57(3):410–420. DOI: 10.1007/s43465-023-00818-5. PMID: 36777071; PMCID: PMC9897604.
15. WitMotion WT901 sensors. Technical documentation. Available from: https://witmotion-sensor.com/products/accelerometer-module-tilt-sensor-mpu9250-imu-for-arduino?srsltid=AfmBOooyN68tv2ZpxrtzrYblCSZ_lxLHlgFy-wY-TbweAqRdEXNkurV.
16. Delgado DA, Lambert BS, Boutris N, McCulloch PC, Robbins AB, Moreno MR, Harris JD. Validation of Digital Visual Analog Scale Pain Scoring With a Traditional Paper-based Visual Analog Scale in Adults. *J Am Acad Orthop Surg Glob Res Rev*. 2018 Mar 23;2(3):e088. DOI: 10.5435/JAAOSGlobal-D-17-00088. PMID: 30211382; PMCID: PMC6132313.
17. Fawley D, Bernard T, Thomason HC 3rd, Zagra L, Ten Broeke RHM, Johnson K. Early functional recovery outcomes and return to work after primary total hip arthroplasty: a novel patient reported outcomes questionnaire. *J Orthop Surg Res*. 2024 Jul 26;19(1):434. DOI: 10.1186/s13018-024-04937-z. PMID: 39061099; PMCID: PMC11282613.
18. Saavedra M, Moraga R, Diaz P, Camacho D, Mardones R. Comparative analysis of kinesiotherapy rehabilitation after hip arthroscopy, quantified by harris and vail hip scores: a retrospective study. *Muscles Ligaments Tendons J*. 2016 Dec 21;6(3):420–426. DOI: 10.11138/mltj/2016.6.3.420. PMID: 28066749; PMCID: PMC5193534.
19. Hulleck AA, Menoth Mohan D, Abdallah N, El Rich M, Khalaf K. Present and future of gait assessment in clinical practice: Towards the application of novel trends and technologies. *Front Med Technol*. 2022 Dec 16;4:901331. DOI: 10.3389/fmedt.2022.901331. PMID: 36590154; PMCID: PMC9800936.
20. Wang QR, An JJ, Zhang WL, Yang ZY, Zhao X, Kang PD. Core Decompression Prevents Progression of Asymptomatic Type C Osteonecrosis of Femoral Head According to the Japanese Investigation Committee Classification: A Retrospective Study. *Orthop Surg*. 2022 May;14(5):851–859. DOI: 10.1111/os.13213. Epub 2022 Apr 18. PMID: 35434904; PMCID: PMC9087457.
21. Nisbet R, Miner G, Yale K. Handbook of Statistical Analysis and Data Mining Applications. 2nd ed. London: Academic Press; 2018. 793 p. ISBN: 978-0-12-416632-5. DOI: 10.1016/C2012-0-06451-4

Avascular necrosis (AVN) of the femoral head is a progressive disorder that may lead to femoral head collapse and substantial disability. Core decompression is a joint-preserving treatment for early-stage AVN, although postoperative rehabilitation remains insufficiently standardized.

Purpose. This study aimed to evaluate a rehabilitation pathway incorporating early graded weight bearing, physiotherapy, and telemonitoring after core decompression.

Materials and Methods. A prospective–retrospective cohort study included 51 patients with ARCO/Ficat stages I–II AVN who underwent core decompression between 2020 and 2025 in orthopedic centers in Odesa and Kyiv, Ukraine. Rehabilitation comprised graded axial loading, kinesiotherapy and proprioceptive training, physiotherapy, and progressive functional restoration. Telemonitoring included inertial measurement unit (IMU) sensors, digital pain assessment, and functional questionnaires. Outcomes were assessed using the Harris Hip Score (HHS), visual analogue scale (VAS), gait parameters, range of motion, and MRI.

Results. Mean patient age was 34.8±7.1 years; glucocorticoid exposure was the leading etiologic factor (64.7%). By postoperative week 4, 82.3% tolerated partial weight bearing without increased pain. HHS improved from 64.2±5.9 to 78.5±6.3 ($p<0.01$), while VAS decreased from 5.2±1.3 to 2.8±0.9 ($p<0.001$). Gait support-phase asymmetry improved by 22% by week 12. Physiological hip flexion was restored in 74.5%, while femoral head collapse occurred in 7.8% during six-month follow-up. Full functional recovery (HHS≥85) was achieved in 72.5%.

Conclusions. The proposed personalized rehabilitation pathway combining graded loading, targeted physiotherapy, and telemonitoring improved functional recovery, pain, and gait biomechanics following core decompression.

Key words: avascular necrosis, core decompression, physical therapy, telemonitoring, gait biomechanics.

Мета дослідження – визначити оптимальний реабілітаційний маршрут для пацієнтів після декомпресійної тунелізації (core decompression) при аваскулярному некрозі (AVN) головки стегнової кістки з оцінкою ефективності раннього дозованого навантаження, фізичної терапії та телемоніторингу функціонального стану кульшового суглоба.

