JBACHS
Journal of Basic and Clinical Health Sciences

J Basic Clin Health Sci 2022; 6: 238-246
https://doi.org/10.30621/jbachs.1000917
RESEARCH ARTICLE

PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION TRAINING IMPROVES SCAPULAR MUSCLE STRENGTH AND PECTORALIS MINOR LENGTH IN INDIVIDUALS WITH ASYMPTOMATIC SCAPULAR DYSKINESIS

Nazli Busra Cigercioglu[1,2], Ezgi Unuvar[2], Polen Hazimoglu[3], Firat Tan[2], Hasan Erkan Kilinc[4], Hande Guney-Deniz[2]

[1] Ankara Private Guven Hospital, Ankara, Turkey
[2] Hacettepe University, Faculty of Physical Therapy and Rehabilitation, Musculoskeletal Rehabilitation Department, Ankara, Turkey
[3] Yalova University, Faculty of Health Sciences, Department of Therapy and Rehabilitation, Yalova, Turkey
[4] Lokman Hekim University, Faculty of Health Sciences, Physiotherapy and Rehabilitation Department, Ankara, Turkey

Corresponding Author: Nazli Busra Cigercioglu, PT, MSc., **E-mail:** nazlicigercioglu@hacettepe.edu.tr
Received: 26.08.2021; **Accepted:** 09.01.2022; **Available Online Date:** 27.01.2022

Cite this article as: Cigercioglu NB, Unuvar E, Hazimoglu P, Tan F, Kilinc HE, Guney-Deniz H. Proprioceptive Neuromuscular Facilitation Training Improves Scapular Muscle Strength and Pectoralis Minor Length in Individuals with Asymptomatic Scapular Dyskinesis. J Basic Clin Health Sci 2022; 6: 238-246.

ABSTRACT

Purpose: Scapular dyskinesis is defined as alteration in scapular movements due to the loss of strength in scapular muscles; tightness of the soft tissues around shoulder and postural problems. Proprioceptive neuromuscular facilitation (PNF) is one of the therapeutic exercises to improve muscles weakness and pain levels. The aim of this study was to investigate the effects of a six-week PNF application on scapular muscle strength, scapular asymmetry, and pectoralis minor (PM) muscle tightness in participants with asymptomatic scapular dyskinesis.
Methods: Twenty-five asymptomatic participants were evaluated using the video analysis method to determine the scapular dyskinesis. Eleven of them diagnosed with scapular dyskinesis and recruited for the PNF application. Lateral scapular slide test (LSST); tightness of PM; the muscle strength of serratus anterior (SA); lower trapezius (LT) and upper trapezius (UT) were evaluated. Anterior elevation-posterior depression; posterior elevation-anterior depression of PNF patterns were applied as repeated contractions technique by 2 times a week for 6 weeks.
Results: The LT (p=0.012) and SA (p=0.035) muscle strength increased following PNF training, while UT muscle strength was similar (p>0,05). The UT/SA (p=0.035) and UT/LT (p=0.012) strength ratios decreased following PNF application. The mean differences of PM tightness and LSST did not exceed the established $MDC_{\%95.}$
Conclusion: Scapular muscle balance improved following scapular PNF training. Therefore, scapular PNF patterns would be considered as an alternative treatment option to provide scapular stabilization and increase muscle strength.
Keywords: Shoulder, scapula, rehabilitation, pectoralis muscle.

INTRODUCTION

The position and moving of the scapula should be in harmony with the motion of the arm for the proper movement of shoulder complex. This movement in other words scapulohumeral rhythm, is mostly based on synergistic coordination between the upper and lower trapezius, rhomboids, and serratus anterior muscles (1). Scapular dyskinesis alters the kinematics of the glenohumeral and acromioclavicular joints, resulting with reduce of periscapular muscles and rotator cuff muscle strength (2,3). Scapular dyskinesis has been associated with various problems such as acromioclavicular instability, shoulder impingement syndrome, rotator cuff injuries, glenoid labrum injuries, clavicle fractures, and neck-related or posture-related injuries (4). It is commonly seen in the asymptomatic population (5).

