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# The effect of proprioceptive neuromuscular facilitation on functional skills, muscle strength, and trunk control in children with cerebral palsy: A randomized controlled trial☆

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ABSTRACT

*Background:* Proprioceptive neuromuscular facilitation (PNF) is generally used for the lower limbs in children with Cerebral Palsy (CP). This study aimed to determine the effect of PNF and Neurodevelopmental Therapy (NDT) on functional abilities, muscle strength, and trunk control in children with CP.
*Methods:* Thirty spastic CP children classified as either level I–II in the Gross Motor Function Classification System (GMFCS) or level I–II in the Manual Ability Classification System (MACS) were included. The PNF ($n = 15$) and the NDT group ($n = 15$) had physiotherapy for six weeks. The ABILHAND-Kids scale, the Purdue Pegboard Test (PBPT), the Nine-Hole Peg Test (9-HPT), and the Jebson-Taylor Hand Function Test (JTHFT) were employed. Pinch meters, Jamar handheld dynamometers, and digital muscular strength assessments were used.
*Results:* The PNF group increased shoulder flexion ($p < 0.05$), adduction ($p < 0.05$), elevation ($p < 0.05$), scapular abduction ($p < 0.05$), elbow extension (right) ($p < 0.05$), grip ($p < 0.05$), and pinch strengths (left $p < 0.05$, right $p < 0.05$). The PNF group had significantly lower 9-HPT ($p < 0.05$), JTHFT (card turning), JTHFT (simulated feeding), JTHFT (lifting light cans), and JTHFT (lifting weight cans) durations ($p < 0.05$), and significantly higher PBPT (right-left) PBPT (bimanual), PBPT (assembly).
($p < 0.05$), ABILHAND ($p < 0.05$), and TCMS total scores ($p < 0.001$). While JTHFT (simulated feeding-left), JTHFT (stacking checkers-left), JTHFT (lifting light cans-left), and JTHFT (lifting weight cans-right/left) ($p < 0.05$) durations decreased in the NDT group, PBPT (right) ($p < 0.05$) had an increase in duration.
*Conclusion:* PNF improves trunk control, upper extremity functional skills, selective proximal muscle strength, and distal upper extremity muscle and grip strength.

## 1. Introduction

Cerebral palsy (CP) represents a non-progressive neurodevelopmental disorder, which leads to activity limitation, and comprises movement and posture deficiencies [1]. Of these children, 80 % have upper extremity dysfunctions, leading to a limitation of their participation in activities of daily living (ADLs) and resulting in a loss of quality of life [2,3]. CP children have difficulties in reaching, grasping, and fine motor skills and display abnormal movement patterns [2,4]. This results in the deficient functional activities of extremities [5].

Although upper extremity involvement is known with CP children, studies on physiotherapy methods have mostly focused on hemiparetic CP [6–8]. Children with hemiparetic CP are most commonly found to have increased muscle tone and decreased normal joint mobility (NJM), a decrease in muscle and grip strength in the upper extremities, a primitive gripping reflex, and a loss of speed and dexterity [6,9]. Sensorimotor problems are also observed [10]. Children with bilateral CP also have similar problems. However, there is a wide variation in the bimanual performance of children with hemiparetic and bilateral CP [9]. The disability in manipulating objects is among the most significant

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causes of the restriction of their participation in ADLs [6,9]. Children with diparetic CP are also reported to have deficiencies in dexterity, grip strength, and functions in ADLs [7]. Dexterity, coordination, upper extremity muscle strength, grip strength, ADLs, and functional skills are negatively affected in these children compared to their healthy peers [7]. Upper extremity rehabilitation has remained in the background in CP, and research on the treatment of upper extremity sequelae has come to the forefront in the last decade [10]. Many methods are used in physiotherapy, including casting, splinting, stretching, strengthening, posture, choosing an orthosis, and movement facilitation [1–4]. However, it is well recognized that studies examining the effectiveness of current treatments on upper extremity functions mostly concentrate on unilateral CP [5]. There are few interventions available for children with bilateral CP that concentrate on improving upper extremity functions [10,11]. Bilateral CP patients been shown to benefit from target-oriented therapy, bimanual intensive task-specific training regimens, and lower extremity training [10,11].

It is observed that proprioceptive neuromuscular facilitation (PNF) strengthening exercise is primarily utilized in the lower extremities and considerably improves muscle strength balance [12,13]. The present study aims to reveal the effect of upper extremity muscle strengthening training with PNF and the traditional neurodevelopmental therapy (NDT) method on functional skills, muscle strength, and trunk control in children with hemiparetic and diparetic CP.

## 2. Methods

### 2.1. Study design

Single blind randomized controlled trial study.

### 2.2. Participants and measurements

Children with CP aged between 8 and 18 years who presented to the pediatric neurology outpatient clinic of XXXXX University Faculty of Medicine were included. The parents signed the consent form. Individuals with hemiparetic-diparetic CP who were able to cooperate, with manual functions at levels according to the Manual Ability Classification System (MACS), the Gross Motor Function Classification System (GMFCS) level I-II, who had an upper extremity muscle tone≤2 according to the Modified Ashworth Scale (MAS) and included. Individuals who had undergone any upper extremity surgery or Botulinum toxin (Btx) in the last 6 months, had an additional neurological disease, and had any upper extremity contracture were excluded.

The individuals' sociodemographic characteristics were recorded. The included individuals ($n = 30$) were selected and randomly divided into two groups. The PNF exercise approach was applied to the first group (study/$n = 15$) for 30 min a day, 3 days a week for 6 weeks. Physiotherapy approach consisting of NDT method was applied to the second group (control/n = 15) for 45 min a day, 3 days a week for 6 weeks. The same physiotherapist applied the physiotherapy approaches. Assessments were carried out twice, before and after the treatment. A physiotherapist who is experienced in pediatric rehabilitation for 7 years, was blinded to the physiotherapy groups carried out all assessments (Fig. 1).

The Clinical Research Ethics Committee of XXXXX University Faculty of Medicine was approved *the study* (*Session*: *2021/09*, *Decision No*: *01*). *The clinical trial number was NCT05115695*.

### 2.3. Measurements

#### 2.3.1. Manual Ability Classification System (MACS)

It categorizes how well kids can use their hands to handle objects throughout regular activities. Although the MACS evaluates bimanual hands' joint engagement in activities, it does not evaluate hands separately [14].

