Comparison of Telerehabilitation and Face-to-Face McKenzie Therapy Following Unilateral Biportal Endoscopic Discectomy: A Multicentre Retrospective Matched Cohort Study

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AIM: To compare short-term pain, disability, and functional outcomes between telerehabilitation and face-to-face McKenzie therapy following unilateral biportal endoscopic (UBE) discectomy for lumbar disc herniation (LDH).

METHODS: This multicentre retrospective matched cohort study included adults undergoing UBE discectomy for LDH at Shanghai Sixth People's Hospital and Xiyuan Hospital of China Academy of Chinese Medical Sciences between October 2023 and December 2024. Patients received either in-home telerehabilitation (Tele) or in-clinic physiotherapy (Clinic) according to the standard practice of the treating centre rather than by random allocation. Propensity score matching (PSM, 1:1) was used to reduce confounding. Both groups completed a 12-week McKenzie programme. Primary outcomes were Modified Von Korff (MvK) pain and disability scales and the Oswestry Disability Index (ODI) at 12 weeks. Secondary outcomes included visual analogue scale (VAS) scores, modified lumbar Schober (MLS), and the 6-minute walk test (6MWT).

RESULTS: After matching, 122 patients were included (Tele: n = 61; Clinic: n = 61). Matching reduced between-group imbalance for every covariate, with all absolute standardised mean differences (SMDs) below 0.25, although modest residual imbalances remained for some covariates. For the primary outcomes, scores decreased significantly from baseline to 12 weeks in both groups (all time effects, $p < 0.001$), with no significant group × time interactions detected (MvK pain, $p = 0.979$; MvK disability, $p = 0.794$; ODI, $p = 0.910$). The between-group difference on the MvK pain scale at 12 weeks was substantially smaller than the established minimal clinically important difference (MCID) of 10 points. All secondary outcomes also improved significantly in both groups (all time effects, $p < 0.001$), with no significant between-group differences detected (all interaction $p > 0.05$). Overall adverse event rates were comparable between groups.

CONCLUSIONS: Telerehabilitation and face-to-face McKenzie therapy were associated with comparable short-term improvements after UBE discectomy. These findings suggest that telerehabilitation may be a feasible alternative to in-clinic rehabilitation, although prospective randomised trials are needed for confirmation.

Keywords: telerehabilitation; McKenzie therapy; unilateral biportal endoscopy; lumbar disc herniation; postoperative rehabilitation; propensity score matching

Introduction

Lumbar disc herniation (LDH) is a common degenerative spinal condition that substantially affects quality of life and imposes considerable healthcare costs globally [1]. Its cardinal clinical manifestations are low back pain (LBP) and sciatica, both of which are leading contributors to years lived with disability worldwide [2,3]. Approximately two-thirds of adults experience LBP during their lifetime [2], and sciatica occurs in roughly 85% of individuals with symptomatic LDH [3]. Global estimates place the prevalence of LDH at 14–20% and its annual incidence at 2–

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4%, with the condition predominantly affecting adults aged 30–50 years and most frequently involving the L4–L5 and L5–S1 levels [4,5]. LDH is also characterised by a high recurrence rate and prolonged symptomatic course, which together contribute to persistent disability and repeated healthcare utilisation [6].

In rural and remote settings, these challenges are compounded by limited access to specialist surgical care and postoperative rehabilitation. Travel distance, workforce shortages, and cost can each delay recovery. Minimally invasive approaches to LDH have steadily replaced open microdiscectomy, driven by evidence of comparable or superior clinical outcomes with reduced tissue damage. A recent Bayesian network meta-analysis of eight randomised controlled trials compared open microdiscectomy, tubular microdiscectomy, and percutaneous transforaminal endoscopic discectomy. It reported superior pain relief and functional outcomes for percutaneous transforaminal endoscopic discectomy (PTED) over open microdiscectomy, with comparable complication and reoperation rates across all three modalities [7]. Unilateral biportal endoscopy (UBE) is a more recent biportal technique not evaluated in that analysis. UBE has gained rapid clinical adoption. It offers enhanced intraoperative visualisation through two independent portals, less paraspinal muscle trauma, and shorter recovery times compared with open or microendoscopic approaches [8,9,10,11,12]. The growing use of these techniques underscores the need for accessible postoperative rehabilitation pathways tailored to this surgical landscape.

McKenzie therapy, also known as Mechanical Diagnosis and Therapy, is a widely employed rehabilitation method that emphasises patient education, self-assessment, and directional-preference exercises tailored to alleviate pain and restore function [13,14]. McKenzie extension exercises were originally developed to treat LBP in selected patients and are now commonly used both as conservative treatment and as part of postoperative rehabilitation, with specific exercises selected to align with the postoperative goals of pain reduction and restoration of mobility [14,15]. Traditionally, McKenzie therapy is delivered through face-to-face sessions in which clinicians perform a detailed mechanical assessment and guide patients through an individualised exercise programme [16].

Telerehabilitation has emerged as a scalable alternative to in-clinic care, with several trials demonstrating its effectiveness in the postoperative rehabilitation of patients with LDH [17,18,19,20,21]. However, because McKenzie therapy relies heavily on precise visual and tactile feedback, adaptation to a remote delivery format is non-trivial. While McKenzie therapy has shown efficacy in postoperative LDH rehabilitation, its application specifically after UBE discectomy has not been systematically examined, and direct comparative evidence between telerehabilitation and face-to-face delivery in this surgical population is lacking. We therefore conducted a multicentre retrospective matched cohort study to compare short-term pain, disability, and functional outcomes between telerehabilitation- and face-to-face-delivered McKenzie therapy following UBE discectomy for LDH, applying propensity score matching (PSM) to reduce confounding by measured baseline characteristics.