Tightness of pectoralis minor (PM) and muscle imbalances are another important biomechanical change that related to scapular dyskinesis (6). PM tightness has been linked to scapular internal rotation and anterior tilt during shoulder elevation (7). Researchers also reported that stretching the PM muscle increases external rotation and posterior tilt of the scapula during shoulder elevation (8). The shortening of the PM alters the scapular kinematics and causes a movement pattern like those with subacromial impingement syndrome (9). Therefore, it is important to optimize the length of PM muscle for gaining the normal scapular kinematics.

Proprioceptive neuromuscular facilitation (PNF) exercises are designed to facilitate the neuromuscular response of the proprioceptors and its diagonal patterns are in line with the topographic orientation of the muscles (10). PNF training proposed to facilitate muscle performance through its movement patterns (11,12). Research showed that PNF training is more efficient than conventional exercise training to improve muscle performance, to relieve pain, to enhance balance, and to increase range of motion (ROM) (13-19). It is stated that scapular PNF patterns are effective in improving shoulder function and ROM, as well as reducing pain immediately in patients with adhesive capsulitis (20). Combination of PNF training with exercise programs is found to be more effective in patients with post-traumatic elbow stiffness in terms of function, elbow flexion, active ROM, and pain (21).

Although PNF is a frequently used treatment method in clinics, its use in individuals with scapular dyskinesis and the effects on muscle strength and scapular muscle strength are unknown. Therefore, this study aims to examine the effects of the scapular PNF training method on muscle strength and PM muscle tightness in individuals with scapular dyskinesis. We hypothesized that after a 6-week PNF training subjects with asymptomatic scapular dyskinesis would demonstrate higher scapular muscle strength, balanced muscle strength ratio, decreased scapular asymmetry and increased PM length.

METHODS

A single group repeated-measure and single blind design was used for this study. Data were obtained between December 2020 and March 2021. Ethics Board of Lokman Hekim University (2020086) was approved the study. A priori sample size calculation was conducted with G-Power 3.1.9.2 (University of Kiel, Germany) using this data for Wilcoxon test, a power of 0.80, an alpha of 0.05, and determined that at least 12 participants were needed in the present study. All participants read and signed informed consent. The study was registered to Clinical Trials with the ID of NCT04622800.

Participants

Twenty-five asymptomatic individuals were evaluated using the video analysis method to determine the scapular dyskinesis. Eleven of them diagnosed with scapular dyskinesis and recruited for the PNF application.

Inclusion criteria for participants; aged between 18-30 year and having Type I or Type II scapular dyskinesis. Exclusion criteria follows; having any pain related to shoulder or scapulothoracic region, having acute orthopedic upper extremity injury in last three weeks, having any history of upper extremity surgery.

Video analyzing of scapular dyskinesis

Participants were videotaped from their back while standing in normal position with a camera (Canon EOS 650D, Canon, Tokyo, JP) fixed on a tripod, which 150 cm height from floor and 204 cm away from the participants. The data were collected at a sample rate of 60 frame per second. The test was performed at sufficiently enlightened room to ensure scapular movement. The participants evaluated during bilateral overhead arm elevation with a dumbbell in scaption position (45° anterior to the frontal plane). Scaption position was evaluated during familiarization session with a goniometer and ensure during test by tester. Arm elevation was performed with 2.5 kg dumbbell for participants with more than 68 kg and 1.5 kg dumbbell for less than 68 kg. Participants were allowed three familiarization trials before test and after that performed five successful trials for test. The movement speed was determined by the metronome and the participants were asked to elevate his/her arm within three seconds and lower it again within three seconds in a synchronized manner. The recordings were by the same physiotherapist (HEK). Four different physiotherapists (EU, FT, PH, HGD) evaluated the records separately and the presence and type of scapular dyskinesis was determined (three of the physiotherapists had five years-experience and the senior author had a 14-year experience in this field). Participants, who all physiotherapists had a consensus on the same type of scapular dyskinesis were included in the study. Participants diagnosed with Type I scapular dyskinesis if they had prominence of the inferior medial scapular angle. Participants diagnosed with Type II scapular dyskinesis if they had prominence of entire medial scapular border (22).