#### 2.3.2. ABILHAND-Kids scale

It represents a parent questionnaire that describes how easy or difficult it is for a child to carry out bilateral activities for the assessment of upper extremity skills. The 21 items are related to ADLs is scored. A maximum of 42 points can be acquired [15,16].

#### 2.3.3. Modified Ashworth Scale (MAS)

It measures the severity of spasticity on the basis of the subjective rating of the tone felt against a passive movement [17]. 0: No increase in tone, 1: Slight increase in tone, manifested by a catch and release or by minimal resistance at the end of the ROM, 1+: Slight increase in tone, manifested by a catch, followed by minimal resistance throughout the remainder of the ROM, 2: More marked increase in tone through most of the ROM, 3: Considerable increase in muscle tone, difficult passive movement, 4: Affected part(s) rigid. Spasticity of the bilateral pectoralis, elbow flexors, pronators, wrist and finger flexor muscles were assessed.

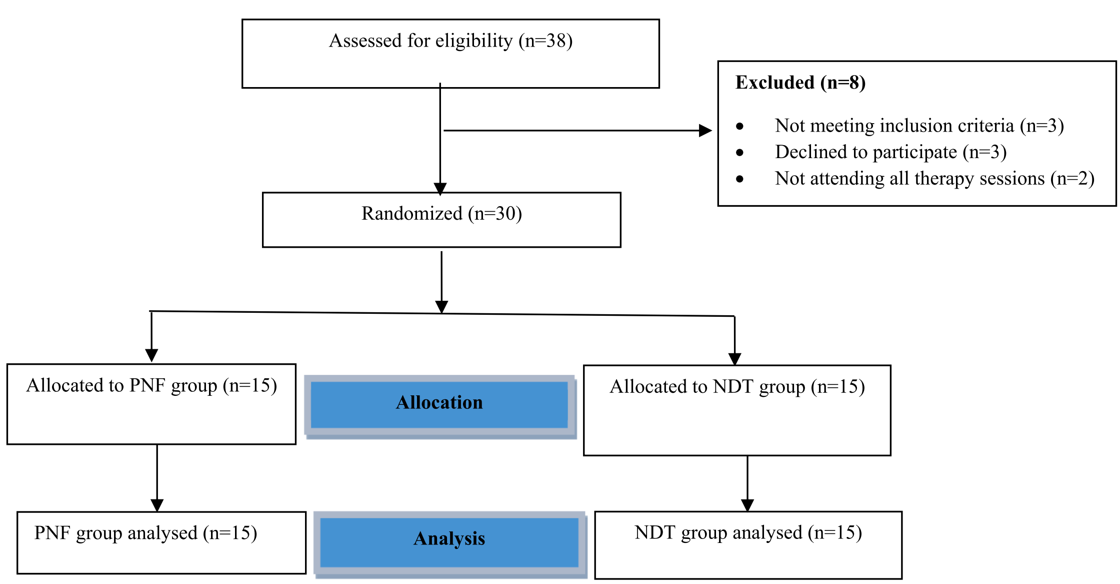


**Fig. 1.** Flowchart of the study (PNF: proprioceptive neuromuscular facilitation, NDT: neurodevelopmental therapy).

#### 2.3.4. Jebsen-Taylor Hand Function Test (JTHFT)

It consists of a number of subtests that reflect common hand functions. The time it takes to complete five tests for each hand is measured in *se*conds (sec), and the test is conducted independently for the dominant and non-dominant extremities. Six functions are applied in total, excluding the writing sub-parameter. Consisting of turning cards, lifting small objects, simulated feeding, stacking checkers, lifting light cans, and lifting weight cans (six functions), are applied [18–20].

#### 2.3.5. Nine-Hole Peg Test (9-HPT)

It is one of the most common, reliable, and valid tools to assess dexterity. The patients are instructed to take the pegs one by one from a container at the top of the test board and place them into the holes at the bottom of the container without any order, then remove the pegs and put them in the container on the side. The time required to complete the test is recorded in *sec* [21,22].

#### 2.3.6. Purdue Pegboard Test (PBPT)

The valid and reliable test measures fingertip dexterity [23]. The PBPT, consists of a board with pegs, collars, and washers. The time is recorded in sec. In the first, second, and third subtests of the PBPT, pegs are put in holes from top to down in 30 s by the (1) dominant hand, (2) non-dominant hand, and (3) both hands simultaneously. In the last assembly subtest, subjects put a peg, a washer, and a collar in sequence by exchanging hands in 60 s.

#### 2.3.7. Upper extremity muscle strength

A digital muscle strength measuring device (KFORCE KINVENT digital muscle strength measuring device) measured the isometric force of shoulder flexion-abduction-extension-adduction-internal/external rotation-elevation, scapular abduction-adduction, elbow flexion-extension, wrist extension-flexion. Hand and finger grip strength was measured with a Jamar handheld dynamometer (Baseline®) and a pinch meter (Baseline Mechanical Pinch Gauge With Case, Blue, 30 Lb).

#### 2.3.8. Trunk Control Measurement Scale (TCMS)

Static sitting balance investigates static trunk control in the course of movements of the upper and lower extremities. The dynamic control of sitting is divided into two, selective motor control and dynamic reach [24,25].

### 2.4. Physiotherapy approaches

#### 2.4.1. Proprioceptive neuromuscular facilitation (PNF)

The following among bilateral upper extremity patterns were applied with PNF using a theraband in the upper extremity, with repetitive stretching and rhythmic stabilization technique for the scapular pattern as 10–15 repetitions;

1. Scapula anterior depression-posterior elevation and anterior elevation-posterior depression. Scapular pattern was passively showed to the children firstly. Then scapular pattern was applied with the true direction actively without resistance. When the children learned the active movement pattern, then repetitive stretching and rhythmic stabilization technique was applied.
2. Shoulder flexion, adduction, external rotation and extension, abduction, internal rotation (elbow in extension),
3. Shoulder extension, adduction, internal rotation and flexion, abduction, external rotation (elbow in extension). In the upper extremity training with an elastic band, the intensity of the exercises was given in line with the principles of progressive resistance exercise [26]. The intensity and number of repetitions in the exercise with an elastic band were first 2 sets of 8–10 repetitions in the first 1–2 weeks, 2 sets of 10–15 repetitions in weeks 3–4, 3 sets of 8–10 repetitions if the elastic band's resistance was increased in weeks 5–6, and 3 sets of 10–15 repetitions if the resistance remained constant. The elastic band's resistance was increased in the week when the child could complete 15 repetitions without any movement compensation and without becoming tired.

