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Long-term effects of deep-learning digital therapeutics on pain, movement control, and preliminary cost-effectiveness in low back pain: A randomized controlled trial

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Abstract

Objective: The present study aimed to compare the effects of a deep learning-based digital application with digital application physical therapy (DPT) and those of conventional physical therapy (CPT) on back pain intensity, limited functional ability, lower extremity weakness, radicular symptoms, limited range of motion (ROM), functional movement, quality of life, cost-effectiveness, and postintervention questionnaires for perceived transmission risk of COVID-19 and satisfaction results in 100 participants with low back pain (LBP).

Methods: One hundred participants with LBP were randomized into either DPT or CPT groups, three times per week over four weeks. Outcome measures included the (1) Oswestry Disability Index, (2) Quebec Back Pain Disability Scale, (3) Roland–Morris Disability Questionnaire (RMDQ), (4) Numeric Pain Rating Scale, (5) functional movement screen (FMS), (6) short form-12, (7) lower extremity strength, (8) ROM of trunk flexion, extension, and bilateral side bending, (9) questionnaires for perceived transmission risk of COVID-19, (10) preliminary cost-effectiveness, and (11) postintervention satisfaction questionnaire results. The analysis of variance was conducted at $p < 0.05$.

Results: Analysis of variance showed that DPT showed superior effects, compared to CPT on RMDQ, hip extensor strength, transmission risk of COVID-19, as well as satisfaction. Both groups showed significant improvement pre- and postintervention, suggesting that DPT is as effective as CPT, and was superior in preliminary cost-effectiveness and transmission risk of COVID-19.

Conclusions: Our results provide novel, promising clinical evidence that DPT was as effective as CPT in improving structural and functional impairment, activity limitation, and participation restriction. Our results highlight the successful incorporation of DPT intervention for clinical outcome measures, lower extremity strength, trunk mobility, ADL improvement, QOL improvement, and FMS in LBP.

Keywords

low back pain, smartphone, artificial intelligence, digital therapy

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Introduction

Artificial intelligence (AI)-based digital therapeutics is a new, promising technology that has evolved at an unprecedented rate, naturally transforming how people with lower back pain (LBP) manage their daily activities. Lower back pain has multifactorial sources, including faulty posture, movement, sleep disturbance, and depression. In particular, essential movements—bending, standing, lifting, twisting (rotation), and walking—are commonly impaired during activities of daily living (ADL) and social activities, compromising the quality of life (QOL) of people with LBP.[1,2] The exact pathomechanism behind the impairment of spinal movement remains unknown.

To mitigate spinal movement impairments, a variety of manual therapeutic approaches including soft tissue massage, electrotherapy, manipulation, mobilization, mechanical lumbar traction, and therapeutic exercise have been used; however, their outcome measures have varied.[3–6] Manual therapeutic approaches are considered a "hands-on" intervention requiring paperwork, evaluation, diagnosis, and treatment. While this approach enables meticulous attention to patient care in a clinical setting, there is limited ability to monitor patient progress or provide patient-specific care in real-life situations (where most injuries from spinal movement occur).

Recently, to address the coronavirus disease 2019 (COVID-19) pandemic, a healthcare model was adapted from the conventional approach to a remote approach, preventing the collapse of national health care systems worldwide.[7] The inability to use palpation and other special tests as diagnostic tools under this approach during the clinical examination may compromise the screening process aimed at identifying red flags. Therefore, a face-to-face first-contact visit should be carefully considered for patients requiring a higher intensity of care (i.e., difficult clinical cases) based on their medical history.[8] Hence, a clear need exists to develop a remote therapy system for effective and sustainable monitoring, diagnosis, and treatment of LBP.

We recently developed the Dr AI system, which is designed to offer accurate, real-time, onsite spinal movement evaluation, monitoring, diagnosis, and intervention based on aggregated clinical evidence.[9–11] The Dr AI system comprises the Dr AI application, which is designed to work with a smartphone. Special software algorithms allow clinicians and clients free virtual access to the Dr AI system without constraints of time and physical space. Recent advances in AI deep learning approaches along with the universal availability of economical smartphones with camera sensors have enabled us to overcome the limitations of laboratory-based motion analysis. Specifically, deep learning algorithms and the convolutional neural network (CNN),[12] random forest,[13] ridge regression,[14] recurrent neural network,[15] long short-term memory,[16] gated recurrent units,[17] and temporal convolutional network models[18] have been applied to estimate kinematic and movement parameters and detect movement or gait abnormalities associated with musculoskeletal diseases. Convolutional neural network results in a faster learning rate when compared to the learning rates of other deep learning algorithms and models and exhibits excellent performance in image recognition due to reduced overfitting through data segmentation analysis. In this study, we utilized CNN, which is more effective for making robust predictions in an impaired population than methods using hand-engineered features.[19] Currently, several home exercise applications based on CNN have been developed; however, they have failed to show significant clinical results due to a lack of validity and reliability; furthermore, a robust experimental clinical trial with a large sample size has not been conducted, and the system lacks standardization and customization.[20,21]

Despite the potential clinical and therapeutic advantages of Dr AI in LBP, these benefits have not been investigated in previous research. The present research has two specific aims. The primary purpose was to ascertain the effects of digital application physical therapy (DPT; two days of Dr AI in addition to an initial in-person meeting with a physical therapist) on lower back pain intensity, limited functional disability, lower extremity weakness, radicular symptoms, limited range of motion (ROM), functional movement, ADL, and QOL. We assessed this using the standardized Oswestry Disability Index (ODI), Quebec Back Pain Disability Scale (QUE), Roland–Morris Disability Questionnaire (RMDQ), and Numeric Pain Rating Scale (NPRS) and compared them to those of conventional physical therapy (CPT; three days of CPT) in LBP. The secondary purpose aimed to investigate functional movement screen (FMS), Short form-12 (SF-12), lower extremity muscle force, and mobility during trunk flexion, extension, and bilateral side bending, the perceived transmission risk of COVID-19 and a satisfaction questionnaire. We hypothesized that differences in outcomes would be observed between DPT and CPT.

Methods

Participants

A convenience sample of 100 participants with chronic LBP (mean age 35.5 ± 8.8 years; 40 female patients) was enrolled after being recruited via bulletin board notices within the hospitals and community centers. Initially, 100 out of 170 participants with LBP were recruited and screened by the investigator (CP) and diagnosed by the certified orthopedist. All participants provided written informed consent, and the study was approved by the Yonsei University Mirae Campus Institutional Review Board (No. 1041849-202106-BM-085-03). This study was conducted in accordance with the Declaration of Helsinki. The present study used a two-group pretest and posttest design in which all participants completed the pretest, the intervention, and the posttest. Inclusion criteria were (1) >18 years of age, (2) having self-reported complaints of LBP for at least three months, (3) ability to perform simple activities at home, (4) using a smartphone with an Android operating system (OS) (as the application was programmed for android devices only), (5) willing and able to perform therapeutic exercises following visual and verbal instructions, and (6) sufficient knowledge of the Korean language to understand the instructions. Exclusion criteria included (1) spine surgery or significant trauma in the previous three months, (2) using crutches or a walking aid, (3) structural deformities such as scoliosis, spinal tumors, ankylosing spondylitis, or spondylolisthesis, (4) neurological and cognitive disorders, (5) congenital asthma, and (6) psychiatric diagnosis.

Sample size was determined according to a power analysis performed with G-power software 3.1.9.7 (Franz Faul, University of Kiel, Kiel, Germany) that was conducted to assess the sample size requirement ($N = 100$) based on a pilot AI application study of four participants with LBP ($n = 2$ in each group), which demonstrated a power of 0.80, an alpha level of 0.05, and an effect size of 0.6. Participant demographic characteristics are presented in Table 1.