Methods

Study Design

This was a multicentre retrospective matched cohort study. Eligible patients were identified from the institutional records of two tertiary trauma centres (Shanghai Sixth People's Hospital and Xiyuan Hospital of China Academy of Chinese Medical Sciences) located in the largest cities of the north and south of China—urban centres with high surgical volumes, advanced facilities, and access to demographically distinct regional populations. Rehabilitation modality (in-home telerehabilitation or in-clinic physiotherapy) was observed as received in routine clinical care rather than by random allocation, with modality largely determined by the treating centre's standard practice and patient-level logistical considerations. The study was approved by the Institutional Review Board (Research Ethics Committee) of Shanghai Sixth People's Hospital Affiliated to Shanghai Jiao Tong University School of Medicine (IRB number: 2024-KY-223 (K)). Given the retrospective nature of the study and the absence of identifiable patient information, the requirement for informed consent was waived by the Ethics Committee. The study was reported in accordance with the STROBE statement [22]. PSM was applied as a pre-specified analytical strategy to reduce confounding by measured baseline characteristics.

We limited the study population to patients who underwent UBE because this procedure is the main minimally invasive discectomy technique used at the participating centres and therefore provided a sufficient and clinically relevant patient pool. In addition, UBE is associated with less paraspinal muscle injury and shorter postoperative hospitalisation, which may allow earlier mobilisation and make home-based telerehabilitation more feasible. Focusing on a single surgical technique also helped reduce variation in postoperative recovery patterns, allowing a more direct comparison between telerehabilitation and face-to-face rehabilitation.

Study Population

Using institutional medical records, we identified eligible adult patients who underwent UBE discectomy for LDH at the participating centres during the study period. Baseline patient-reported measures were defined as those recorded at hospital discharge (typically postoperative day 2–5) as part of routine clinical care and were extracted from the record. All patients received initial instruction from a physiotherapist on postoperative day 2, marking the initiation

of the postoperative rehabilitation programme. Baseline patient-reported outcome measures were collected at hospital discharge (postoperative days 2–5). Therefore, depending on the timing of discharge, some baseline assessments may have been performed after the initial rehabilitation instruction and a short period of early rehabilitation exposure. The interval between rehabilitation initiation and baseline assessment may consequently have varied among patients. The operated level was confirmed radiologically using preoperative imaging reports and operative documentation and was verified by author MW.

Patients were eligible if they: (1) were aged ≥18 years; (2) underwent first-time surgery for LDH; (3) received UBE as the surgical technique; and (4) had sufficient language comprehension and cognitive capacity, as documented by the treating clinical team, to understand and follow rehabilitation instructions.

Patients were excluded if they had: (1) a history of prior spinal surgery; (2) documented neurological deficits in the lower extremities; (3) evidence of spinal instability such as spondylolisthesis; (4) missing baseline or 12-week outcome data; or (5) comorbid conditions expected to substantially affect postoperative rehabilitation or outcome assessment, including acute or chronic infection, malignancy, systemic inflammatory disease, severe cardiovascular or pulmonary disease, or major psychiatric or neurological disorders.

The flow of participants from screening and exclusion to PSM, group allocation, and 12-week follow-up is shown in Fig. 1.

Propensity Score Matching

Propensity scores were estimated using logistic regression with the treatment group (Tele vs. Clinic) as the dependent variable and study centre together with the following baseline covariates as predictors: sex, age, body mass index (BMI), occupation, education level, insurance type, use of non-steroidal anti-inflammatory drugs (NSAIDs), duration of pain, number of healthcare visits for LBP in the prior 12 weeks, operative level, and magnetic resonance imaging (MRI) morphology. Patients were matched 1:1 using nearest-neighbour matching without replacement on the logit of the propensity score with a caliper of 0.2 standard deviation (SD); patients without an acceptable match within the caliper were excluded. Covariate balance before and after matching was assessed using absolute standardised mean differences (SMDs), interpreted in graded fashion: an SMD below 0.10 indicated good balance, an SMD between 0.10 and 0.25 indicated modest residual imbalance, and an SMD above 0.25 indicated substantive imbalance. Pre- and post-matching distributions and SMDs for each covariate are presented in Table 1.

Postoperative Rehabilitation

All patients began a 12-week rehabilitation programme based on McKenzie Mechanical Diagnosis and Therapy on postoperative day 2. Exercise progression was determined by symptomatic response to loading strategies, exercise tolerance, and functional recovery, rather than by fixed intensity thresholds. Exercises progressed from prone lying and repeated extension in lying during the early postoperative phase to standing extension and graded functional activities as tolerated. Details of the exercise progression are provided in **Supplementary Material 1**.

On postoperative day 2, patients received initial instruction from a physiotherapist. After discharge, they continued rehabilitation through either in-clinic physiotherapy or home-based telerehabilitation according to the standard practice of the treating centre. All interventions were delivered by certified attending-level physiotherapists (PT) with at least five years of clinical experience and McKenzie-specific training. Both groups received the same back-care education package, which covered LDH, postoperative care, early mobilisation, pain management, muscle fatigue, and gradual return to activity.

The two groups differed in the amount of supervised contact by design. The Clinic group received three supervised sessions per week, whereas the Tele group performed sensor-guided home exercises with weekly video consultations and unlimited asynchronous text communication with physiotherapists. This difference reflected the intended comparison between rehabilitation delivery modes and is discussed as a limitation.