#### 2.4.2. Neurodevelopmental therapy (NDT)

The control group underwent upper extremity rehabilitation by NDT approach. In this method, all of the exercises started with passive preparation phase of the activities like scapular mobilization and scapular humeral elongation. Then dynamic weight transfers to the trunk and lower extremities and elongations with grips was performed. These exercises was prolonged and made difficult by active stretching with dynamic weight transfers to the elbow and wrist flexors, weight transfers to the upper extremities on different floors and at different angles, stimulation of the protective reactions of the upper extremities in all directions, stimulation of correction and balance reactions during the extension of the upper extremity in all direction in the course of dynamic weight transfers to the trunk and lower extremities. Then the training went on grasping and using the antispastic muscles in the elbow and wrist with different toys with NDT handlings in the wrist and elbow, functional exercises including bilateral hand activities and weight transfers, exercises that require reaching, grasping, holding, carrying, relaxation, manipulation in the hand, and bilateral hand use that will increase dexterity on a chair and table with the height suitable for the child were performed. NDT handlings was used at first stage of all grasping and reaching activities goals, but when the goal was achieved, the handling was removed. Also the direction of the reaching direction was made difficult or the shoulders' range of motion was changed during grasping activities. In all exercises, detailing and type are made more difficult, respectively. Additionally, shoulder and elbow joint ranges of motion were increased, requiring proximal joint stabilization. In addition, the activity targets were achieved in one hand and then progressed to bimanual.

### 2.5. Data analysis

In group comparisons, the Mann-Whitney *U* test was conducted. The chi-square test was employed in the group comparisons of qualitative variables. The Wilcoxon paired-sample test was used for non-normally distributed data in dependent measure comparisons. Cohen d was calculated for effect size to quantify the magnitude of differences between groups. The effect size of the study was calculated as 0.94 to 0.90 when posthoc power analysis was conducted with the post-treatment averages of the groups in the TCMS and 9-HPT total score, with an alpha value of 0.05 and a power of 0.80.

## 3. Results

Sociodemographic characteristics of the children is shown in Table 1. When upper extremity muscle strengths were compared within the group, shoulder flexion ($p < 0.05$, d = 0.52) adduction (p < 0.05, d = 0.47), elevation (right) ($p < 0.05$, d = 0.25), scapular abduction ($p < 0.05$, d = 0.50), elbow extension (right) (p < 0.05, d = 0.43), grip ($p < 0.05$, d = 0.51 (right), p < 0.05, d = 0.58 (left)), and pinch strengths ($p < 0.05$, d = 0.46 (right) p < 0.05, d = 0.43 (left)) were increased in the PNF group (Table 2). No significant change in muscle strength was revealed in the NDT group ($p > 0.05$) (Table 2).

When we analyzed the intra-group and intergroup comparison of upper extremity functional skills and trunk control, a significant reduction in the 9-HPT ($p < 0.05$) (right d = 0.53) (left d = 0.45), JTHFT (card turning) ($p < 0.05$) (right d = 0.52) (left d = 0.49), JTHFT (simulated feeding) ($p < 0.05$) (right d = 0.47) (left d = 0.50), JTHFT (lifting light cans) ($p < 0.05$) (right d = 0.61) (left d = 0.57), and JTHFT (lifting weight cans) (p < 0.05) (right d = 0.44) (left d = 0.57) durations, and significant increases in the PBPT (right-left) (p < 0.05), PBPT (bimanual) (p < 0.05), PBPT (assembly) (p < 0.05) durations, ABIL-HAND (p < 0.05), and TCMS total scores (p < 0.05) were found in the

**Table 1**
Sociodemographic characteristics of the children.

| Variable | Group 1: PNF (n = 15) (Mean ± SD) (min-max) | Group 2: NDT (n = 15) (Mean ± SD) (min-max) | p[a,b] |
|---|---|---|---|
| Age (year) | 11.46 ± 3.15 (8–18) | 11.13 ± 2.16 | 0.784[a] |
| Sex n (%) | | | |
| Male | 7 (46.7) | 7 (46.7) | 0.642[b] |
| Female | 8 (53.3) | 8 (53.3) | |
| Height (cm) | 142.20 ± 19.89 | 143.53 ± 13.5 | 0.771[c] |
| Weight (kg) | 43.06 ± 11.81 | 41.40 ± 12.23 | 0.835[c] |
| Dominant hand n (%) | | | |
| Right | 9 (60) | 9 (60) | 0.645[b] |
| Left | 6 (40) | 6 (40) | |
| GMFCS level n (%) | | | |
| Level I | 6 (40) | 7 (46.7) | 0.717[a] |
| Level II | 9 (60) | 8 (53.3) | |
| MACS level n (%) | | | |
| Level I | 8 (53.3) | 7 (46.7) | 0.720[a] |
| Level II | 7 (46.7) | 8 (53.3) | |
| CP type n (%) | | | |
| Spastic diparetic | 10 (66.7) | 11 (73.3) | 0.690[b] |
| Spastic hemiparetic | 5 (33.3) | 4 (26.7) | |
| Duration of disease (year) | 10.93 ± 3.01 (7–17) | 10.66 ± 2.22 (7–14) | 0.834[a] |
| Education n (%) | | | |
| None | 1 (6.7) | – | 0.453[b] |
| Primary school | 5 (33.3) | 5 (33.3) | |
| Middle school | 6 (40) | 9 (60) | |
| High school | 3 (20) | 1 (6.7) | |
| Treatments received n (%) | | | |
| Physiotherapy | 15 (100) | – | 0.483[b] |
| Physiotherapy+ special education | 13 (86.7) | 2 (13.3) | |

SD: standard deviation, n: number, kg: kilogram, cm: centimeter, PNF: proprioceptive neuromuscular facilitation, NDT: neurodevelopmental therapy, CP: cerebral palsy, GMFCS: Gross Motor Function Classification System, MACS: Manual Ability Classification System.
[a] Mann Whitney U test.
[b] Chi-square test (Fisher's &Pearson).
[c] Wilcoxon.

PNF group (Table 3).