Experimental procedure

A randomized, single-blind, experimental design was used in the present study. The sample randomization was done to minimize the potential recruitment and selection bias by means of coin flipping. The coin-flipping method involved assigning participants to either the control or experimental group by the investigator (CP) using the random allocation sequence while the other investigator (SHY) who was blinded to the intervention or the group assignment assessed outcome measures. To remove experimental biases associated with the participants' expectations, experimental information that could affect the participants was masked until the experiment was completed. The randomization was confirmed by asking the participants and the investigator about the group assignment information.

An experimental checklist was used to consistently implement the pretest, intervention, and posttest. The pretest and posttest were performed using the standardized clinical outcome measures including ODI, QUE, RMDQ, NPRS as well as FMS, SF-12, mobility, post-questionnaire for perceived transmission risk of COVID-19, preliminary cost-effectiveness, and postintervention satisfaction questionnaire and obtained from the respective copyright holder(s) the necessary permission to use all applicable tools/questionnaires in this study.

Clinical outcome measures

Oswestry Disability Index. We used the ODI to examine symptoms and severity of LBP in terms of disablement and the extent to which LBP or radiating pain impacted functional activities. It includes ten questions relating to pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sexual activity, socializing, and travel.[22] Each item consists of six statements correlating to scores 0 ("least disability") to 5 ("greatest disability"), with the participants choosing the statement as per their ability. Reliability and validity were reported as intraclass correlation $(\text{ICC})_{3,\ k} = 0.97$ and $r = 0.82$, respectively.[23,24]

Quebec Back Pain Disability Scale. We used the QUE to measure functional disability related to LBP. The scale

Table 1. Demographic characteristics of participants with LBP ($N = 100$).

	DPT group ($n = 50$)	CPT group ($n = 50$)	p value
Sex (male/female)	30/20	30/20	1.00
Age (years)	37.11 ± 8.33	33.21 ± 6.11	0.22
Body height (cm)	163.38 ± 14.52	161.27 ± 11.21	0.48
Body weight (kg)	66.48 ± 10.11	68.11 ± 8.38	0.37
Smoking (yes/no)	8/42	11/39	0.28
Type of LBP (discogenic/nonspecific LBP)	20/30	20/30	1.00
Duration (month)	8.21 ± 1.88	7.46 ± 3.38	0.72

DPT: digital application physical therapy; CPT: conventional physical therapy.

comprises one central question: “Do you have trouble today with…?” followed by 20 ADLs. Examples of ADLs are taking something out of the refrigerator or getting out of bed. In every activity, there are six answer categories, measured using a Likert scale from 0 to 5 (0 = no effort and 5 = unable to).[25] If the participant experiences a lot of pain that day, he scores that activity with a 5, and if he has no problems, he scores 0. The sum of scores on the difficulty in performing the 20 daily activities yields the final outcome. This score ranges from 0 to 100 and reflects the level of functional disability (higher scores represent greater levels of disability). Reliability and validity were reported to be $ICC_{3,\ k} = 0.85$ and $r = 0.86$, respectively.[26]

Roland–Morris Disability Questionnaire. We used the RMDQ to assess self-reported disability, in which greater levels of disability are reflected by higher scores on a 24-point scale. The participant is asked to mark a statement if it applies to him on that day, thus making it possible to follow changes in time. Scores range from 0 (no disability) to 24 (maximal disability). Reliability and validity were reported to be $ICC_{3,\ k} = 0.83$ and $r = 0.89$, respectively.[27]

Numeric Pain Rating Scale. We used the NPRS to examine unidimensional measures of pain intensity. The NPRS can be administered verbally (e.g., by telephone) or by written questionnaire for self-completion. The respondent is asked to indicate the numerical value that best describes their pain intensity. The 11-point scale ranges from 0 (“no pain”) to 10 (“pain as bad as you can imagine” or “worst pain imaginable”). Reliability and validity were reported to be $ICC_{3,\ k} = 0.89$ and $r = 0.94$.[28,29]

Functional movement screen. The FMS was designed to identify functional movement deficits and asymmetries that may be predictive of general musculoskeletal injuries and conditions, with the goal of being able to modify the identified movement deficits by prescribing an individualized exercise regimen. These movements included deep squats, hurdle steps, line lunges, shoulder mobility, active straight leg raises, trunk stability push-ups, and rotary stability. The test had seven graded tasks that assess whole-body movement quality on a four-point ordinal scale. According to the published criteria, scores ranging from 0 (pain during the movement pattern regardless of quality) to 3 (performing the pattern as directed) are assigned for each task; a cumulative grade is calculated out of 21 possible points.[30,31] Reliability and validity were reported to be $ICCC_{3,\ 1} = 0.76$ and $r = 0.81$, respectively.[32,33]

Short form-12. The SF-12 is a health-related QOL questionnaire consisting of 12 questions. We used this to measure eight health domains, assessing physical and mental health. The physical health-related domains included general health, physical functioning, physical roles, and body pain. Mental health-related scales included vitality, social functioning, emotional roles, and mental health. Reliability and validity were reported to be $ICC_{3,1} = 0.78$ and $r = 0.61$, respectively.[34]

Muscle strength examination. We examined muscle force with a hand-held dynamometer (HHD; J-Tech Medical, UT, USA) to quantify hip and knee isometric muscle force output. Test positions were selected according to the processes often applied in a clinical experimental setting and included six isometric tests (hip flexor, hip extensor, hip adductor, hip abductor, knee flexor, and knee extensor). The testing order was randomized during the initial testing session. For all tests, participants gripped the sides of the treatment table with both hands. The investigator applied resistance with the HHD, and participants were instructed to push against it using maximum strength.[35] Strength data were expressed in Newton meter (Nm) and normalized to body weight (Nm/kg).

Dr AI-based motion capture range of motion. Range of motion (degrees) was determined using the Dr AI application, a smartphone, and a tripod. The AI-based ROM software captured video of the participants as they performed lumbar flexion, extension, and bilateral side bending for 5 s each at a sample rate of 60 Hz. Convolutional neural network has shown superiority in tasks such as pose estimation and object detection. We evaluated five body parts (trunk, hip, knee, ankle, and pelvis). In each frame, positions of the pelvis, hip, knee, and ankle were stored in the software relative to the trunk.[36,37] The kinematic movement video was then analyzed using CNN and saved for further statistical analysis. We programmed the software to store peak ROM data in a computer database. The accuracy of the kinematics using CNN was reported to be 94.32%.[38]

Preliminary cost-effectiveness analysis. We used the incremental cost-effectiveness ratio (ICER) to compare the cost-effectiveness of DPT and CPT. The formula is as follows:

ICER=ΔCost/ΔEffectiveness = (Cost of DPT-Cost of CPT)/ (Quality-adjusted life year for DPT-Quality-adjusted life year for CPT)

The ICER compares costs and outcomes between DPT and CPT. The numerator in the ICER is calculated by subtracting the monetary cost of CPT from that of DPT. If the ICER is below a certain threshold (which varies depending on the context), it suggests that the intervention is cost-effective compared to the other intervention. If the ICER is above the threshold, it suggests that the intervention may not be cost-effective. We computed ICER using incremental total costs in the numerator and incremental quality-adjusted life year (QALY) for the denominator. Both values were adjusted using the covariates listed previously. The bootstrapping method with 1000 replications was employed to obtain 95% confidence interval of ICERs. The acceptability curve of bootstrapped ICERs was used to show the proportions of ICERs under the specific willingness-to-pay level. We compared the ICER against WTP thresholds of \$50,000 to \$100,000 per additional QALY obtained. Sensitivity analyses were performed to account for uncertainties in the missing data assumptions by evaluating the subset of participants who completed all monthly online cost diaries ($N = 100$) without imputation. The annual costs of the projects were calculated by converting the four-week cost, which is the period used for implementation, and subtracting the QALY gained by DPT from that gained by CPT.[39]