Pectoralis Minor Tightness Measurement

PM tightness was evaluated bilaterally while participant standing in relaxed position. The distance between the coracoid process and forth rib was measured with a tape (23). Measurements were repeated three times and the average value was recorded.

Lateral Scapular Slide Test

Scapular asymmetry was evaluated with lateral scapular slide test (LSST). The LSST evaluated at three different arm positions. At position 1, both arms placed in glenohumeral neutral position on the side; at position 2 the hands placed waist with the thumbs facing back and humerus in medial rotation at 45° abduction; at position 3 both arms evaluated 90° abduction with maximum internal rotation. Measurement of scapular asymmetry was recorded bilaterally with a tape measure from the inferior scapular angle to the spinous process of vertebra in the same horizontal plane in all three tests position. Measurements were repeated three times and the average value was recorded. To measure scapular asymmetry, extremity differences was calculated. This difference was used for statistical analysis. A bilateral difference of greater than 1.5 cm was used to determine positive LSST (24).

Scapular Muscle Strength Tests

Scapular muscle strength evaluated as previously reported by hand-held dynamometer (*Nicholas Manuel Muscle Tester, Lafayette Indiana Instruments*) (25). The participants were placed at scapular midrange position to optimize length-tension relationship and instructed to generate maximum isometric force against the dynamometer. All tests repeated three times and average value was recorded.

The upper trapezius (UT) muscle strength test was performed at sitting position. The dynamometer was placed on the superior scapula. The participants were asked to lift their shoulder with a maximum strength against the dynamometer. Force was applied downward in direction to scapular depression movement (25). The lower trapezius (LT) muscle strength was evaluated in prone position with shoulder elevated 140° and thump faced up. The dynamometer was placed over scapular spine in between the acromion and the root of spine of the scapula and participants was asked to lift their arm with maximum strength. Force was applied along the humerus long axis parallel to the ground (25). The serratus anterior (SA) muscle strength was evaluated in supine position with shoulder and elbow flexed at 90°. The force was applied to the olecranon process of ulna along the long axis of humerus and the participants were asked to lift their elbow with maximum strength. Activation of triceps muscles was not allowed through observation and palpation of the muscle to ensure that only SA muscle generate the force (25).

PNF Intervention

Anterior Elevation-Posterior Depression and Anterior Depression-Posterior Elevation Patterns of Scapula were applied with repeated contractions technique (Appendix A). Each pattern was repeated 10 times, with a 2-minute rest break. The PNF was applied 2 times a week for a total of 6 weeks. The same physiotherapist was applied the PNF to all individuals and this physiotherapist did not know the diagnosis, affected side or any medical condition of the individuals for blindization (NBC).

For the level of perceived resistance, the Rated Perceived Exertion (RPE), (graded between 0-10, 0=no effort at all, 10= very, very hard, maximal effort), was used to determine, and the perceived effort level was set to 5-6 (somewhat hard) to ensure standardization.

Pectoralis minor tightness, scapular asymmetry and scapular muscle strength were evaluated before the application, at 6th weeks following PNF application and 12th weeks. There were no PNF application applied between 6th and 12th weeks period.

Statistical Analysis

Data were visually analyzed with histograms, Q-Q plots and Shapiro-Wilk tests for normality of the distribution. Friedman analysis of variance by ranks tests were conducted to test whether there was a significant change in the PM tightness, LSST, UT/SA and UT/LT strength ratios use to violation of parametric tests assumptions (non-normal distribution and low number cases, respectively). The Wilcoxon test was performed to test the significance of pairwise differences using Bonferroni correction to adjust for multiple comparisons. An overall 0.05 type-I error level was used to infer statistical significance.
Intraclass correlation coefficient ($ICC_{3,1}$) was used to determine the consistency of three repetitions of PM tightness, LSST and muscle strength measurements. The error of measurement was determined with standard error of measurement (SEM) and minimal detectable change with 95% confidence interval ($MDC_{\%95}$): $SEM=SD\ X \sqrt{1-ICC}$, $MDC_{\%95}= 1.96\ X \sqrt{2xSEM}$ (26,27).