It was found that the PBPT (right) ($p < 0.05$) ($d = 0.42$) duration increased, while JTHFT (simulated feeding-left) ($p < 0.05$) ($d = 0.42$), JTHFT (stacking checkers-left) ($p < 0.05$) ($d = 0.52$), JTHFT (lifting light cans-left) ($p < 0.05$) ($d = 0.44$), and JTHFT (lifting weight cans-right/left) ($p < 0.05$) (right $d = 0.38$) (left $d = 0.37$) durations decreased in the NDT group. Upon comparing upper extremity functional skill tests and trunk control between the groups, no significant difference was found ($p > 0.05$, Table 3).

## 4. Discussion

This is the first study investigating the effect of PNF muscle strengthening training applied with scapular and upper extremity patterns and traditional NDT on functional skills, muscle strength, and trunk control in children with hemiparetic and diparetic CP. Strengthening training with PNF was found to improve upper extremity functional skills more than NDT by increasing the selective proximal muscle strength in the upper extremity and the strength of all distal muscles, grip strength, and trunk control. It was revealed that NDT did not increase muscle strength in the upper extremity but contributed to functional skills. However, PNF provided positive gains in upper extremity functional skills by further improving fine hand skills, in addition to muscle strength.

While upper extremity rehabilitation in CP is usually applied to children with hemiparetic CP, it remains in the background in children with bilateral CP. Although numerous effective treatment approaches

**Table 2**
Intra-group and inter-group comparison of upper extremity muscle strength.

| Variable | Group 1: PNF (n = 15) (Mean ± SD) (min-max) | Group 2: NDT (n = 15) (Mean ± SD) (min-max) | p[a] |
|---|---|---|---|
| Shoulder flexion (R) | | | |
| Before treatment | 8.93 ± 2.9 (3.3–13) | 8.43 ± 3.18 (4–16.2) | 0.52 |
| After treatment | 10.84 ± 3.33 (5.3–15.2) | 8.4 ± 3.58 (4.3–16.4) | 0.09 |
| p[b] | 0.004* | 0.754 | |
| d | 0.52 | 0.05 | |
| Shoulder flexion (L) | | | |
| Before treatment | 8.87 ± 2.89 (4.1–14.1) | 8.42 ± 3.25 (3.5–14.7) | 0.66 |
| After treatment | 15.64 ± 21.82 (5.3–94) | 8.38 ± 3.32 (2.9–15.2) | 0.06 |
| p[b] | 0.011* | 0.842 | |
| d | 0.46 | 0.03 | |
| Shoulder abduction (R) | | | |
| Before treatment | 9.32 ± 2.93 (2.4–16) | 8.76 ± 3.44 (3.1–16) | 0.32 |
| After treatment | 9.61 ± 2.75 (4.2–13.4) | 8.38 ± 3.27 (1.7–13.4) | 0.27 |
| p[b] | 0.426 | 0.378 | |
| d | 0.14 | 0.16 | |
| Shoulder abduction (L) | | | |
| Before treatment | 8.41 ± 2.76 (2.8–16.6) | 7.32 ± 2.79 (3.5–12.6) | 0.3 |
| After treatment | 8.87 ± 2.75 (4–13.1) | 7.09 ± 2.52 (2.9–11.2) | 0.08 |
| p[b] | 0.280 | 0.801 | |
| d | 0.19 | 0.04 | |
| Shoulder extension (R) | | | |
| Before treatment | 8.79 ± 3.2 (3.3–14) | 9.38 ± 3.58 (4.9–16.5) | 0.74 |
| After treatment | 9.1 ± 2.94 (4–13.5) | 8.1 ± 2.47 (3.2–12) | 0.28 |
| p[b] | 0.258 | 0.124 | |
| d | 0.20 | 0.27 | |
| Shoulder extension (L) | | | |
| Before treatment | 8.34 ± 3.69 (2.8–16.8) | 9.7 ± 4.08 (4.3–17.4) | 0.36 |
| After treatment | 9.68 ± 3.13 (3.9–14.7) | 8.63 ± 2.49 (3.6–11.9) | 0.29 |
| p[b] | 0.088 | 0.363 | |
| d | 0.31 | 0.16 | |
| Shoulder adduction (bilateral) | | | |
| Before treatment | 10.51 ± 4.43 (3.9–15.8) | 14.62 ± 16.83 (5–73) | 0.77 |
| After treatment | 12.68 ± 4.98 (5–20.9) | 10.58 ± 5.3 (4.2–21) | 0.22 |
| p[b] | 0.009* | 1.000 | |
| d | 0.47 | 0 | |
| Shoulder internal rotation (R) | | | |
| Before treatment | 7.69 ± 2.82 (4–13.5) | 6.8 ± 2.03 (4–10.4) | 0.49 |
| After treatment | 7.7 ± 2.16 (3.2–11.3) | 6.54 ± 2.36 (3.5–11.1) | 0.08 |
| p[b] | 0.691 | 0.529 | |
| d | 0.07 | 0.11 | |
| Shoulder internal rotation (L) | | | |
| Before treatment | 7.94 ± 2.66 (3.3–11.7) | 7.34 ± 2.24 (3.9–12.1) | 0.45 |
| After treatment | 8.54 ± 2.45 (4–11.6) | 7.5 ± 2.58 (3.6–12) | 0.25 |
| p[b] | 0.510 | 0.649 | |
| d | 0.11 | 0.08 | |
| Shoulder external rotation (R) | | | |

(continued on next page)