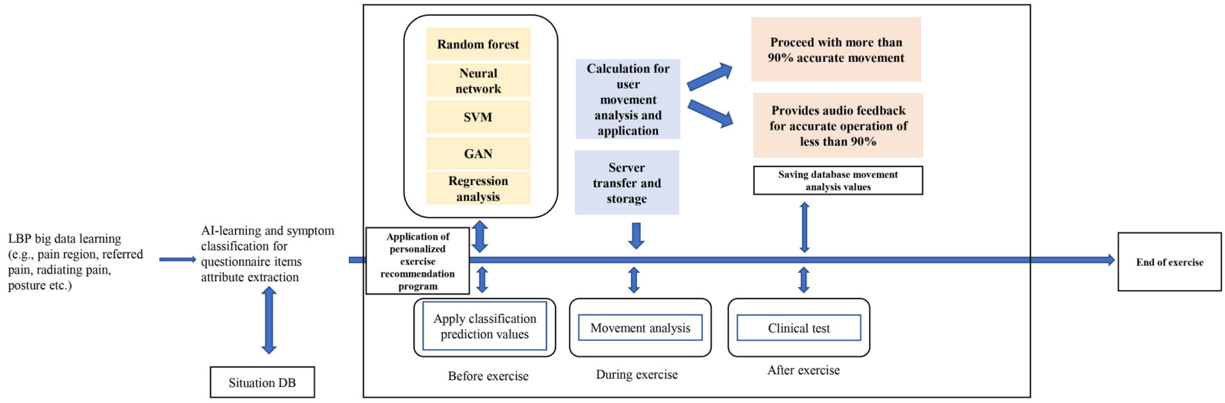
Post-questionnaire for perceived transmission risk of COVID-19. Participants completed a questionnaire with questions on the perceived transmission risk of COVID-19, including social distancing, duration of contact time, and evidence of COVID-19 transmission. Possible scores ranged from 0 (“COVID-19-free”) to 10 (“COVID-19 high-risk of infection”).

Postintervention satisfaction questionnaire. Participants completed a postintervention satisfaction questionnaire that included questions on accessibility, effectiveness, cost, sustainability, and real-time audiovisual feedback. Possible scores ranged from 0 (“very dissatisfied”) to 5 (“very satisfied”).

Dr AI platform development and validation

The AI-based diagnosis and intervention platform were developed by the investigator (SHY) who was certified and experienced with mechanical diagnosis and therapy (MDT) and dynamic neuromuscular stabilization (DNS) (11 years) based on the principles and guidelines of the MDT exercise and DNS core stability. We have employed the deep learning CNNs because it is capable of learning from historical examples, analyzing nonlinear data, and handling imprecise information with a higher accuracy among other algorithms. For the diagnosis and exercise platform development, the 6000 samples of the diagnosis and exercise prescription image data were initially weighted, classified into the MDT diagnostic criteria (e.g., posture syndrome, anterior or posterior derangement syndrome, dysfunctional syndrome) or DNS diagnostic criteria (e.g., core instability) and trained by the CNN deep learning model using the open-source Python software (ver. 3.12). The algorithm used data input from the subjective assessment (input layer), processed the information through the neurons to select the appropriate exercise prescription from the exercise or intervention bank (hidden layer), and then most accurately diagnosed or prescribed the exercise (output layer) with relatively acceptable specificity, and sensitivity thresholds.[40] The weightage of the exercise was based on the individual’s audiovisual feedback about the successful end range movement, correct posture, and movement. Similarly, the five potential exercise prescription photo and video image data recorded from 1000 healthy people for posture syndrome, anterior or posterior derangement syndrome, dysfunctional syndrome, or DNS core stability were processed in this sequential CNN algorithm (Figure 1). To improve accuracy, specificity, and sensitivity of the Dr AI platform, the back-propagation algorithm was used to refine the training until reaching up to >80%.[40]

Dr AI model validation was performed by comparing the Dr AI-generated diagnosis and exercise prescription with the investigator-generated diagnosis and exercise prescription. We conducted the feasibility test and observed the receiver operating characteristic cure = 0.85.



LBP, Low back pain
AI, Artificial intelligence
DB, Data base
SVM, Support vector machine
GAN, Generative adversarial network

Figure 1. Dr AI algorithm.

Intervention

All participants were assigned to either CPT or DPT. Both interventions were provided 30-min/session, three times/ week over four weeks. Initially, the participants in both groups underwent one time 30-min face-to-face session before the start of the study to ensure clear understanding of the experimental tests as well as CPT and DPT intervention protocols. The CPT and DPT protocols were developed on the international classification of functioning, disability, and health clinical decision-making model, which identifies functional and structural impairments, activity limitations, and participation restrictions.[41] Specifically, the identified impairments also included the presence of pain, reduced mobility, and muscle power. The associated limited activity was evaluated using the FMS, which comprises the deep squat, hurdle step, line lunge, shoulder mobility, active straight leg raises, trunk stability, and rotary stability. Restricted participation encompassed physical activity, socioemotional, and community participation using QOL.[41]

For DPT protocol, at the first face-to-face meeting prior to the start of the intervention, all participants in the DPT group were introduced to the proper usage of the AI-based diagnosis and intervention platform including downloading the DrAI application, entering baseline demographic and clinical data, setting the smartphone camera (1-m distance away from the participant, height at the umbilicus level), recording posture and repeated movement test, core stabilization during the prone hip extension, and diagnosing and prescribing the exercise or intervention program.

The entering baseline demographic and clinical data included name, sex, date of birth, present symptoms, time of onset, symptoms at onset, frequency of symptoms, NPRS score, position with worst pain, pain provoking or alleviating pain, previous medical, surgical and treatment history, and diagnostic imaging. Based on the entered DPT demographic and clinical data as well as the posture and movement test data including the correct posture, end range movement test, NPRS pain level (increase/decrease, reduce, no effect, etc.), duration (intermittent or constant), and location (e.g., centralizing/peripheralizing) were manually entered to the Dr AI application. The Dr AI made a provisional MDT diagnosis with directional preference, which was consistently confirmed by the same investigator (YSH). Dr AI then prescribed a selective self or active exercise with a video format in the DrAI platform system (Figure 2).