RESULTS

The demographic characteristics of the participants are shown in Table 1.
The reliability results of the PM tightness; LSST and muscle strength measurements revealed high reliability (Table 2).
PM tightness reduced among measurement time points following PNF application (p=0.001). This reduction was observed both from baseline to 12th week (mean difference=1.27 cm; p=0.005) and from 6th week to 12th week (mean difference=0.95 cm; p= 0.012). But none of these differences were exceed the established level of $MDC_{\%95}$=2.27 cm. There was no difference between baseline and 6th week (p>0.016).
The LSST results of 45° test position were different among measurement time points (p=0.019). The LSST difference reduced only from baseline to the 6th week (mean difference=0.51 cm; p=0.016). But the mean difference between time points was below the established level of $MDC_{\%95}$=0.69 cm. There were no differences between baseline - 12th week and between 6th - 12th week (p>0.016).
The muscle strength of both LT (p=0.012) and SA (p=0.035) were improved following PNF application while UT strength was similar among time points (p>0.05). LT muscle strength increased between baseline and 6th week (mean difference= 36.53 N; p=0.006). There were no differences from baseline to 12th week results and from 6th to 12th week results (p>0.016). Similarly, SA muscle strength increased between baseline and 6th week (mean difference= 36.49 N; p=0.004). There were no differences from baseline to 12th week results and from 6th to 12th week results (p>0.016) (Table 3). The mean differences for both LT ($MDC_{\%95}$=5.71 N) and SA ($MDC_{\%95}$=7.18 N) muscle strength were exceeded the established $MDC_{\%95}$.
The UT/SA (p=0.035) and UT/LT (p=0.012) strength ratios decreased following PNF application. These strength ratios decreased only from baseline to 6th week (p=0.006) (Figure 1). The results between baseline and 12th week; 6th week and 12th week were similar (p>0.016).

Table 1. Demographic characteristics

Years	25.4±4.1 years
Height	171.6±9.9 cm
Weight	65.8±15.6 kg
Body Mass Index	22.1±3.4 kg/m^2

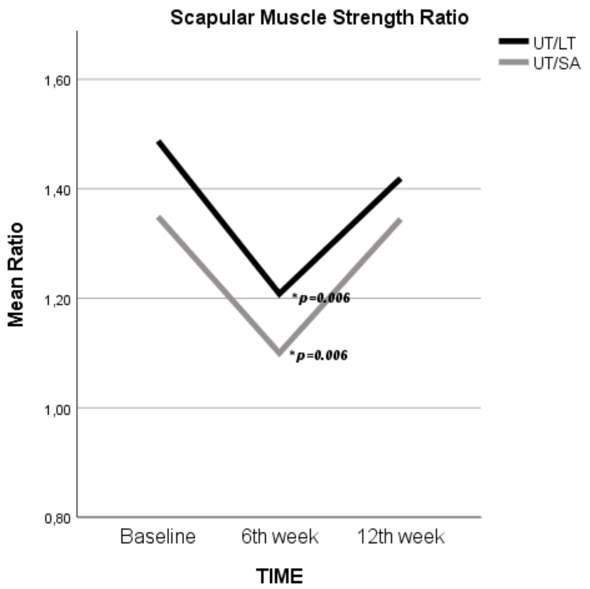
Table 2. The reliability data of the measurements

Parameters	ICC	SEM	MDC
PM tigthness (cm)	0.96	0.67	2.27
LSST (cm)			
0°	0.97	0.08	0.79
45°	0.98	0.06	0.69
90°	0.96	0.08	0.79
Muscle Strength(N)			
UT	0.96	12.55	9.81
LT	0.97	4.25	5.71
SA	0.98	6.71	7.18