**Table 2** (*continued*)

| Variable | Group 1: PNF (n = 15) (Mean ± SD) (min-max) | Group 2: NDT (*n* = 15) (Mean ± SD) (min-max) | p[a] |
|---|---|---|---|
| Before treatment | 5.44 ± 1.65 (2.5–7.4) | 4.78 ± 1.38 (2.-6.7) | 0.23 |
| After treatment | 6.1 ± 1.36 (3.4–7.9) | 4.94 ± 1.52 (2.2–7.2) | 0.04* |
| p[b] | 0.060 | 0.509 | |
| d | 0.34 | 0.12 | |
| Shoulder external rotation (L) | | | |
| Before treatment | 5.44 ± 2.28 (1.4–10) | 5.49 ± 1.68 (2.8–8.8) | 0.91 |
| After treatment | 5.63 ± 1.52 (3–8.8) | 4.89 ± 1.5 (3–8.3) | 0.10 |
| p[b] | 0.167 | 0.201 | |
| d | 0.25 | 0.23 | |
| Shoulder elevation (R) | | | |
| Before treatment | 11.28 ± 4.03 (5.1–17) | 10.65 ± 4.45 (3.5–18.8) | 0.70 |
| After treatment | 13.26 ± 3.85 (7–19) | 10.14 ± 2.52 (6.6–15.3) | **0.02*** |
| p[b] | 0.005* | 0.691 | |
| d | 0.25 | 0.23 | |
| Shoulder elevation (L) | | | |
| Before treatment | 10.84 ± 4.17 (4.6–17.9) | 11.24 ± 3.9 (4.5–19.9) | 0.86 |
| After treatment | 11.83 ± 2.44 (6–14.4) | 10.93 ± 3.74 (4.6–17.75) | 0.40 |
| p[b] | 0.118 | 0.615 | |
| d | 0.28 | 0.09 | |
| Scapular abduction (R) | | | |
| Before treatment | 5.62 ± 2 (3.1–8.7) | 5.68 ± 2.3 (2.3–13) | 0.69 |
| After treatment | 6.96 ± 2.99 (2.8–12.9) | 5.19 ± 2.04 (2.8–10.2) | 0.08 |
| p[b] | 0.015* | 0.909 | |
| d | 0.50 | 0.02 | |
| Scapular abduction (L) | | | |
| Before treatment | 6.12 ± 2.15 (3–9.9) | 5.6 ± 2.18 (2.2–9) | 0.54 |
| After treatment | 7.28 ± 2.92 (4.1–13.3) | 5.62 ± 2.54 (2.3–10.2) | 0.12 |
| p[b] | 0.029* | 0.776 | |
| d | 0.39 | 0.05 | |
| Scapular adduction (R) | | | |
| Before treatment | 4.95 ± 1.6 (2.2–8.3) | 4.53 ± 1.64 (2.2–8) | 0.29 |
| After treatment | 6.03 ± 2.17 (2.9–9.9) | 5.04 ± 1.95 (2.2–9.9) | 0.22 |
| p[b] | 0.065 | 0.125 | |
| d | 0.33 | 0.27 | |
| Scapular adduction (L) | | | |
| Before treatment | 4.82 ± 1.6 (2.9–8.3) | 4.34 ± 2.02 (1.6–8.3) | 0.44 |
| After treatment | 5.56 ± 1.37 (3.5–7.5) | 3.92 ± 1.77 (1.6–7.1) | 0.01* |
| p[b] | 0.012 | 0.689 | |
| d | 0.45 | 0.07 | |
| Elbow flexion (R) | | | |
| Before treatment | 8.3 ± 3.38 (4.4–15.4) | 7.34 ± 2.7 (2.5–12.6) | 0.6 |
| After treatment | 8.74 ± 2.63 (5.2–14.5) | 7.44 ± 2.10 (3.9–11) | 0.15 |
| p[b] | 0.210 | 0.609 | |
| d | 0.22 | 0.09 | |
| Elbow flexion (L) | | | |
| Before treatment | 8.59 ± 2.35 (4.2–11.4) | 8.29 ± 2.9 (3.8–14) | 0.52 |
| After treatment | 9.8 ± 3.92 (5–19.1) | 8.31 ± 3.24 (4–14) | 0.39 |
| p[b] | 0.191 | 0.733 | |
| d | 0.23 | 0.06 | |
| Elbow extension (R) | | | |
| Before treatment | 8.09 ± 2.33 (31–10.9) | 7.5 ± 2.73 (2–10.9) | 0.42 |
| After treatment | 9.38 ± 3.14 (3.7–13.9) | 8.01 ± 2.8 (2.95–13.9) | 0.17 |
| p[b] | 0.017* | 0.222 | |
| d | 0.43 | 0.22 | |
| Elbow extension (L) | | | |
| Before treatment | 8.8 ± 2.54 (5.6–12.4) | 8.04 ± 2.55 (3.9–13.8) | 0.29 |
| After treatment | 9.68 ± 3.34 (3.9–15.1) | 7.99 ± 2.62 (4–13.6) | 0.11 |
| p[b] | 0.088 | 0.777 | |
| d | 0.31 | 0.05 | |
| Wrist extension (R) | | | |
| Before treatment | 4.6 ± 2.19 (0–8.9) | 5.33 ± 1.73 (2–8.9) | 0.41 |
| After treatment | 5.37 ± 1.49 (2.1–7.5) | 4.94 ± 1.59 (2.6–7.2) | 0.37 |
| p[b] | 0.073 | 0.426 | |
| d | 0.32 | 0.14 | |
| Wrist extension (L) | | | |
| Before treatment | 5.18 ± 3.42 (0.5–11.6) | 5.6 ± 2 (3–9.7) | 0.28 |
| After treatment | 6.1 ± 2.7 (2.9–10.4) | 4.9 ± 1.31 (2.4–6.6) | 0.46 |
| p[b] | 0.105 | 0.327 | |
| d | 0.29 | 0.17 | |
| Wrist flexion (R) | | | |
| Before treatment | 5.19 ± 1.67 (1.5–7.5) | 5.18 ± 1.19 (3.3–8) | 0.83 |
| After treatment | 5.36 ± 1.5 (2.5–9) | 4.88 ± 1.19 (2.4–6.9) | 0.31 |
| p[b] | 0.073 | 0.426 | |
| d | 0.33 | 0.12 | |
| Wrist flexion (L) | | | |
| Before treatment | 5.54 ± 2.31 (2.2–9.7) | 8.24 ± 10.3 (3.5–45) | 0.41 |
| After treatment | 5.93 ± 1.9 (3.1–9.1) | 5.04 ± 1.6 (2–7.1) | 0.26 |
| p[b] | 0.330 | 0.330 | |
| d | 0.17 | 0.17 | |
| Grip strength (R) | | | |
| Before treatment | 9.1 ± 4.92 (1–14) | 10.388.24 ± 4.98 (1.33–19.3) | 0.70 |
| After treatment | 10.56 ± 5.97 (2–21.3) | 11.6 ± 5.76 (3–22.6) | 0.58 |
| p[b] | 0.005* | 0.037* | |
| d | 0.51 | 0.38 | |
| Grip strength (L) | | | |
| Before treatment | 7.95 ± 5.98 (0–18) | 9.568.24 ± 4.26 (1.66–17.3) | 0.40 |
| After treatment | 9.79 ± 6.33 (1−20) | 10.63 ± 5.53 (2.66–24) | 0.67 |
| p[b] | 0.001* | 0.032* | |
| d | 0.58 | 0.39 | |
| Pinch grip (R) | | | |
| Before treatment | 2.13 ± 1.53 (0–5.6) | 2.698.24 ± 1.71 (0.5–5.6) | 0.60 |
| After treatment | 2.88 ± 1.41 (0–5) | 2.57 ± 1.59 (0.5–6) | 0.42 |
| p[b] | 0.011* | 0.972 | |
| d | 0.46 | 0.01 | |
| Pinch grip (L) | | | |