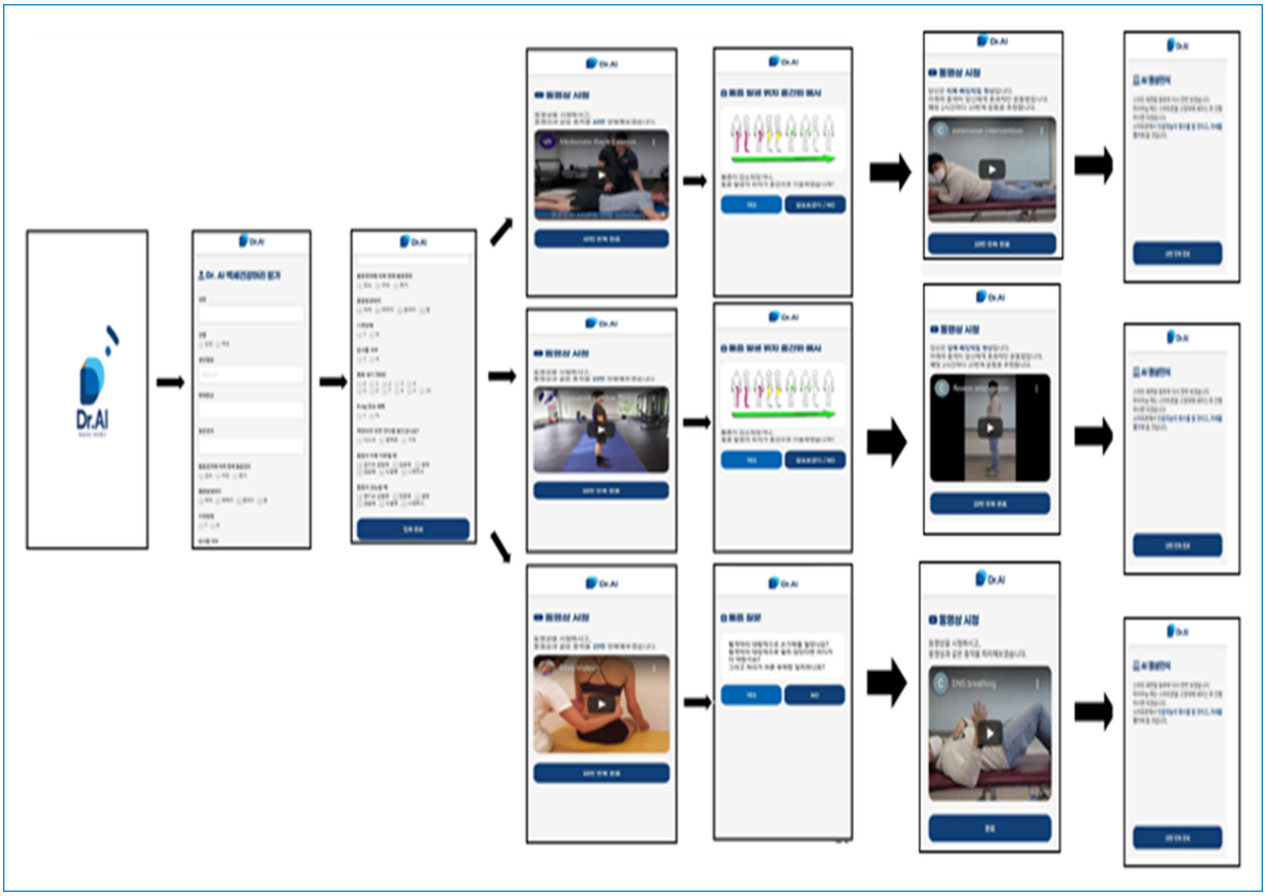


Figure 2. Dr AI smartphone application.

The audiovisual feedback for the diagnosis and exercise involved the correct posture and movement test procedure without compensatory movement. Depending on the different characteristics of LBP type, intensity, and duration (irradiated, localized, etc.), the interventional exercise was modified or readjusted. For example, the pain and movement characteristics were improving, the exercise directional preference was confirmed and instructed to continue the same prescribed exercise. However, the pain and movement characteristics were unfavorably worsening, the exercise directional preference was reassessed by means of the identical diagnostic testing procedure.

Conventional physical therapy intervention comprised therapeutic modalities (heat, ultrasound, and transcutaneous electrical nerve stimulation [TENS]), mobilization, manipulation, and therapeutic exercises (stretching, sling exercise, and core stability training). Conventional physical therapy was consistently provided by two licensed, experienced (6–12 years) physical therapists according to standardized intervention protocols. The further detailed description about CPT intervention procedure is presented in Appendix 1.

Statistical analysis

Descriptive statistics included means and standard deviations. We used the nonparametric chi-square test for categorical variables to compare demographics and clinical characteristics between groups. We used independent t-tests to compare general participant characteristics between groups. We used a 2 × 2 mixed analysis of variance (ANOVA) to compare intervention-related changes in outcome variables (ODI, QUE, RMDQ, NPRS, FMS, SF-12, lower extremity force, and ROM with trunk flexion, extension, and bilateral side bending) between groups. If a significant difference was observed, a post hoc test was performed to compare changes in variables from pretest and posttest within-group differences. If a significant interaction and main effects were observed, a Tukey post hoc test was performed. We used independent t-tests to compare postintervention questionnaire results for the perceived transmission risk of COVID-19 and postintervention satisfaction between groups. The mean medical cost of DPT and CPT and overall outcome measures were determined. All statistical analyses were performed with Statistical Package for the Social Sciences (SPSS) version 26 software (SPSS Inc., Chicago, IL, US). The statistical significance level was set at 0.05 for all tests.

Results

Clinical outcome measurements

Repeated-measures ANOVA revealed a significant time effect ($p = 0.001$) for ODI, indicating improved back disability following both-intervention for participants who suffered from LBP. No significant difference in ODI was observed between groups ($p = 0.44$). Moreover, no significant interaction effects were seen ($p = 0.08$). Post hoc analysis revealed a significant difference in ODI scores obtained at pre- and posttest in both groups ($p = 0.001$) (Table 2).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$), between-group ($p = 0.001$), and group-by-time interaction ($p = 0.001$) for QUE. Interaction post hoc test revealed a greater decrease in QUE in CPT than DPT, supporting that functional disability related to LBP became less common and less severe after CPT compared to DPT. Post hoc analysis revealed a significant difference in QUE scores pre- and posttest in both groups ($p = 0.001$) (Table 2).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) and group-by-time interaction ($p = 0.03$) for RMDQ. Interaction post hoc test showed a greater decrease in RMDQ with DPT than it showed with CPT, supporting a greater increase in ADL disability related to LBP

Table 2. Clinical outcome measurements.

	DPT			CPT			*p* value		
	Pretest	Posttest	Mean Change, MCID	Pretest	Posttest	Mean Change, MCID	Time	Groups	Time × Group
ODI	44.82 ± 6.88	28.38 ± 7.43	16.44> 14.31‡	46.72 ± 5.32	27.54 ± 6.33	19.18> 11.65‡	0.001*	0.44	0.08
QUE	30.27 ± 12.83	22.26 ± 11.54	8.01< 12.19	48.83 ± 8.46	35.38 ± 4.78	13.45> 13.24‡	0.001*	0.001*	0.001*
RMDQ	13.88 ± 2.74	7.88 ± 2.78	6.00> 5.52‡	13.28 ± 2.18	7.94 ± 2.20	5.34> 4.38‡	0.001*	0.31	0.03*
NPRS	5.88 ± 2.03	3.27 ± 0.88	2.61< 2.91	6.37 ± 1.51	4.11 ± 1.27	2.26< 2.78	0.001*	0.41	0.10
SF-12	61.24 ± 6.44	75.20 ± 6.18	13.96> 12.62‡	61.18 ± 4.16	72.14 ± 8.59	10.96< 12.75	0.001*	0.18	0.08

DPT: digital application physical therapy; CPT: conventional physical therapy; ODI: Oswestry Disability Index; QUE: Quebec Back Pain Disability Scale; RMDQ: Roland-Morris Disability Questionnaire; NPRS: Numeric Pain Rating Scale; SF-12: short form-12.

‡ Change in Minimal Clinical Importance Difference (MCID) is significant.

after DPT than after CPT. Post hoc analysis revealed a significant difference in RMDQ scores pre- and posttest in both groups ($p = 0.001$) (Table 2).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) for NPRS. Post hoc analysis revealed a significant difference in NPRS scores pre- and posttest in both groups ($p = 0.01$), representing improved pain scale following both-intervention for participants who suffered from LBP (Table 2).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) for SF-12. Post hoc analysis revealed a significant difference in SF-12 scores pre- and posttest in both groups ($p = 0.01$ and $p = 0.03$, respectively), indicating that both-intervention improve in QOL related to LBP than preintervention (Table 2).

Lower extremity muscle strength

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) and group-by-time interaction ($p = 0.001$) for the hip flexor. Interaction post hoc test showed a greater improvement in the hip flexor with CPT than it showed with DPT. Post hoc analysis revealed significant differences in hip flexor force pre- and posttest in both groups ($p = 0.001$), supporting improved hip flexor force following both-intervention for participants who suffered from LBP (Table 3).