Modes of Service Delivery

In-home Telerehabilitation (Tele Group)

The telerehabilitation programme was delivered through a smartphone application (Joymotion™; Shanghai Fudong Medical Management Co., Ltd., Shanghai, China). The application was installed on the day of discharge, and patients used their home Wi-Fi networks for connectivity. Before discharge, physiotherapists provided individualised instruction on key McKenzie exercises, correct movement execution, common errors, and use of the application and inertial measurement unit (IMU) sensor. Patients also received the McKenzie extension protocol and a standard back-care education package covering standing, sitting, lifting, and other daily activities [14,15].

During home exercise sessions, the IMU sensor was attached to the lumbar region and lower extremity to monitor flexion–extension angle, sagittal range of motion, and movement velocity. The application provided real-time visual and auditory feedback to help patients correct movement errors during exercise. Rehabilitation progress was monitored through weekly video consultations with physiotherapists and unlimited asynchronous in-app text communication. Patients were instructed to perform the prescribed exercises daily, with at least three sessions per week recommended; each session lasted approximately 45 minutes. All patients returned to the clinic at 12 weeks for outcome assessment.

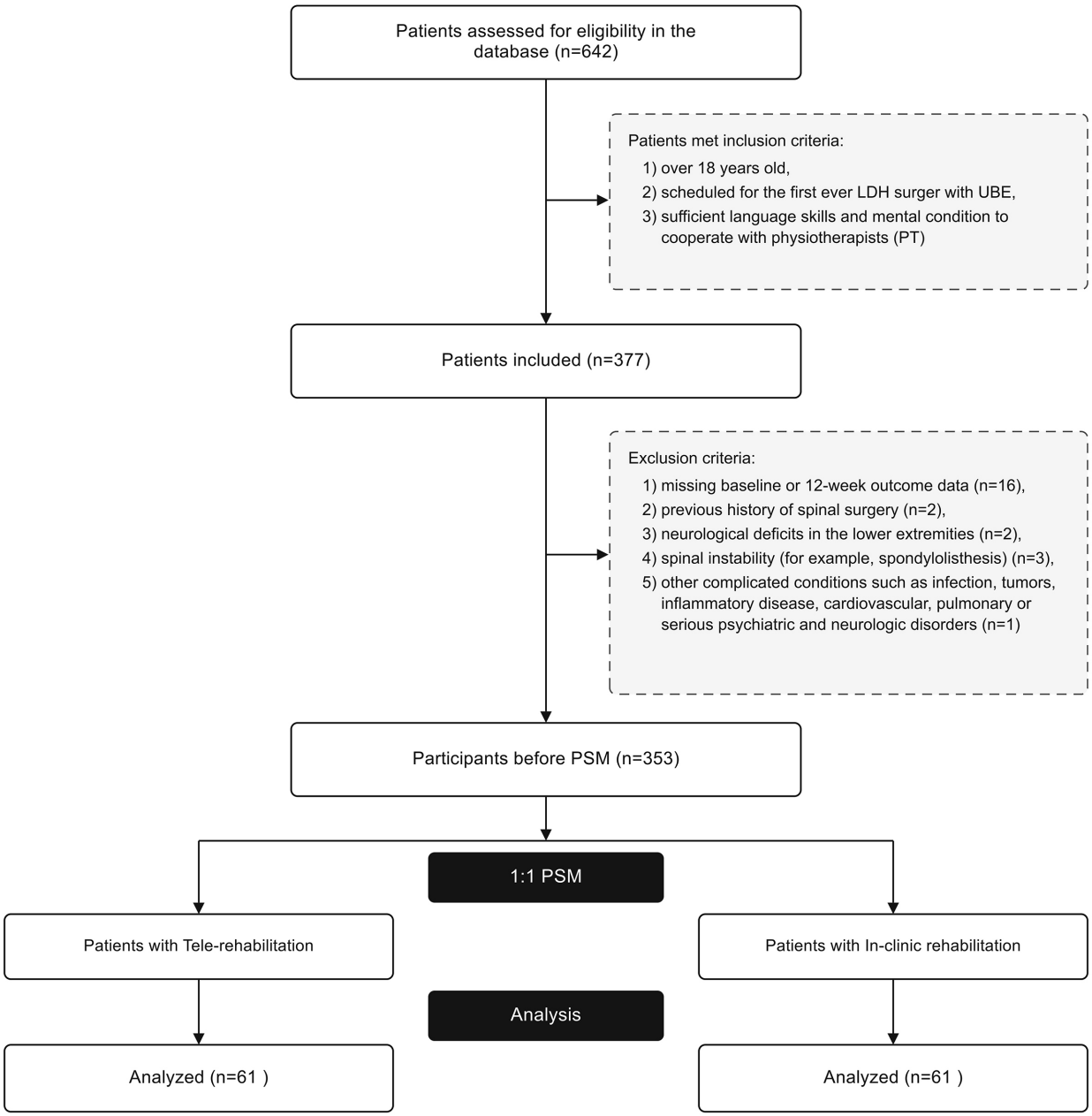


Fig. 1. Study flow diagram. LDH, lumbar disc herniation; UBE, unilateral biportal endoscopic; PSM, propensity score matching; PT, physiotherapists.