Матеріали та методи. Проведено проспективно-ретроспективне когортне дослідження, до якого включено 51 пацієнта віком 18–60 років з AVN головки стегнової кістки стадій ARCO I–II та Ficat I–II, яким у 2020–2025 роках у спеціалізованих ортопедичних центрах Одеси та Києва виконано декомпресію головки стегнової кістки. Критеріями включення були відсутність субхондрального колапсу понад 2 мм, наявність до- та післяопераційної МРТ і участь у структурованій програмі реабілітації та телемоніторингу. Реабілітаційний маршрут передбачав раннє дозоване осьове навантаження, кінезотерапію, пропріоцептивні тренування, фізіотерапевтичні втручання та поетапне функціональне відновлення. Телемоніторинг здійснювали за допомогою IMU-сенсорів WitMotion WT901, цифрової візуально-аналогової шкали болю (VAS), щоденних функціональних опитувальників і щотижневого дистанційного контролю фізичного терапевта. Результати оцінювали за Harris Hip Score (HHS), VAS, параметрами ходи, амплітудою рухів та МРТ.

Результати. Середній вік пацієнтів становив $34,8 \pm 7,1$ року; переважали чоловіки молодого та середнього віку. Провідним етіологічним чинником було тривале або високодозове застосування глюкокортикостероїдів, яке встановлено у 64,7% випадків. За класифікацією ІС у 58,8% пацієнтів некротичні ураження відповідали типам В–С, що характеризуються помірним або високим ризиком біомеханічної нестабільності. Реабілітація включала раннє дозоване навантаження протягом 1–4-го тижнів, цілеспрямовану кінезотерапію упродовж 4–12-го тижнів та фізіотерапію в поєднанні з телемоніторингом до 6 місяців. На 4-му тижні 82,3% пацієнтів переносили часткове осьове навантаження без посилення больового синдрому.

Функціональний стан достовірно покращився: ННС збільшився з $64,2 \pm 5,9$ до $78,5 \pm 6,3$ бала ($p < 0,01$), тобто у середньому на 14,3 бала, тоді як інтенсивність болю за VAS зменшилася з $5,2 \pm 1,3$ до $2,8 \pm 0,9$ бала ($p < 0,001$), або на 2,4 бала. За даними ІМУ-моніторингу асиметрію фази опори початково виявлено у 41 (80,4%) пацієнта; до 12-го тижня її вираженість зменшилася у середньому на 22%. Фізіологічну амплітуду згинання у кульшовому суглобі відновлено у 74,5% пацієнтів, водночас у разі більших некротичних уражень (Steinberg II) нормалізації досягнуто лише у 51,8% випадків.

Протягом 6-місячного спостереження рентгенологічно підтверджений колапс головки стегнової кістки виник у 4 (7,8%) пацієнтів; усі випадки характеризувалися несприятливою локалізацією ІС С–D та об'ємом некротичного ураження понад 30%. У пацієнтів без прогресування за даними МРТ спостерігали стабільне трабекулярне ремоделювання, зменшення набряку кісткового мозку та вираженості симптому подвійної лінії. Через 6 місяців повного функціонального відновлення (ННС ≥ 85) досягли 72,5% пацієнтів, помірного відновлення (ННС 70–84) – 21,6%, тоді як клінічно значущі функціональні обмеження зберігалися лише у 5,9%.

Висновки. Запропонований поетапний реабілітаційний маршрут після декомпресійної тунелізації (core decompression) забезпечує контрольоване раннє навантаження, зменшення болю, покращення функції кульшового суглоба та нормалізацію біомеханіки ходи. Інтеграція ІМУ-сенсорів і телемоніторингу дозволяє об'єктивізувати динаміку відновлення та індивідуально коригувати інтенсивність навантаження. Найбільший ризик структурного прогресування зберігається у разі локалізації некрозу ІС С–D та об'єму ураження $> 30\%$, що обґрунтовує необхідність особливо обережного режиму навантаження у цієї категорії пацієнтів.

Ключові слова: аваскулярний некроз, декомпресія головки стегнової кістки, фізична терапія, телемоніторинг, біомеханіка ходи, реабілітація.

Конфлікт інтересів: відсутній.

Conflict of interest: absent.

Information about the authors

Varzar Serhii Oleksandrovych – Candidate of Medical Sciences, Orthopaedic Trauma Surgeon of the Municipal Non-Profit Enterprise “City Clinical Hospital No. 11”; Vitaliia Nesterenko Str., 5-G, Odesa, Ukraine, 65000.
varzar.s@i.ua, ORCID ID: 0009-0005-8304-9997 ^{A, B, C, D, E, F}

Babova Iryna Kostiantynivna – Doctor of Medical Sciences, Professor, Physical and Rehabilitation Medicine Physician of the State Institution “Territorial Medical Association of the Ministry of Internal Affairs of Ukraine in Odesa Region”; Karkashadze Lane, 3, Odesa, Ukraine, 65044; Senior Researcher of the State Institution “Institute of Market and Economic & Ecological Research of the National Academy of Sciences of Ukraine”, 29 Frantsuzkyi Boulevard, Odesa, Ukraine, 65044.
babovairina@gmail.com, ORCID ID: 0000-0003-1018-8302 ^{A, D, E, F}

Babov Kostiantyn Dmytrovych – Doctor of Medical Sciences, Professor, Honoured Worker of Science and Technology of Ukraine, Director of the State Non-commercial Enterprise “Ukrainian Research Institute of Rehabilitation and Balneology of Ministry of Health of Ukraine”; Dzhevetskoho (Lermontovskiy) Lane, 6, Odesa, Ukraine, 65014.
mrik.odessa@gmail.com, ORCID ID: 0000-0003-2066-6152 ^{A, F}

Дата першого надходження статті до видання: 16.06.2026

Дата прийняття статті до друку після рецензування: 31.08.2026

Дата публікації (оприлюднення) статті: 28.10.2026