Repeated-measures ANOVA showed a significant group-by-time interaction ($p = 0.001$) for the hip extensor. Interaction post hoc test showed a greater improvement in the hip extensor with DPT than it showed with CPT, indicating improved hip extensor force following both-intervention for participants who suffered from LBP (Table 3).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) and group-by-time interaction ($p = 0.001$) for the hip adductor. Interaction post hoc test showed a greater improvement in the hip adductor with DPT than it showed with CPT. Post hoc analysis revealed a significant difference in hip adductor force pretest and posttest in both groups ($p = 0.001$), representing improved hip adductor force following both-intervention for participants who suffered from LBP (Table 3).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$), between-group ($p = 0.001$), and group-by-time interaction ($p = 0.001$) for the hip abductor. Interaction post hoc test revealed showed a greater improvement in the hip abductor with DPT than with CPT. Post hoc analysis revealed a significant difference in hip abductor force pre- and posttest in both groups ($p = 0.001$), supporting improved hip abductor force following both-intervention for participants who suffered from LBP (Table 3).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) and group-by-time interaction ($p = 0.001$) for the knee flexor. Interaction post hoc test showed a greater improvement in the knee flexor with DPT than with CPT, supporting that knee flexor became more common after CPT compared to DPT. Post hoc analysis revealed a significant difference in hip flexor force pretest and posttest in both groups ($p = 0.001$) (Table 3).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) for the knee extensor. Post hoc analysis revealed significant differences in knee extensor force pre- and posttest in both groups ($p = 0.01$), supporting improved knee extensor force following both-intervention for participants who suffered from LBP (Table 3).

Trunk ROM

Repeated-measures ANOVA showed a significant time effect ($p = 0.00$) for trunk flexion. Post hoc analysis revealed a significant difference in trunk flexion ROM pre- and posttest in both groups ($p = 0.00$), supporting improved trunk flexion ROM following both-intervention for participants who suffered from LBP (Table 4).

Table 3. Lower extremities muscle force (Unit: Nm/kg).

	DPT		CPT		*p* value		
	Pretest	Posttest	Pretest	Posttest	Time	Groups	Time × Group
Hip flexor	0.83 ± 0.11	0.84 ± 0.21	0.80 ± 0.08	0.83 ± 0.11	0.001*	0.38	0.001*
Hip extensor	0.88 ± 0.14	0.91 ± 0.22	0.84 ± 0.14	0.83 ± 0.11	0.13	0.88	0.001*
Hip adductor	0.61 ± 0.16	0.66 ± 0.18	0.64 ± 0.17	0.65 ± 0.22	0.001*	0.33	0.001*
Hip abductor	0.82 ± 0.15	0.88 ± 0.21	0.84 ± 0.14	0.84 ± 0.16	0.001*	0.001*	0.001*
Knee flexor	1.08 ± 0.28	1.14 ± 0.14	1.08 ± 0.21	1.13 ± 0.16	0.001*	0.33	0.001*
Knee extensor	0.90 ± 0.14	0.94 ± 0.16	0.88 ± 0.37	0.93 ± 0.14	0.001*	0.88	0.13

DPT: digital application physical therapy; CPT: conventional physical therapy.

Repeated-measures ANOVA showed a significant time effect ($p = 0.01$) for trunk extension. Post hoc analysis revealed a significant difference in trunk extension ROM pre- and posttest in both groups ($p = 0.01$), indicating improved trunk extension ROM following both-intervention for participants who suffered from LBP (Table 4).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) and between-group difference ($p = 0.03$) for left-side bending. Post hoc analysis showed a significant difference in left-side bending ROM pre- and posttest in both groups ($p = 0.001$), supporting improved left-side bending following both-intervention for participants who suffered from LBP (Table 4).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) for right-side bending. Post hoc analysis showed a significant difference in right-side bending ROM pre- and posttest in both groups ($p = 0.001$), indicating improved right-side bending ROM following both-intervention for participants who suffered from LBP (Table 4).

Functional movement screen

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) for the deep squat. Post hoc analysis revealed a significant difference in the deep squat pre- and posttest in both groups ($p = 0.001$), representing improved deep squat following both-intervention for participants who suffered from LBP (Table 5).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) for the hurdle step. Post hoc analysis revealed a significant difference in the hurdle step pre- and posttest in both groups ($p = 0.001$), indicating supporting

Table 4. Trunk range of motion.

	DPT		CPT		*p* value		
	Pretest	Posttest	Pretest	Posttest	Time	Groups	Time × Group
Flexon	33.18 ± 4.15	42.38 ± 5.61	30.48 ± 5.34	41.20 ± 3.81	0.001*	0.21	0.88
Extension	14.82 ± 1.83	16.88 ± 2.14	14.38 ± 1.25	16.28 ± 1.41	0.001*	0.38	0.77
Left side bending	13.48 ± 1.80	18.11 ± 1.59	13.15 ± 2.15	17.38 ± 2.77	0.001*	0.03*	0.21
Right side bending	12.88 ± 1.48	16.48 ± 2.52	13.68 ± 2.11	17.48 ± 2.16	0.001*	0.63	0.68

DPT: digital application physical therapy; CPT: conventional physical therapy.

Table 5. Functional movement screen.

	DPT		CPT		*p* value		
	Pretest	Posttest	Pretest	Posttest	Time	Groups	Time × Group
Deep squat	1.02 ± 0.14	1.76 ± 0.43	0.98 ± 0.014	1.84 ± 0.37	0.001*	0.35	0.13
Hurdle step	1.02 ± 0.14	1.86 ± 0.35	1.00 ± 0.00	1.96 ± 0.20	0.001*	0.11	0.12
Line lunge	1.02 ± 0.14	1.88 ± 0.33	1.00 ± 0.00	1.96 ± 0.20	0.001*	0.19	0.22
Shoulder mobility	1.04 ± 0.20	1.90 ± 0.30	1.00 ± 0.00	1.96 ± 0.20	0.001*	0.44	0.22
Active straight leg raises	1.00 ± 0.20	1.88 ± 0.33	1.00 ± 0.00	1.96 ± 0.20	0.001*	0.67	0.13
Trunk stability	1.02 ± 0.14	2.50 ± 0.49	1.00 ± 0.00	1.58 ± 0.58	0.001*	0.10	0.02*
Rotary stability	1.02 ± 0.14	2.36 ± 0.35	1.00 ± 0.00	1.96 ± 0.20	0.001*	0.21	0.02*
Total	7.14 ± 0.99	15.74 ± 2.22	6.98 ± 0.14	13.22 ± 1.42	0.001*	0.92	0.18

DPT: digital application physical therapy; CPT: conventional physical therapy.

improved hurdle step following both-intervention for participants who suffered from LBP (Table 5).

Repeated-measures ANOVA showed a significant time effect ($p = 0.010$) for the line lunge. Post hoc analysis revealed a significant difference in the line lunge pre- and posttest in both groups ($p = 0.001$), indicating improved line lunge following both-intervention for participants who suffered from LBP (Table 5).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) for shoulder mobility. Post hoc analysis revealed a significant difference in shoulder mobility pre- and posttest in both groups ($p = 0.001$), supporting improved shoulder mobility following both-intervention for participants who suffered from LBP (Table 5).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) for the active straight leg raise. Post hoc analysis revealed a significant difference in the active straight leg raise pre- and posttest in both groups ($p = 0.001$), indicating improved active straight leg raise following both-intervention for participants who suffered from LBP (Table 5).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) and group-by-time interaction ($p = 0.02$) for trunk stability. Interaction post hoc test showed a greater increase in trunk stability with DPT than with CPT, representing improved trunk stability following DPT for participants who suffered from LBP. Post hoc analysis revealed a significant difference in trunk stability pretest and posttest in both groups ($p = 0.001$) (Table 5).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) and group-by-time interaction ($p = 0.02$) for rotary stability. Interaction post hoc test showed a greater increase in rotary stability with DPT than with CPT, suggesting a greater increase in rotary stability after DPT than after CPT. Post hoc analysis revealed a significant difference in rotary stability pretest and posttest in both groups ($p = 0.001$) (Table 5).