In-clinic Physiotherapy (Clinic Group)

Patients in the Clinic group attended designated physiotherapy clinics in the participating cities, where they received the McKenzie extension protocol together with back-care education equivalent to that provided to the Tele group [16]. Patients performed the exercises under PT supervision three times per week at the clinic. Programme progression was adjusted individually according to each patient's exercise tolerance, symptomatic response, and functional improvement.

Outcome Measures

Outcomes were defined as those recorded at hospital discharge (usually 2 to 5 days postoperatively) and at the 12-week follow-up, extracted from the medical record.

Primary Outcomes

Three primary outcomes were assessed at baseline and at 12 weeks. Participants completed the Modified Von Korff (MvK) scales, which provide separate 0–100 scores for pain and disability (0 = no pain/disability; 100 = maximum pain/disability) [23]. The third primary outcome was the Oswestry Disability Index (ODI), also scored 0–100 (0 = no

Table 1. Baseline characteristics of patients before and after propensity score matching.

Characteristic	Tele, before (n = 105)	Clinic, before (n = 248)	SMD, before	Tele, after (n = 61)	Clinic, after (n = 61)	SMD, after
Male sex, n (%)	48 (45.7)	72 (29.0)	0.350	33 (54.1)	29 (47.5)	0.131
Age, years, mean (SD)	42.0 (8.0)	46.0 (8.0)	0.500	43.7 (6.8)	45.4 (7.3)	0.241
BMI, kg/m^2, mean (SD)	22.5 (3.5)	24.0 (3.5)	0.429	23.2 (3.3)	23.7 (2.8)	0.163
Occupation						
Manual worker, n (%)	30 (28.6)	112 (45.2)	0.349	24 (39.3)	26 (42.6)	0.067
Non-manual worker, n (%)	75 (71.4)	136 (54.8)	0.349	37 (60.7)	35 (57.4)	0.067
Education level						
Lower than high school, n (%)	42 (40.0)	142 (57.3)	0.351	27 (44.3)	26 (42.6)	0.033
Equal/higher than high school, n (%)	63 (60.0)	106 (42.7)	0.351	34 (55.7)	35 (57.4)	0.033
Insurance type						
Government, n (%)	87 (82.9)	231 (93.1)	0.321	51 (83.6)	52 (85.2)	0.045
Commercial, n (%)	9 (8.6)	7 (2.8)	0.250	2 (3.3)	3 (4.9)	0.083
Self, n (%)	9 (8.6)	10 (4.0)	0.188	8 (13.1)	6 (9.8)	0.103
Taking NSAIDs, n (%)	77 (73.3)	220 (88.7)	0.400	45 (73.8)	47 (77.0)	0.076
Duration of pain, months, mean (SD)	8.8 (2.8)	10.2 (3.4)	0.450	9.3 (2.7)	9.9 (3.1)	0.206
Healthcare visits for LBP, prior 12 weeks, median (IQR)	1 (1–2)	2 (1–3)	0.398	2 (1–2)	1 (1–2)	0.182
Operative level						
L3–L4, n (%)	12 (11.4)	57 (23.0)	0.310	12 (19.7)	15 (24.6)	0.119
L4–L5, n (%)	68 (64.8)	95 (38.3)	0.549	31 (50.8)	26 (42.6)	0.165
L5–S1, n (%)	25 (23.8)	96 (38.7)	0.326	18 (29.5)	20 (32.8)	0.071
MRI findings						
Protrusion, n (%)	35 (33.3)	55 (22.2)	0.251	19 (31.1)	18 (29.5)	0.036
Extrusion, n (%)	70 (66.7)	193 (77.8)	0.251	42 (68.9)	43 (70.5)	0.036
Study Center						
Center A, n (%)	40 (38.1)	68 (27.4)	0.229	29 (47.5)	31 (50.8)	0.066

BMI, body mass index; LBP, low back pain; MRI, magnetic resonance imaging; NSAIDs, non-steroidal anti-inflammatory drugs; SMD, standardised mean difference; SD, standard deviation.

Continuous variables are presented as mean (SD), except the number of healthcare visits for LBP, which was non-normally distributed and is presented as median (IQR); categorical variables as n (%). SMD below 0.10 indicates good balance.

disability; 100 = total disability) [24]. A positive treatment effect was concluded only when significant effects were observed for all three primary outcomes, a conservative criterion intended to limit false-positive findings across multiple primary endpoints.

Secondary Outcomes

A visual analogue scale (VAS) was used to assess back pain severity, scored from 0 (no pain) to 100 (worst imaginable pain). A second VAS measured interference with daily activities, scored from 0 (no interference) to 100 (worst interference). Mobility was evaluated using the modified lumbar Schober (MLS) score, which measures the change in distance between marked points on the lower back during lumbar flexion. Functional capacity was assessed using the 6-minute walk test (6MWT), which records the maximum distance participants can walk within 6 minutes at a comfortable pace. Prior to data collection, all assessors completed a standardised training session—including review of published protocols, supervised practice, and proficiency checks—to ensure consistent tape placement and marking for the MLS, as well as standardised administration of the 6MWT (flat 30 m corridor, scripted encouragement, and track markings) in accordance with (early active training) EAT guidelines [25]. These outcomes were assessed at baseline and again after the 12-week intervention in both groups. Intervention fidelity and adherence were monitored throughout the study. Adherence was measured by the total number of completed sessions, categorised as moderate (12–24 sessions) or high (>24 sessions) over the 12-week intervention. Engagement with educational content (via the mobile application for the Tele group, and printed materials for the Clinic group) was also recorded regularly.