PM: Pectoralis minor; LSST: Lateral scapular slide test; UT: Upper trapez; LT: Lower trapez; SA: Serratus anterior; ICC: Intraclass Correlation Coefficient; SEM; Standard Error of Measurement; MDC: Minimal Detectable Change

DISCUSSION

In present study, we aimed to investigate the effect of a six-week PNF application on scapular muscle strength, scapular asymmetry, and pectoralis minor muscle tightness in individuals with asymptomatic



Abbreviations: UT; upper trapezius, LT; lower trapezius, SA; serratus anterior. significant differences between baseline and 6th week (Wilcoxon Test with Bonferonni correction

Figure 1. Comparison of scapular muscle strength ratio at baseline, 6th week and 12th week after PNF application

scapular dyskinesis. The most important findings of the present study were that LT and SA muscle strength increased and UT/LT and UT/SA strength ratio decreased significantly following PNF application. Even there were significant time difference in LSST results and PM tightness; the differences did not exceed the established $MDC_{\%95}$ levels. Therefore, the hypothesis of the study was only supported on scapular muscle strength balance would improve following PNF training in individuals with asymptomatic scapular dyskinesis.

Both overhead and non-overhead athletes have a high prevalence of scapular dyskinesis (5,28). A current systematic review revealed that asymptomatic athletes with scapular dyskinesis had a 43% greater risk of developing future shoulder pathology than those without scapular dyskinesis (28). The strength deficits or strength imbalance of scapular muscles lead to disoriented scapular movement, which may contribute to future shoulder injuries. Therefore, many of rehabilitation programs targets to strengthening of scapular muscles to promote proper scapular positioning and optimal scapulohumeral rhythm. It is well known that trapezius and SA muscles displayed high to very high electromyographic (EMG) activation during upper extremity PNF patterns (29,30). Furthermore, Park et al (30) showed that a modified PNF exercise in push-up plus position was more effective than only push-up plus exercises to increase the LT and SA muscle activity levels and therefore to optimize the UT/SA ratio.

Several researchers examined the effect of PNF techniques on muscle performance (14,16,31,32). Kofotolis et al. [16] showed that an eight-week lower extremity PNF training would change the vastus lateralis (VL) fiber type distributions, increase the mean cross-sectional area of VL muscle in healthy population. Hall et al. (32) stated that isometric inversion muscle strength improved around 28% and eversion strength increased around 31% while no change was detected in dorsiflexion and plantar flexion strength following ankle PNF patterns (3 times a week for 6 weeks) in individuals with chronic ankle instability. They applied two diagonal patterns: dorsiflexion-inversion & plantar flexion-eversion and dorsiflexion-eversion & plantar flexion-inversion. The authors emphasized that strength improvement was specific to manual resistance direction that applied via PNF, since they did not find any difference in dorsiflexion and plantar flexion strength (32). In the present study, we applied the repeated contraction techniques of PNF using the scapular patterns to restore periscapular muscle strength. The results showed that LT muscle strength increased 21.7% and SA muscle strength increased 22.6% following a six-week PNF application. In addition, UT muscle strength did not show any difference following PNF application (difference=1.8%). The significant increase of LT and SA muscle strength relative to UT strength resulted with decrease of UT/LT and UT/SA muscle strength ratios. The optimal UT/SA muscle strength ratio recommended as lower than 0.60 in healthy individuals (33). The present study's baseline results of UT/LT and UT/SA strength ratio were range between 0.35-0.49 and these strength ratios improved to 0.10-0.21 with the 6-week PNF training. But these beneficial effects did not continue when PNF training was ended (between 6th and 12th weeks) and the ratios reversed to their baseline values (ratios ranged between 0.34-0.42). These results showed that, PNF application would improve the scapular muscle strength balance only during the application period in individuals with scapular dyskinesis. Adding functional exercises combination with PNF training might maintain the beneficial effects of only PNF application in long term.