Repeated-measures ANOVA showed a significant time effect ($p = 0.001$) for the total FMS score. Post hoc analysis revealed a significant difference in total FMS score pre- and posttest in both groups ($p = 0.001$, 0.001, and 0.02, respectively), indicating supporting improved FMS score following both-intervention for participants who suffered from LBP (Table 5).

Table 6. Incremental preliminary cost-effectiveness ratio.

	DPT	CPT
Cost US$	9	124
Incremental cost, US $	−113	N/A
Effects, mean QALY	0.090	0.089
Incremental effects, mean QALY	N/A	N/A
Incremental cost-effectiveness ratio of US $/QALY gained	Dominant	N/A

DPT: digital application physical therapy; CPT: conventional physical therapy; QALY: quality-adjusted life year; N/A: not applicable.

Preliminary cost-effectiveness analysis

Table 6 shows the point estimates of the incremental costs and effects per participant. The total health care cost in patients who received DPT was less (US $113) than that in participants who received CPT. Additionally, participants who received DPT had an additional therapeutic benefit (0.001 QALY) than those who received CPT. Thus, the ICER showed that DPT was less costly and more beneficial than CPT (Table 6).

Postintervention questionnaire for COVID-19 transmission risk

An independent *t*-test showed a significantly greater decrease in social distance time, duration of contact time, and actual infection rate of COVID-19 in DPT than in CPT ($p = 0.01$), suggesting a greater increase in perceived

Table 7. Post questionnaire for COVID-19 transmission risk.

	DPT	CPT	*p* value
Social distance time (min)	23.50 ± 4.74	1.00 ± 2.10	0.01*
Duration of contact time (min)	11.00 ± 3.94	23.00 ± 2.11	0.01*
Perceived risk of COVID-19 transmission	1.10 ± 2.07	4.81 ± 1.15	0.01*

DPT: digital application physical therapy; CPT: conventional physical therapy; COVID-19: coronavirus disease 2019.

Table 8. Post intervention satisfaction questionnaire.

	DPT	CPT	*p* value
Accessibility	4.67 ± 0.48	3.27 ± 0.84	0.02*
Effectiveness	4.09 ± 0.72	4.39 ± 0.75	0.10
Cost	4.91 ± 0.29	2.76 ± 0.97	0.01*
Sustainability	4.06 ± 0.75	3.97 ± 0.88	0.68
Real-time feedback	3.58 ± 0.75	2.42 ± 1.39	0.01*

DPT: digital application physical therapy; CPT: conventional physical therapy.

questionnaire for COVID-19 transmission risk after DPT than after CPT (Table 7).

Postintervention satisfaction questionnaire

The independent *t*-test showed a significant difference in accessibility and cost as well as real-time feedback in DPT than in CPT, suggesting a greater increase in postintervention satisfaction questionnaire after DPT than after CPT ($p = 0.017$ and 0.001, respectively) (Table 8).

Discussion

To the best of our knowledge, this is the first prospective long-term intervention on a deep learning–based self-management application to evaluate the effects of DPT and CPT on clinical pain, pain-associated disability, mobility, muscle strength, FMS, ADL, QOL, and cost-effectiveness associated with LBP. As hypothesized, DPT was as effective as CPT based on clinical outcome measures (ODI, RMDQ, and NPRS), lower extremity strength, trunk mobility, ADL (QUE), QOL (SF-12), and FMS. Most importantly, DPT was better than CPT in reducing COVID-19 transmission risk, cost-effectiveness, accessibility, and real-time feedback.

Pain and associated disability analysis showed significant differences in ODI (36.68% and 41.05%), NPRS (44.39% and 35.48%), and RMDQ (43.23% and 40.21%) between groups, respectively. This finding was consistent with previous clinical evidence that compared the differential effects of CPT and DPT in participants with chronic mechanical LBP. Chhabra and colleagues reported improved recovery following 12 weeks of smartphone application treatment (54.79%) compared with that with conventional treatment (51.52%) in 93 patients with LBP-associated disability.[42] Similarly, Almhdawi and colleagues reported better recovery from back pain-associated disability following six weeks of application intervention (35.70%) when compared with that of conventional intervention (2.86%) in 40 office workers with chronic LBP.[43] It is possible that the pain and associated disability were improved in both groups because CPT (passive manual reduction) and DPT (participant self-reduction) improved pathologies that occurred due to maligned soft tissue and lumbar disc prolapse.[11]

Muscle force analysis demonstrated that both interventions were equally effective in improving the hip flexors (1.20% and 3.75%), hip adductor (7.32% and 1.56%), hip abductor (8.20% and 1.56%), knee flexor (5.56% and 4.63%), and knee extensor (4.44% and 5.68%) in the DPT and CPT groups, respectively. Our findings were consistent with those of a previous study that reported improvements in back extension, flexion, and lateral bending muscle force after using a training device by 8.03%, 14.28%, and 15.41%, respectively, in 41 patients with LBP.[44]

The addition of strengthening exercises and functional activities can be performed without peripheralization of symptoms. After centralization, through CPT and DPT intervention, the muscle is strengthened, resulting in a more immediate effect.[11] Unlike other muscle-strengthening exercises for treating LBP stability and restoring ROM, CPT, and DPT aim to directly diminish or even eliminate the participant's symptoms. This is accomplished by applying a corrective directional movement. Conventional physical therapy and DPT intervention educates participants on movement and position strategies that can reduce pain.[45] A cautious progression of repeated forces and loads is used in this method. The exercises may be uncomfortable for the participant at first, but after some repetition, their symptoms decrease.[46]

Trunk mobility analysis demonstrated that both interventions were equally effective in improving trunk ROM in flexion (27.73%; 35.17%), extension (13.90%; 13.21%), left-side bending (34.35%; 32.17%), and right-side bending (27.95%; 27.78%). Our initial assessments showed that LBP was the primary factor limiting trunk mobility followed by muscle weakness and tightness. After completing both CPT (therapist-induced) and DPT (participant self-applied), treatments significantly decreased pain along with providing increased centralization of the initially peripheralized pain, thereby increasing limited spinal trunk mobility. Our findings were consistent with those of a previous study that reported a 5.77% improvement in back ROM after telerehabilitation in 56 patients with LBP. Lara-Palomo and colleagues found improved flexion mobility following eight weeks of an e-health program (60.57%) and home rehabilitation program (24.21%) in 74 patients with LBP.[47] Interestingly, DPT with audiovisual feedback and the individualized Dr AI application were as effective as programs based on traditional hands-on physical therapy in restoring impaired trunk mobility. Similarly, previous digital therapeutics using telehealth (e.g., by videoconferencing) employing repetitive movement, activity, and posture correction (by audiovisual feedback) reduced pain and increased spinal mobility.[48] In the case of telehealth, the physical therapist performs the evaluation through a teleconference meeting; however, in DPT, the AI can diagnose anytime and anywhere, requiring less time. Conversely, physical therapists can provide the appropriate posture and movement guidance to improve mobility, forces, and pain in CPT.[49] In patients with LBP, shortness and weakness may occur in the soft tissues due to reduced use and stretching of the muscles and ligaments. This may result in decreased flexibility and limit the functional ROM of the spine, increasing disability. Through evidence-based intervention by a physical therapist, the flexibility, mobility, and function of the spine were improved. Conventional physical therapy intervention performed by a therapist using a sling exercise or core stability exercise realigns the upright movement and positioning of the pelvic girdle, normalizing the proprioceptive inputs of the cervical-lumbo-pelvic region.[30] Subsequently, the enhanced proprioceptive feedback facilitates the selective concentric activation of the deep core muscles. Proper posture realignment reduces strain on muscles and related supporting structures by maintaining balance in the musculoskeletal system and protecting the body from deforming forces.[50]

DPT provided real-time postural recommendations and individualized exercises with audiovisual feedback in real time to participants with LBP. One possible underlying mechanism for observed improvement is the audiovisual feedback since improvements in visual motor learning strategies (motor and clinical) are related to better memory and planning abilities. Examples of such audiovisual feedback instructions are "keep your feet straight and go a little further," "bend your back a little more," and "put your hands on your back." Motor control failures often result from active movement in coordination with lumbar joint movement during exercise.[51] AI provides continuous postural feedback ensuring that participants with LBP use the correct posture during exercise. This results in reduced pain, better mobility, and muscle strength associated with DPT and CPT. Digital application physical therapy and CPT are evidence-based approaches that allow for diagnosis of symptoms based on systematic history-taking, assessment of neurological function and motion loss, and assessment of symptomatic and mechanical changes. Treatment principles are designed for each group, and each patient is provided with an individualized intervention plan.[52] With DPT, feedback on exercises can be received in real time at home and work throughout the day through a smartphone application. However, participants undergoing CPT can only receive feedback on posture and exercise after visiting a hospital or meeting with a physical therapist.