(*continued on next page*)

Table 2 (*continued*)

| Variable | Group 1: PNF (n = 15) (Mean ± SD) (min-max) | Group 2: NDT (*n* = 15) (Mean ± SD) (min-max) | p[a] |
|---|---|---|---|
| Before treatment | 2.04 ± 1.4 (0–4.6) | 2.058.24 ± 1.72 (0–6.3) | 0.88 |
| After treatment | 3.04 ± 2.2 (1–8) | 2.27 ± 1.43 (0–4.5) | 0.39 |
| p[b] | **0.017*** | 0.172 | |
| d | 0.43 | 0.24 | |

PNF: proprioceptive neuromuscular facilitation, NDT: neurodevelopmental therapy, R: right, L: left.
[a] Mann Whitney U.
[b] Wilcoxon ($p < 0.05$).

have been recently developed in the upper extremity rehabilitation of individuals with CP, treatments for upper extremity strengthening training are still needed. Secondary complications such as decreased joint movements, cardiovascular endurance, and muscle strength are also observed in CP, in addition to increased muscle tone. Muscle spasticity and weakness are observed together. It has been observed that randomized controlled trials (RCTs) with high levels of evidence, including upper extremity strengthening training in CP, are limited [2,4,27]. Based on these studies, there are no consistent recommendations regarding training types, intensity level, and duration for strength training. All reported upper extremity strengthening training was found to increase muscle strength. It is expressed that more RCTs are needed to assess the impact and potential of upper extremity strengthening training improving daily activities and participation in children with CP [2,4,27]. It is known that in the studies conducted, upper extremity strengthening training is combined with electrical stimulation or Btx and is applied in the form of functional strengthening training, isolated muscle strengthening training, or independent strength training [2,4,27,28]. The studies show that the type of strengthening exercises consists of task-oriented strengthening exercises, including a wide variety of exercises, from isokinetic exercises to concentric and eccentric single-joint exercises [1,2,4,27]. Furthermore, it is remarkable that mostly wrist and elbow flexors and extensors are trained [27]. Additionally, studies only on strengthening have reported no results regarding the upper extremity-related activity level [1,2,4,27]. Elvrum et al. investigated the effects of additional resistance training after Btx with the training of single-joint resistance training (using hand-held, free weights) for strengthening of elbow flexors and extensors, forearm pronators and supinators, and wrist flexors and extensors and grip force. They reported that only elbow extension and supination strength increased with single joint resistance training, and active range of supination also increased [28]. Moreau et al. investigated the effects of muscle endurance, range of motion exercises combined with resistance training of shoulder abduction, flexion, extension, and elbow extension in children with CP at the level of GMFCS IV and MACS III. They found that both upper extremity muscle mass and active range of motion at the wrists, elbows, and shoulders had risen. They reported that improvements were also made in terms of reaching accuracy and speed as well as upper extremity explosive force production [29]. These studies show the potential improvements of the resistance training of proximal parts of upper extremity. But as far as is known, there is no research in the literature examining the effects of PNF and scapular girdle and upper extremity strengthening training in children with CP [1,2,4]. Only Sant et al. explored the effectiveness of combined surge faradic stimulation and PNF approach on for wrist extensors and hand functions in a hemiplegic CP children [30]. They stated hand function skills and trunk control was improved, also spasticity was decreased in hemiplegic CP children [30]. But this study also used goal-directed exercise program, surge faradic stimulation, PNF and neurodevelopmental techniques for gross and fine motor activities of hand different from our study. The present study found that upper extremity strengthening training with

**Table 3**
Intra-group and intergroup comparison of upper extremity functional skills and trunk control measurement.

| Variable | Group 1: PNF (n = 15) (Mean ± SS) (min-max) | Group 2: NDT (n = 15) (Mean ± SS) (min-max) | p[a] |
|---|---|---|---|
| 9-HPT (R) | | | |
| Before treatment | 48.6 ± 40.91 (19.11–145) | 40.19 ± 27.49 (17.74–129.73) | 0.96 |
| After treatment | 33.31 ± 16.8 (16.23–64.94) | 36.01 ± 15.45 (17.39–61.68) | 0.66 |
| p[b] | 0.003* | 0.256 | |
| d | 0.53 | 0.20 | |
| 9-HPT (L) | | | |
| Before treatment | 44.72 ± 26.62 (16.6–92.27) | 44.59 ± 24.38 (19.23–89) | 0.93 |
| After treatment | 40.22 ± 25.43 (14.2–94.06) | 44.83 ± 26.57 (18.45–91.75) | 0.61 |
| p[b] | 0.012* | 0.233 | |
| d | 0.45 | 0.21 | |
| PBPT (R) | | | |
| Before treatment | 8.73 ± 3.43 (3–13) | 8.53 ± 3.48 (2–15) | 0.75 |
| After treatment | 10.06 ± 3.86 (4–15) | 9.2 ± 3.89 (2–16) | 0.54 |
| p[b] | 0.001* | 0.021* | |
| d | 0.62 | 0.42 | |
| PBPT (L) | | | |
| Before treatment | 7.46 ± 3.39 (3–13) | 8.53 ± 3.11 (4–14) | 0.38 |
| After treatment | 9 ± 3.85 (4–16) | 8.73 ± 3.36 (4–14) | 0.88 |
| p[b] | 0.002* | 0.439 | |
| d | 0.56 | 0.14 | |
| PBPT (bimanual) | | | |
| Before treatment | 5 ± 2.5 (2–10) | 5.06 ± 2.31(1–9) | 0.81 |
| After treatment | 5.6 ± 2.61 (2–12) | 5.26 ± 2.37 (1–9) | 0.83 |
| p[b] | 0.013* | 0.180 | |
| d | 0.45 | 0.24 | |
| PBPT (assembly) | | | |
| Before treatment | 18.4 ± 8.82 (8–32) | 19.6 ± 10.74 (2–38) | 0.73 |
| After treatment | 20.33 ± 9.02 (10–34) | 19.93 ± 9.84 (4–38) | 0.81 |
| p[b] | 0.005* | 0.916 | |
| d | 0.51 | 0.01 | |
| Abilhand | | | |
| Before treatment | 32.4 ± 8.71 (18–42) | 35 ± 5.61 (25–42) | 0.66 |
| After treatment | 36 ± 6.12 (24–42) | 34.8 ± 4.7 (26–42) | 0.35 |
| p[b] | 0.003* | 0.766 | |
| d | 0.53 | 0.05 | |
| TCMS | | | |
| Before treatment | 44.46 ± 6.44 (33–54) | 45 ± 8.59 (23–56) | 0.55 |
| After treatment | 50.46 ± 4.48 (42–56) | 45.66 ± 8.78 (23–56) | 0.12 |
| p[b] | 0.001* | 0.245 | |
| d | 0.62 | 0.21 | |
| JTHFT (card turning-R) | | | |
| Before treatment | 12.02 ± 8.64 (3.24–34.15) | 7.39 ± 2.87 (3.01–12.25) | 0.19 |
| After treatment | 9.95 ± 7.35 (4.45–30.12) | 7.14 ± 3.12 (3–14.81) | 0.41 |
| p[b] | 0.004* | 0.222 | |
| d | 0.52 | 0.22 | |