Adverse Event Assessment

Adverse events and serious adverse events were retrospectively identified from electronic health records (EHRs) and physiotherapy (PT) notes at both participating hospitals throughout the 12-week follow-up period. All study participants were included in the adverse event assessment. The

relationship of each recorded event to the rehabilitation intervention was assessed by the physician or physiotherapist who documented the event.

Statistical Analysis

All analyses were performed on complete matched pairs with available baseline and 12-week data. Participants with missing outcome data were not included. The distribution of continuous variables was assessed for normality using the Shapiro-Wilk test, and homogeneity of variance using Levene's test. Normally distributed continuous variables are presented as mean (SD) and non-normally distributed continuous variables as median (IQR); categorical variables are presented as n (%). Balance between the matched groups was assessed using absolute standardised mean differences (SMDs) rather than significance tests, as SMDs are independent of sample size; an SMD below 0.10 indicated good balance.

Between-group differences in changes from baseline to 12 weeks for primary and secondary continuous outcomes were examined in the propensity score–matched cohort using repeated-measures multivariate analysis of variance (MANOVA) with fixed effects for group, time, and the group × time interaction. Study centre was included as a covariate to account for potential site effects. The primary estimand was the between-group difference in change from baseline to 12 weeks. Categorical variables were compared using Pearson's chi-square test or Fisher's exact test, as appropriate. All analyses accounted for the matched-pair structure, including the repeated-measures MANOVA, linear models, and categorical outcome analyses. All tests were two-sided with α set at 0.05. To control the Type I error rate across multiple primary endpoints, a significant effect on all three primary outcomes was required before a positive treatment effect could be claimed. Because this was a retrospective analysis of existing records, the sample size was determined by the number of eligible matched patients rather than by an a priori calculation; a post hoc sensitivity power analysis (G*Power, version 3.1.9.6, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) indicated that 61 patients per group provided 80% power (α = 0.05, two-sided) to detect a between-group difference in the change in Modified Von Korff pain of approximately 7 points, smaller than the 10-point minimal clinically important difference. To assess robustness to residual imbalance after matching, the analysis of each outcome was repeated with additional adjustment for age and duration of pain—the two covariates with standardised mean differences above 0.20 after matching. Analyses were performed in SPSS Statistics for Windows (version 27.0; SPSS Inc., Chicago, IL, USA).

Results

Participants

During the study period, 642 patients were screened of whom 377 met the inclusion criteria. After excluding 24 patients (16 with missing baseline or 12-week outcome data, 2 with a history of prior spinal surgery, 2 with neurological deficits in the lower extremities, 3 with spinal instability, and 1 with other exclusionary comorbidities), 353 patients entered the propensity score matching process (Tele, n = 105; Clinic, n = 248). After 1:1 nearest-neighbour matching without replacement, 122 patients were retained in 61 matched pairs (Tele, n = 61; Clinic, n = 61), while 231 patients were excluded because no acceptable match was found within the specified caliper. Before matching, the two groups differed across most measured covariates, with absolute SMDs ranging from approximately 0.19 to 0.55 (Table 1). Matching reduced imbalance for every covariate. After matching, the majority of SMDs fell below 0.10. Modest residual imbalance (SMD between 0.10 and 0.25) persisted for age, BMI, duration of pain, number of healthcare visits for LBP, male sex, self-paid insurance, and operative levels L3–L4 and L4–L5. After matching, all SMD were below 0.25, indicating adequate covariate balance (Table 1). Full pre- and post-matching distributions with SMDs are presented in Table 1.

Primary and Secondary Outcomes

All outcomes showed significant improvement from baseline to 12 weeks in both groups (time effect, $p < 0.001$), with no significant group × time interactions observed on any measure (Table 2).

On the primary MvK pain scale, mean scores decreased from 50.5 to 32.8 in the Tele group and from 49.9 to 32.2 in the Clinic group (interaction $p = 0.979$). The between-group difference at 12 weeks is well below the established 10-point minimal clinically important difference (MCID). Similarly, reductions in MvK disability and ODI scores were comparable between groups, with no detectable differences (interaction $p = 0.794$ and $p = 0.910$, respectively). Secondary outcomes showed a similar trend. VAS pain and interference scores decreased in both groups (interaction $p = 0.629$ and 0.531, respectively). Spinal mobility (MLS test) improved by approximately 2 cm in both arms (interaction $p = 0.215$), and 6MWT distance increased by over 100 m in each group without significant divergence (interaction $p = 0.494$). In a sensitivity analysis additionally adjusting for age and duration of pain (the covariates with residual SMD >0.20 after matching), all between-group differences in change remained small and non-significant, with every confidence interval including zero (Table 2), suggesting that the findings were robust to additional adjustment for these covariates.

Table 2. Within-group and between-group changes in functional outcomes from baseline to 12 weeks, with sensitivity analysis.