Activities of daily living and FMS analysis showed that both DPT and CPT lead to significant improvements in QUE (26.46%; 27.54%) and FMS (120.45%; 89.40%). This finding supports previous evidence seen from digital therapeutic care regarding more substantial improvements in ADL (24.17%) for patients with LBP.[53] Notably, positive changes in ADL seen with the digital therapeutic application ranged from 14.28% to 51.85% in patients with LBP who exhibited improved ADLs associated with pain despite prolonged deconditioning after LBP onset.[42] It is plausible that the improvement in patient symptoms is from an individualized exercise regimen.[54] This could explain the differences observed when comparing a movement-based approach to a nonspecific exercise regimen, such as ROM exercises, which may not address pain immediately. Repeated movement is the method by which the pain radiating from the spine is sequentially eliminated distally to proximally in response to a specific therapeutic exercise.[55] Digital application physical therapy comprises a thorough clinical history followed by a physical examination, where symptomatic, mechanical, and functional baselines are assessed, and the response to repeated end-range movements, posture, and core stability is determined. Such customized, repetitive, and accurate movement training helps restore activity limitations such as squatting, lunging, and climbing stairs. Moreover, DPT is useful for controlling posture, reduction, and core stability function by allowing changes and correcting movement in response to AI-based audiovisual feedback. Conversely, CPT provides encouragement and motivation through direct guidance and verbal feedback from an experienced physical therapist. Our findings support previous FMS studies by reporting that deep squat (41.93%), hurdle step (25.64%), active straight leg raise (37.84%), and rotary stability (56.52%) scores in 20 patients with LBP were lower than those in 20 healthy adults.[49] The FMS is designed to challenge both kinetic chain mobility and stability, which are necessary to perform fundamental movement patterns. Therefore, the FMS may be a useful tool for identifying movement deficits in patients with LBP, who tend to show decreased mobility, core stability, and coordination. An explanation for the low score on the FMS is the restricted hip joints, common in patients with LBP due to limited lumbar and hip joint mobility.[30] Moreover, FMS tasks require proper stability and coordination between the hips and torso when stepping, which we expected to be lacking in patients with LBP. The low scores of patients with LBP on the FMS confirm that spine and hip mobility are restricted. Digital application physical therapy and CPT have shown slight improvement in transversus abdominis thickness as well as other local trunk muscles, including the external and internal obliques. Furthermore, other studies found that lumbar stabilization exercises and dynamic strengthening exercises improved the isometric strength of the lumbar musculature and reduced pain in chronic LBP. Digital application physical therapy and CPT can include active or passive lumbar flexion and extension and intensive modalities for the lumbar specifically designed to improve neuromuscular control, strength, and endurance of the muscles that primarily maintain dynamic spinal and trunk stability.[56] Since mobile devices are personally available and constantly accessible to patients, DPT, specifically using smartphone applications, is considered a powerful way for patients to monitor their condition as it enhances the ability and willingness for self-management, improving treatment compliance. Our research suggests that providing incremental real-time feedback when progressing toward a goal, along with the use of activity monitors, enables patients to adjust their behavior with sufficient time to enhance their progress. Thus, the feedback in DPT may be more helpful than traditional feedback. The use of such activity monitors has been shown to increase the level of physical activity, providing more improvement in function and decreases in pain in patients with LBP.[43]

Quality of life analysis demonstrated that both interventions were equally effective in enhancing SF-12 results

(22.80%; 17.91%). This finding supports that of a previous study that combined an e-health program (21.82%) and home exercise (12.88%) and demonstrated substantial improvement in the Short Form 36 Item Health Survey in 74 patients with LBP. Therefore, we believe that the support of an online platform during DPT or CPT would increase patient motivation and interest in the intervention, making it more effective in the short- and medium term. Moreover, DPT increases the amount of free time available to patients and decreases financial burden compared to CPT. Almhdawi and colleagues reported an 18.15% increase in SF-12 data after six weeks in 40 office workers with LBP. Using the AI-based mobile app may therefore play a role in increasing access to exercise therapy[43] and is also supported by the reported increase in time engaged in therapeutic exercise. Adequate adherence to a therapeutic exercise program in LBP management has been a long-standing issue. Previous research showed that 50%–70% of patients with LBP did not adhere to a home exercise program.[57] The users' self-rated improvement following intervention was used in assessing its impact on chronic pain. The self-rating of symptom improvement observed in this study corresponded to centralization, peripheralization, or the reduction of pain.

The preliminary cost-effectiveness analysis for both DPT and CPT showed substantially more decrease in cost ($115) and more increase in overall effectiveness (30%) in the DPT group than the controls. This suggests that smartphone application-based interventions are an alternative modality to in-person physical therapy in LBP. This is consistent with the earlier study (Fatoye and colleagues, 2020), who reported that telerehabilitation had a decreased cost burden (41.88%) compared to that with clinical-based MDT in 47 patients with LBP.[39] Digital application physical therapy can reduce the time needed for care with significant positive effects on program engagement (based on the number of weekly workouts). Patients who seek care can access it immediately, which may motivate them to initiate behavioral changes that alleviate pain and restore functionality.[39] Thus, telerehabilitation is a viable option that can help remedy challenges with commuting distance, time, and travel to receive care. Being transferred from one provider to another is time-consuming and can be frustrating; moreover, it may negatively impact patients' motivation toward the recovery process. Given the evidence, mobile applications can provide prompt access to care that yields result comparable with those of in-person care. Digital application physical therapy may also deliver better and more cost-effective results than the typical care pathway that begins with a physician.[39] Telerehabilitation via mobile apps also removes barriers to recovery that can make initiating CPT inconvenient, such as appointment scheduling and travel.[58] Issues with participation can arise by having a commitment to patients' social life such as working and housekeeping. For most patients with LBP, the main goal of intervention is the return to normal levels of activity participation, allowing the continuation of their self-management. Conventional physical therapy intervention may lead to more sustainable LBP management and exercise adherence through voluntary participation by seeing a therapist directly every time while visiting the hospital. Conventional physical therapy has the benefit of direct support from a physical therapist, which can be important in maintaining adherence, especially in the longer term. Encouraging patients to seek support from a physical therapist can also be helpful. Digital application physical therapy encourages more independent LBP management as it provides deep learning–based image recognition to be performed at any time through real-time posture correction, audiovisual feedback, and AI-based exercise recommendation algorithms for participants with LBP.[21] Conversely, CPT provides LBP management through therapist-dependent manual assessment and intervention programs.

The transmission risk of COVID-19 (as determined by social distancing, duration of contact time, and evidence of COVID-19 transmission) was lower during DPT than during CPT. This suggests that the smartphone application approach can be more suitable for reducing the risk of COVID-19 transmission. Additionally, postintervention satisfaction questionnaire results support that DPT was inexpensive, sustainable, and helpful. Most participants wished to continue using the deep learning–based application. Through interventions performed remotely via deep learning–based applications, participants learn to control the progression of LBP by modifying their behavior. If painful symptomatology improves without interrupting the participant's daily life and healthcare costs can be avoided, thereby favoring greater cost savings.