(*continued on next page*)

**Table 3** (*continued*)

| Variable | Group 1: PNF (n = 15) (Mean ± SS) (min-max) | Group 2: NDT (n = 15) (Mean ± SS) (min-max) | p[a] |
|---|---|---|---|
| JTHFT (card turning-L) | | | |
| Before treatment | 15.68 ± 125.14 (3.47–496) | 8.22 ± 3.11 (3.47–13.53) | 0.14 |
| After treatment | 10.78 ± 9.7 (4.01–42.1) | 8.02 ± 3.16 (3.92–14.3) | 0.96 |
| p[b] | 0.006* | 0.43 | |
| d | 0.49 | 0.13 | |
| JTHFT (lifting small objects-R) | | | |
| Before treatment | 14.65 ± 12.23 (4.73–53.07) | 10.2 ± 2.79 (4.73–15.96) | 0.67 |
| After treatment | 12.3 ± 8 (5.01–33.5) | 9.88 ± 3.07 (5.01–16.88) | 0.96 |
| p[b] | 0.053 | 0.293 | |
| d | 0.35 | 0.19 | |
| JTHFT (lifting small objects-L) | | | |
| Before treatment | 15.48 ± 10.65 (5.29–38.35) | 10.37 ± 5.16 (5.29–26.77) | 0.17 |
| After treatment | 15.05 ± 11.8 (4.9–48.46) | 11.62 ± 7.04 (4.9–26.65) | 0.61 |
| p[b] | 0.307 | 0.733 | |
| d | 0.18 | 0.06 | |
| JTHFT (simulated feeding-R) | | | |
| Before treatment | 34.86 ± 35.27 (8.3–101.3) | 19.15 ± 11.28 (8.63–52.56) | 0.43 |
| After treatment | 20.11 ± 13.27 (6.71–42.99) | 18.3 ± 11.07 (9.12–48.86) | 0.90 |
| p[b] | 0.009* | 0.307 | |
| d | 0.47 | 0.18 | |
| JTHFT (simulated feeding-L) | | | |
| Before treatment | 29 ± 18.52 (6.92–60.31) | 22.46 ± 14.19 (8.95–65) | 0.43 |
| After treatment | 22.79 ± 12.81 (6.65–42.95) | 20.21 ± 14.12 (9.17–62) | 0.5 |
| p[b] | 0.005* | 0.020* | |
| d | 0.50 | 0.42 | |
| JTHFT (stacking checkers-R) | | | |
| Before treatment | **7.7** ± 4.9 (3.09–17.89) | 5.77 ± 2.36 (3.09–10.4) | 0.54 |
| After treatment | 7.23 ± 4.74 (2.85–18.9) | 5.58 ± 2.05 (3.05–9.87) | 0.74 |
| p[b] | 0.191 | 0.670 | |
| d | 0.23 | 0.07 | |
| JTHFT (stacking checkers-L) | | | |
| Before treatment | 10.82 ± 10.01 (3.55–38.8) | 7.11 ± 3.34 (3.16–13.5) | 0.90 |
| After treatment | 8.68 ± 6.19 (2.9–20.52) | 6.17 ± 2.87 (3.33–11.98) | 0.48 |
| p[b] | 0.125 | 0.004* | |
| d | 0.27 | 0.52 | |
| JTHFT (lifting light cans-R) | | | |
| Before treatment | 7.96 ± 4.37 (3.8–18.75) | 6.37 ± 2.31 (3.8–11.68) | 0.48 |
| After treatment | 6.53 ± 3.41 (3.23–15.2) | 5.67 ± 1.75 (2.86–9.03) | 0.91 |
| p[b] | 0.001* | 0.011 | |
| d | 0.61 | 0.46 | |
| JTHFT (lifting light cans-L) | | | |
| Before treatment | 7.98 ± 4.26 (3.35–18.82) | 6.60 ± 2.53 (3.35–11.33) | 0.56 |
| After treatment | 6.51 ± 2.8 (3.03–13.5) | 6.06 ± 2.25 (3.03–11.01) | 0.80 |
| p[b] | 0.002* | 0.015* | |
| d | 0.57 | 0.44 | |
| JTHFT (lifting weight cans-R) | | | |
| Before treatment | 10.35 ± 8.49 (3.56–35.15) | 8.21 ± 5.36 (3.29–23.25) | 0.69 |
| After treatment | 8.74 ± 6.12 (3.55–25.33) | 7.66 ± 5.59 (3.55–25.29) | 0.77 |
| p[b] | 0.015* | 0.036* | |
| d | 0.44 | 0.38 | |
| JTHFT (lifting weight cans-L) | | | |
| Before treatment | 8.97 ± 5.21 (3.51–19.95) | 8.3 ± 5.8 (3.51–27.2) | 0.64 |
| After treatment | 7.29 ± 3.84 (3.55–17.5) | 7.81 ± 5.63 (3.55–26.89) | 0.96 |
| p[b] | 0.002* | 0.041* | |
| d | 0.57 | 0.37 | |

PNF: proprioceptive neuromuscular facilitation, NDT: neurodevelopmental therapy, R: right, L: left, 9-HPT: Nine-Hole Peg Test, PBPT: Purdue Pegboard Test, TCMS: Trunk Control Measurement Scale, JTHFT: Jebsen-Taylor Hand Function Test.