Measure	Tele (n = 61)	Clinic (n = 61)	Estimate (95% CI)	*p*-value
MvK pain				
Baseline, mean (SD)	50.5 (14.5)	49.9 (14.7)		
12 weeks, mean (SD)	32.8 (13.5)	32.2 (12.7)		
Within-group change (95% CI)	−17.7 (−21.3 to −14.1)	−17.7 (−21.0 to −14.3)		
Difference in change, Tele − Clinic †			−0.1 (−4.9 to 4.8)	0.979
Adjusted difference in change ‡			0.1 (−4.8 to 5.1)	0.954
MvK disability				
Baseline, mean (SD)	33.4 (17.0)	36.5 (17.1)		
12 weeks, mean (SD)	21.1 (12.7)	23.3 (12.7)		
Within-group change (95% CI)	−12.4 (−15.8 to −8.9)	−13.2 (−17.3 to −9.0)		
Difference in change, Tele-Clinic †			0.7 (−4.6 to 6.0)	0.794
Adjusted difference in change ‡			1.3 (−4.1 to 6.6)	0.633
ODI				
Baseline, mean (SD)	23.2 (10.2)	24.5 (11.2)		
12 weeks, mean (SD)	18.8 (8.5)	19.8 (9.7)		
Within-group change (95% CI)	−4.5 (−7.2 to −1.8)	−4.7 (−8.1 to −1.3)		
Difference in change, Tele-Clinic †			0.2 (−4.1 to 4.6)	0.910
Adjusted difference in change ‡			0.2 (−4.2 to 4.6)	0.914
VAS pain				
Baseline, mean (SD)	45.5 (14.8)	45.2 (14.5)		
12 weeks, mean (SD)	26.4 (3.1)	24.9 (3.3)		
Within-group change (95% CI)	−19.1 (−22.7 to −15.6)	−20.3 (−23.7 to −17.0)		
Difference in change, Tele-Clinic †			1.2 (−3.6 to 6.0)	0.629
Adjusted difference in change ‡			0.6 (−4.3 to 5.5)	0.802
VAS daily interference				
Baseline, mean (SD)	37.6 (16.4)	40.5 (16.8)		
12 weeks, mean (SD)	21.6 (4.1)	22.9 (3.3)		
Within-group change (95% CI)	−16.0 (−19.8 to −12.1)	−17.6 (−21.7 to −13.6)		
Difference in change, Tele-Clinic †			1.7 (−3.8 to 7.2)	0.531
Adjusted difference in change ‡			2.1 (−3.5 to 7.6)	0.469
MLS, cm				
Baseline, mean (SD)	4.1 (1.5)	4.2 (1.6)		
12 weeks, mean (SD)	6.2 (1.3)	6.6 (1.6)		
Within-group change (95% CI)	2.10 (1.76 to 2.43)	2.39 (2.05 to 2.74)		
Difference in change, Tele − Clinic †			−0.30 (−0.78 to 0.18)	0.215
Adjusted difference in change ‡			−0.25 (−0.73 to 0.23)	0.306
6MWT, m				
Baseline, mean (SD)	417.6 (88.4)	399.3 (91.7)		
12 weeks, mean (SD)	536.1 (74.7)	528.3 (69.8)		
Within-group change (95% CI)	118.5 (93.7 to 143.4)	128.9 (110.2 to 147.6)		
Difference in change, Tele − Clinic †			−10.7 (−41.4 to 20.1)	0.494
Adjusted difference in change ‡			−9.9 (−41.1 to 21.3)	0.530

CI, confidence interval; MvK, Modified Von Korff; ODI, Oswestry Disability Index; MLS, modified lumbar Schober; 6MWT, 6-minute walk test; VAS, visual analogue scale; SD, standard deviation.

Continuous variables are presented as mean (SD). The within-group change is the mean change from baseline to 12 weeks within each group; all within-group changes were statistically significant (paired comparison, all $p < 0.01$).

The difference in change is the between-group difference in the change from baseline to 12 weeks (Tele minus Clinic), with the *p*-value corresponding to the group × time interaction; negative values favour the Clinic group.

† Estimated from a linear model of the change score with study centre as a covariate.

‡ Additionally adjusted for age and duration of pain—the two covariates with residual standardised mean differences above 0.20 after propensity score matching.

Engagement and Adherence

Engagement with the rehabilitation programme was similar between groups, with no statistically significant differences observed (Table 3). All participants completed at least six of the educational articles provided, and the distribution of the number of articles read did not differ significantly between groups ($p = 0.244$).

Table 3. Engagement and adherence indicators of the rehabilitation programme over 12 weeks.

	Tele group (n = 61)	Clinic group (n = 61)	*p*-value
Total rehabilitation sessions completed, n (%)†			0.817
12–24 sessions	11 (18.0)	12 (19.7)	
>24 sessions	50 (82.0)	49 (80.3)	
Educational articles read, n (%)‡			0.244
6 articles	3 (4.9)	0 (0.0)	
7–10 articles	58 (95.1)	61 (100.0)	

p-values were derived from Pearson's chi-square test or Fisher's exact test.

†Sensor-guided exercise sessions for the Tele group; supervised physiotherapy appointments for the Clinic group.

‡Educational articles delivered via the mobile application for the Tele group and as printed materials for the Clinic group.

Adverse Events

Adverse event rates were low and comparable between groups, with no serious adverse events considered related to the study therapy. A total of 19 minor intervention-related events were reported across both groups. The overall proportion of patients experiencing any adverse event did not differ significantly between groups (Table 4).

Discussion

This is, to our knowledge, the first study to compare telerehabilitation- and face-to-face-delivered McKenzie therapy after UBE discectomy. It offers preliminary evidence on the feasibility and short-term outcomes of remote rehabilitation in this surgical population. Patients with LDH commonly develop muscle atrophy and pain-related psychological sequelae that surgery alone cannot resolve. Postoperative rehabilitation is widely supported, yet direct comparisons of delivery modes after UBE remain scarce, and no consensus exists on the optimal approach. McKenzie therapy involves patient education, symptom self-assessment, and structured exercises. These features may facilitate remote delivery, although the suitability of this approach and the potential contribution of sensor-based monitoring require further investigation. Our findings are broadly consistent with previous studies investigating telerehabilitation for musculoskeletal conditions, including chronic low back pain and knee osteoarthritis [26,27,28].