Analysis results of the postintervention satisfaction questionnaire showed significantly better accessibility (29.98%), cost (43.79%), and real-time feedback (32.40%) with DPT than with CPT. Özden and colleagues reported that video exercise-based telerehabilitation improved (22.51%) motivation, expectation, satisfaction, and usability more than CPT did after eight weeks in 50 patients with LBP.[54] Smartphone applications with user-friendly interfaces ensure that all sociocultural backgrounds can easily be incorporated into the intervention. Deep learning–based applications can make exercises more enjoyable primarily by utilizing audiovisual feedback. A written exercise progression can be more challenging. Specifically, when using the smartphone application for managing LBP, the AI updates the exercise prescription online, and the new program or protocol is sent immediately to the patient. The features of deep learning–based application therapy may have led to better clinical and social results observed in the telerehabilitation group. We observed a positive effect on sustainability in both groups of the current study. Patients took responsibility for their

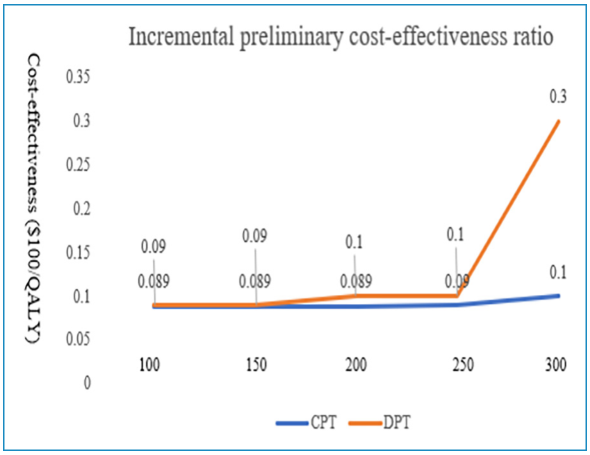


Figure 3. Incremental preliminary cost-effectiveness ratio.

performance during the four-week exercise period and were supervised only during the experimental period. However, deep learning–based guiding and controlling over time are essential, which may motivate patients. Furthermore, the level of compliance may improve with frequent follow-ups. Patient beliefs and attitudes play an important role in improving function and disability; moreover, deep learning–based therapeutic exercises can decrease the negative affective consequences of LBP, as well as increase positive cognitive and behavioral attitudes.[59]

Research limitations of the present study should be addressed in future. One limitation is that the follow-up evaluation may be of great interest to elucidate the sustainable therapeutic efficacy of DPT in the participants with LBP. The other limitation is that only Android OS users have access to the application, which should be further developed to accommodate the Apple OS users. Lastly, albeit the sample size deemed to be appropriate for the randomized clinical trial variables, the sufficient sample size for a cost-effectiveness analysis considered to be 300 participants with LBP (Figure 3). A careful interpretation of cost-effectiveness data should be applied to generalize our preliminary cost-effectiveness data.

Conclusion

In the present study, we demonstrated that DPT was as effective as CPT in improving structural and functional impairment, activity limitation, and participation restriction. Our results highlight the successful incorporation of DPT intervention for clinical outcome measures, lower extremity strength, trunk mobility, ADL improvement, QOL improvement, FMS, perceived transmission risk of COVID-19, preliminary cost-effectiveness, and post-intervention satisfaction in LBP. Digital application physical therapy has the flexibility to provide real-time audiovisual feedback as well as a corrective diagnosis and sustainable intervention. We believe our study serves as a basis to advance deep learning clinical science and research.

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Appendix 1

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Body functions and structure impairment (Pain control)				ICF[b] model	
Stretching	Mobilization	TENS[d]	Ultrasound	Heat therapy	CPT[c]
• · Tension increases, the collagen fibers in the connective tissue align themselves along the same line of force as the tension. [1]	• · Stimulates mechanoreceptors in the joints and muscles. [2]	• · Activate large diameter non-noxious afferents (A-beta) to reduce nociceptor cell activity and sensitization. [3]	• Increase in nerve conduction speed [4] • Activation of A beta fiber • · Alternation of C fiber [5].	• Increase in blood flow and metabolism • · Increase elasticity of connective tissue.[6,7]	Rationale
15 min/ session for a week	15 min/ session for a week	10 min/ session for a week	10 min/ session for a week	10 min/ session for a week	Dosage
Postural correction		Core strengthening exercise		Directional preference for extension (posterior lumbar derangement) or flexion (anterior derangement)	DPT[e]
· To perform poor postural positions followed by the symptom-abolishing positions for them to ‘understand’ what is leading to their discomfort and train patients to avoid them.[8]		· To integrate of local, single-joint muscles and multi-joint muscles to provide stability and produce motion. [9]		· To reduce posteriorly deranged lumbar facet joint structure · To improve pain from peripheralization to centralization. [10]	Rationale
Minimum of 10–12 repetitions × 3 times		Minimum of 10–12 repetitions × 3 times		Minimum of 10–12 repetitions × 3 times	Dosage
30 min/session for a week		30 min/session for a week		30 min/session for a week	Total time

Body functions and structure impairment (Reduced strength)	Body functions and structure impairment (Limited lumbar spine mobility and posterior derangement)	ICF model		
Sling exercise	Core stability exercise	Manipulation	Mobilization	CPT
· Strengthens deep muscles that engage in stability, which is effective in normalizing muscle response patterns control using the subconscious feedforward mechanism. [11]	· To maintain the reduced pain or centrated lumbar joint. [12]	· Activation of endogenous descending pathways in the brain inhibitory systems. [13]	· Stimulates mechanoreceptors in the joints and muscles. [2]	Rationale
30 min/ session for a week	30 min/ session for a week	15 min/ session for a week	15 min/ session for a week	Dosage
Functional movement integration training at home and work	Core strengthening exercise	Extension directional preference Repeated movement	DPT	
· Repeated extension exercise prior to the lifting work or task to maintain the reduced lumbar position and associated pain recurrence. [8]	· To maintain the reduced pain or centrated lumbar joint structure. [9]	· To reduce posterior derangement and Posterioanterior glide with self-overpressure. [8]	Rationale	
Minimum of 10–12 repetitions × 3 times	Minimum of 10–12 repetitions × 3 times	Minimum of 10–12 repetitions × 3 times	Dosage	
30 min/session for a week	30 min/session for a week	30 min/session for a week	Total time	

Activities limitation		ICF model
Sling exercise	Core stability exercise	CPT
· Strengthens deep muscles that engage in stability, which is effective in normalizing muscle response patterns control using the subconscious feedforward mechanism.[14]	To maintain the reduced pain or centrated lumbar joint. [12]	Rationale
30 min/ session for a week	30 min/ session for a week	Dosage
Sustainability training–self-low back care exercise and ergonomic education		DPT
To prevent recurrent low back and sustain therapeutic effectiveness. [8]		Rationale
Minimum of 10–12 repetitions × 3 times		Dosage
30 min/ session for a week		Total time

[a]LBP: Low back pain [b]ICF: International classification of functioning, disability and health [c]CPT: Conventional physical therapy [d]TENS: Transcutaneous electrical nerve stimulation [e]DPT: Digital application physical therapy	Participation restriction		ICF model
	Core stability during social communities		CPT
	To maintain the reduced pain or centrated lumbar joint structure. [9]	Rationale	
	Minimum of 10–12 repetitions × 3 times		Dosage
	30 min/session for a week		Total time
	Functional movement integration training at home and work	Maintenance	DPT
	· Repeated extension exercise prior to the lifting work or task to maintain the reduced lumbar position and associated pain recurrence. [8]	· To solve the problems persisting can more likely be prevented through self-maintenance. [8]	Rationale
Minimum of 10–12 repetitions × 3 times	Minimum of 10–12 repetitions × 3 times	Dosage	
	30 Min/ Session For A Week	30 Min/ Session For A Week	Total Time