[a] Mann Whitney U.

[b] Wilcoxon ($p < 0.05$).

the PNF approach increased upper extremity proximal and distal muscle strength and grip strength and also increases upper extremity functionality in children with hemiparetic and diparetic CP. In this respect, it is recommended to add the PNF approach to rehabilitation programs. Studies have determined that PNF training usually has positive effects on lower extremities, selective motor control, gait and balance in children with CP [12,13,31–34].

Treatments targeting upper extremity function in children with CP aim to enhance functional skills, support functional independence, or decrease muscle tone. CIMT, bimanual training, virtual reality and computer-based training, or combinations of these treatments with Btx are the frequently reported treatments [1,2,11,14,35]. However, the current studies on upper extremity functions mainly focus on children with hemiparetic CP [11]. There is strong evidence that HABIT (hand-arm bimanual intensive therapy) is the most effective rehabilitation method in children with bilateral CP [11]. Additionally, it is known that HABIT-ILE (HABIT-including lower extremities), robotic therapy, intrathecal baclofen (ITB), Btx, hippotherapy, virtual reality, ergotherapy, and transcranial magnetic stimulation methods are used in children with bilateral CP [11]. Most review studies have stated that HABIT-ILE is moderately effective in enhancing dexterity, fine motor control and personal care, and repetitive transcranial magnetic stimulation is moderately effective in improving passive joint movement, while ITB and physiotherapy are effective in enhancing upper extremity coordination, arm and fine dexterity [11,36].

However, reviews recommend conducting more studies with high-quality multicenter RCTs aimed at bimanual intensive, target-oriented, and task-specific training programs for the upper extremity in children with bilateral CP [11]. In our study designed in this respect, it was observed that the PNF approach improved upper extremity functional skills, coordination, and hand functions more than NDT, and the PNF approach was more effective in terms of fine motor skills. It is indicated that strengthening training in children with CP should improve upper extremity functional skills enhancing daily activities and participation [27]. Meta-analysis study shows that activity-based and body structure and function interventions are more effective than NDT for improving motor function [37]. Park et al. investigated the effectiveness of the NDT on the upper and lower extremity muscle tone, strength, and also gross motor function in children with spastic CP. Then they stated that spasticity was significantly reduced, the GMFCS I–II level group showed a significant increase in muscle strength compared with the GMFCS levels III–V, and the latter showed a significant decrease in spasticity compared with the former [38]. However, this study did not specify which muscle groups increased muscle strength.

Trunk control, reaching for objects, manipulation, grasping, and releasing skills are necessary for ADLs, such as feeding and dressing. The trunk ensures stability within the support surface to allow free movements of the entire upper extremity and hand. Studies have shown that children with CP have insufficient trunk control [39–42]. Nevertheless, the impact of trunk control on upper extremity functions in these children is not yet completely known. It has been shown in the literature that trunk control is associated with upper extremity functions in children with CP [39,40]. Hence, trunk control should definitely be considered in the upper extremity rehabilitation plan since it may also be the cause of problems with upper extremity functions. NDT, hippotherapy, functional training, therapies stimulating postural reactions, pilates, virtual reality, visual biofeedback, bodyweight gait systems, electrical stimulation, kinesio taping, robotic therapy, and conventional physiotherapy methods are employed for trunk training in CP [43,44]. In the literature, the low effects of upper extremity training on the trunk are reported [44]. Our study found that upper extremity training with PNF significantly improved trunk control, whereas there was no change in trunk control in the NDT group. The above-mentioned results indicated that PNF training, involving the proximal muscle girdle, has positive results on the entire trunk and should be added to rehabilitation programs. There is only one study comparing the effect of target-oriented trunk exercises and the PNF approach on trunk control, and this study revealed that task-oriented training was superior [45,46]. Our study suggested that PNF might be an alternative to task-oriented training by showing that it increases trunk control.

Although PNF is an important neurophysiological physiotherapy approach, there are very few studies conducted on spastic CP. All of these studies include the PNF involving the lower extremities and trunk. However, the PNF approach is also applied in upper extremity rehabilitation, and as far as is known, it is the first study to investigate its effect in CP. The effective PNF treatment method determined by this study can ensure that upper extremity dysfunctions are reduced and individuals' adaptation to daily life is accelerated, and they catch up with their peers in terms of muscle strength and functional skills in the shortest time.

One of our study's limitations is that it included spastic CP types. Hence, it is recommended to conduct further studies comparing the PNF approach with other strengthening methods in CP children with different clinical types, different dexterity levels, and mobility levels on larger samples in upper extremity rehabilitation in CP.

## 5. Conclusion

The present study concluded that the PNF approach improved grip strength and upper extremity functional skills by increasing selective proximal muscle strength and all of the distal upper extremity muscle strength and trunk control. It was shown that NDT did not impact muscle strength increase and trunk control and did not contribute to fine hand skills, although it enhanced upper extremity skills.

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## Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The Clinical Research Ethics Committee of XXXXX University Faculty of Medicine was approved the study (Session: 2021/09, Decision No: 01).

## Consent to participate

Informed consent was obtained from all participants' parents included in the study.

## CRediT authorship contribution statement

**Hatice Adiguzel:** Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Zekiye Ipek Katirci Kirmaci:** Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mehmet Gogremis:** Writing – review & editing, Validation, Supervision, Project administration. **Yusuf Sinasi Kirmaci:** Writing – review & editing, Visualization, Supervision, Methodology. **Cengiz Dilber:** Writing – review & editing, Supervision, Data curation. **Deniz Tuncel Berktas:** Writing – review & editing, Visualization, Project administration, Data curation.

## Declaration of competing interest

No conflict of interest was declared by the authors.

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