Both groups improved across all seven outcomes from baseline to 12 weeks, with no significant group × time interactions on any measure (all interaction $p > 0.05$). Adherence was high in both arms, reflected in session completion rates and engagement with educational content.

The between-group difference on the MvK pain scale at 12 weeks was well below the established MCID of 10 points, and no significant group × time interaction emerged on any outcome. The pattern is what one would expect if telerehabilitation- and clinic-delivered McKenzie therapy produce comparable short-term clinical effects. No statistically significant between-group differences in short-term outcomes were detected; however, these findings do not establish equivalence or non-inferiority between the two rehabilitation approaches. The study was retrospective and was not designed or powered as a formal non-inferiority trial, so these results should be read as hypothesis-generating. A prospective, adequately powered non-inferiority randomised controlled trial with a pre-specified margin remains the next step.

Various exercise programmes—including spinal flexion and extension exercises, aerobic training, Pilates, and Dynamic Lumbar Stabilisation (DLS)—have been recommended in the postoperative period [29]. Our observations are consistent with previous studies suggesting that early, structured lumbar muscle training initiated between one day and six weeks after lumbar microdiscectomy can be a safe and practicable strategy for postoperative recovery [25,30]. A key aim of postoperative rehabilitation is to strengthen the lumbar paraspinal musculature, particularly the multifidus, to mitigate surgery-related atrophy and enhance spinal stability [31]. In the present study, the rehabilitation protocol was based on the McKenzie method, focusing on symptom relief through directional-preference exercises and incorporating DLS techniques to support muscle strength and spinal stability.

Perioperative pain management shapes the early window in which McKenzie exercises must take hold. Anaesthetic technique, preoperative analgesia, and multimodal pain control all influence how soon and how vigorously a patient can engage with structured rehabilitation. A recent randomised controlled trial in PTED patients showed that an ultrasound-guided erector spinae plane block, compared with local anaesthesia alone, achieved more stable intraoperative haemodynamics and significantly lower intraoperative pain scores. Between-group differences in VAS and ODI at 3 and 6 months postoperatively did not reach statistical significance [32]. Perioperative analgesia therefore appears to influence intraoperative and early postoperative comfort more than longer-term recovery. In our cohort, perioperative analgesia protocols were not standardised between centres, and pain scores in the first 24 to 48 hours were not systematically captured. This variability should

Table 4. Adverse events and serious adverse events.

Event	Tele group (n = 61)	Clinic group (n = 61)	*p*-value
Adverse events (n = 19)			
Patients with any adverse event, n (%)	11 (18.0)	13 (21.3)	0.649
Total number of non-serious adverse events, n	9	10	
Classified by type, n			
Pain	3	4	
Numbness of lower limb	1	0	
Muscle strain	2	3	
Fall with minor symptoms	1	1	
Nausea and dizziness	1	1	
Anxiety about recovery	1	1	
Serious adverse events (n = 5)	2 (3.3)	3 (4.9)	1.000
Classified by relationship to study therapy, (n = 5)			
Related to study therapy	0	0	
Unrelated to study therapy	2	3	
Classified by type, (n = 5)			
Degradation of general condition	1	0	
Waist fracture due to fall	0	1	
Severe scapulohumeral periarthritis	0	1	
Gastrointestinal disorder	0	1	
Stroke	1	0	

p-values for between-group comparisons of adverse-event rates were derived from Pearson's chi-square test or Fisher's exact test. The 19 non-serious adverse events (9 in the Tele group and 10 in the Clinic group) represent individual events, with no patient experiencing more than one event. The numbers of patients with any adverse event (11 and 13, respectively) also include patients who experienced serious adverse events.

be kept in mind when interpreting the early recovery trajectories we observed.

A potential advantage of digital telerehabilitation lies in its capacity to actively involve patients in their recovery. A previous study reported that a mobile application delivering multidisciplinary care for LBP was associated with improvements in VAS pain scores [33]. Previous literature has suggested that stronger self-management and exercise adherence may promote a greater sense of internal control, which could support the success of digital interventions, although this mechanism was not directly assessed in the present study [34]. The programme used here facilitated engagement through personalised content, real-time sensor feedback, flexible scheduling, and ongoing remote therapist contact; support was accessible via weekly video consultations and unlimited asynchronous messaging. In contrast, conventional care relies on fixed appointments and multiple providers and typically lacks real-time monitoring or immediate between-visit support.

Our results fit within the wider framework of Enhanced Recovery After Surgery (ERAS). ERAS protocols in spinal neurosurgery are evolving quickly, with growing emphasis on early mobilisation, patient empowerment, reduced hospital stay, and multimodal self-management [35]. Telerehabilitation-delivered McKenzie therapy aligns with several core ERAS principles. It supports early initiation of structured rehabilitation. It promotes patient autonomy through education and self-monitoring. It reduces reliance on repeated in-person clinic visits. The comparable short-term outcomes in the Tele group suggest that remote delivery may be a feasible option for postoperative rehabilitation after minimally invasive lumbar surgery, particularly where geographic or workforce barriers limit access to in-person postoperative care.

UBE patients are well suited to home-based telerehabilitation. The technique reduces paraspinal trauma, shortens hospital stay, and supports early mobilisation. Whether the recovery trajectory we observed mirrors that of other endoscopic techniques is a fair question. Trials of PTED have reported short-term VAS pain and ODI improvements broadly similar to those in our cohort [36], suggesting that postoperative functional recovery may follow comparable curves across minimally invasive endoscopic approaches. This raises the possibility that the present telerehabilitation protocol could extend to other endoscopic spinal procedures, although direct comparative studies are needed to confirm this. Findings from our cohort may not generalise to open or fusion surgery. Future research should evaluate telerehabilitation across a broader range of lumbar conditions and surgical techniques.

Engagement in the Tele group held steady through the 12-week intervention. Because the Clinic group was scheduled for 36 supervised sessions over 12 weeks, completion of more than 24 sessions, roughly two-thirds, was set as the threshold for high adherence. The same threshold was applied to the Tele group for comparability. The high ad-

herence we observed in both arms is consistent with the premise that sensor-guided home exercise, paired with remote therapist contact, can sustain patient engagement at levels comparable to in-clinic supervision [30]. Adherence has long been recognised as a determinant of treatment effect in structured rehabilitation and behavioural programmes for low back pain [37,38,39,40,41,42]. This pattern should be confirmed prospectively with validated measures of exercise fidelity and self-management behaviour. If reproduced, the convenience and adaptability of telerehabilitation could meaningfully reduce the burden of postoperative clinic attendance and support scalable delivery of structured rehabilitation in this population.

Study Limitations

Our study has several limitations. Most importantly, its retrospective nature means the rehabilitation modality was determined by clinical routine rather than randomization, introducing potential selection bias. Furthermore, because rehabilitation modality was largely determined by centre-specific practice and only two centres were included, centre effects may have been difficult to separate from the effects of rehabilitation modality, leaving the possibility of residual confounding despite propensity score matching. While PSM improved the balance of baseline characteristics, we cannot rule out residual confounding from unmeasured factors like health literacy, psychosocial traits, or patient motivation. Notably, digital literacy was not formally assessed; patients opting for telerehabilitation might have been more tech-savvy, which could have inherently boosted their adherence.

The use of PSM also reduced our final sample size by excluding patients without acceptable matches. This lower statistical power may limit the generalizability of our findings to the broader patient population. Furthermore, since our baseline was set at hospital discharge, we could only capture the recovery trajectory from the early postoperative phase to 12 weeks, missing the full preoperative-to-postoperative transition. In addition, all patients received initial rehabilitation instruction on postoperative day 2, whereas baseline assessments were performed at hospital discharge (postoperative days 2–5). Consequently, some baseline measurements may have been obtained after the initiation of rehabilitation, and the interval between rehabilitation initiation and baseline assessment may have varied among patients. Thus, the discharge measurements should not be regarded as strictly pre-intervention baseline values. Any early changes occurring before discharge were not captured, and variations in the timing of baseline assessment and prior rehabilitation exposure may have introduced measurement heterogeneity and influenced the estimation of changes from baseline to 12 weeks. The magnitude and direction of this potential influence could not be determined.

We also acknowledge that the rehabilitation dose and therapist contact frequency were not standardized between groups. The differences in supervision and real-time feedback—inherent to comparing these two delivery models—might have influenced motivation and exercise fidelity. Therefore, the effects of rehabilitation delivery mode cannot be isolated from those of supervision frequency and feedback technology, and the observed outcomes should be interpreted as reflecting the overall intervention packages rather than delivery mode alone. Lastly, with a follow-up limited to 12 weeks, our findings do not reflect long-term outcomes, such as recurrence rates or the long-term retention of self-management behaviors.

Conclusions

In this multicentre retrospective matched cohort of adults undergoing UBE discectomy for LDH, McKenzie therapy delivered via telerehabilitation was associated with improvements in pain, disability, and function over 12 weeks. No statistically significant group × time interactions were detected, but these findings should not be interpreted as evidence of equivalence or non-inferiority. The between-group difference on the MvK pain scale was below the established MCID, and no other outcome showed a statistically significant group × time interaction. However, given the retrospective nature of this study, these results should be interpreted as hypothesis-generating rather than definitive evidence of non-inferiority. Future research should prioritize follow-up periods of six to twelve months and integrate implementation metrics such as rehabilitation fidelity as well as cost-effectiveness to better inform clinical practice in digital health.

Availability of Data and Materials

The data used and analyzed during the current study are available from the corresponding authors on reasonable request.

Author Contributions

CZ: Writing – original draft, Methodology, Formal Analysis. NZ: Writing – original draft, Software, Data curation, Formal Analysis. YL: Writing – original draft, Methodology, Investigation. ZL: Writing – original draft, Investigation. JC: Writing – original draft, Investigation. JS: Writing – original draft, Supervision. LH: Writing – original draft, Methodology. JS and SL: Writing – review & editing, Supervision, Validation. MW: Writing – review & editing, Conceptualization, Project administration. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The studies involving humans were approved by the Institutional Review Board (Research Ethics Committee) of Shanghai Sixth People's Hospital Affiliated to Shanghai Jiao Tong University School of Medicine (IRB number: 2024-KY-223 (K)). Other participating institutions and hospitals acknowledged the IRB approval. The studies were conducted in accordance with the local legislation and institutional requirements. Since this retrospective study involved no patient-identifiable information and ensured complete anonymization, the ethics review board waived the requirement for informed consent. All procedures were conducted in accordance with the ethical standards and the Declaration of Helsinki.

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Conflict of Interest

YL is an employee of Medmotion Clinic. Joymotion™ software is supplied by Medmotion Clinic (Shanghai, China). Other authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.62713/aic.4585.

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