Table 3. Measurement parameters at baseline, 6th week and 12th week after proprioceptive neuromuscular facilitation training.

Parameters	Baseline Mean±SD	Baseline %95 CI	6th week Mean±SD	6th week %95 CI	12th week Mean±SD	12th week %95 CI	p
Pectoralis minor thickness (cm)	14.18±3.24	12.00-16.36	14.50±3.38	12.23-16.77	15.45±3.10	13.37-17.54	<0.001*
LSST 0 (cm)	0.86±0.64	0.44-1.29	0.41±0.49	0.08-0.74	0.45±0.47	0.14-0.77	0.122
LSST 45	0.86±0.55	0.49-1.23	0.36±0.39	0.10-0.63	0.36±0.45	0.06-0.67	0.019*
LSST 90	0.95±0.82	0.40-1.51	0.82±0.75	0.31-1.32	0.23±0.41	-0.05-0.50	0.078
UT Strength (Nm)	249.69±60.20	209.25-290.13	254.30±70.32	207.06-301.54	239.98±62.75	197.05-281.36	0.148
LT Strength (Nm)	168.38±36.38	143.94-192.82	204.91±46.21	173.85-235.97	164.0±24.56	147.50-180.49	0.012*
SA Strength (Nm)	186.45±64.20	143.32-229.57	228.47±62.13	186.74-270.21	179.86±47.47	147.97-211.75	0.035*
UT/LT Ratio	1.49±0.40	1.22-1.76	1.21±0.19	1.08-1.34	1.42±0.28	1.23-1.60	0.012*
UT/SA Ratio	1.35±0.22	1.20-1.49	1.10±0.19	0.98-1.22	1.34±0.35	1.11-1.58	0.035*

*p<0.05, Friedman analysis of variance by ranks tests,
UT; Upper trapezius, LT; Lower trapezius, SA; Serratus anterior; LSST: Lateral scapular slide test

Exercise therapy is considered as the primary treatment method for restoring the scapular muscle strength balance and the proper movement of the scapula (34-36). In a previously published study, Sung-Min Ha et al. [34] stated that UT and SA muscle strength increased approximately 60% after a six-week self-scapular upward rotation exercise treatment in subjects with scapular dyskinesis. Also, the authors speculated that strengthening of these muscle groups could optimize the resting muscle length and restore scapular alignment. Similarly, in another study Başkurt et al. (35) reported that strength of UT (≈12%); MT (≈11%); LT (≈10%) and SA (≈16%) muscle strength improved after a 6-week home-based scapular stabilization exercise training which included scapular PNF exercises combined with shoulder stretching and strengthening in patients with subacromial impingement syndrome. The results of the present study showed that a greater increase in LT and SA muscle strength achieved with the scapular PNF training. The UT strength remained without change among timepoints. We observed that these strength improvements were specific to the scapular patterns, which included anterior elevation-posterior depression and anterior depression-posterior elevation of the scapula. We believe that these PNF patterns would optimize the strength imbalance between UT with both LT and SA in individuals with scapular dyskinesis.

Several studies showed the effectiveness of PNF training in different shoulder problems (20,37,38). In a case study, it was concluded that scapular patterns of PNF application was an alternative and effective option when standard strengthening, mobilization or electrotherapy modalities were not efficient in patient with subacromial impingement syndrome and scapular dyskinesis (37). Meneghini et al. (38), examined the immediate effect of scapula PNF patterns in 32 volleyball players with scapular dyskinesis; the authors showed that the number of individuals with scapular dyskinesis decreased after the scapular PNF training. Balcı et al. (20) stated that a combination of scapular PNF patterns with physiotherapy modalities was effective in improving shoulder function and ROM, while reducing pain in patients with adhesive capsulitis. These results showed that application of the scapular patterns of PNF is an effective way for improving shoulder function, for reducing pain and to optimize scapular symmetry in different shoulder problems.

A few studies investigated the effectives of PNF training on PM muscle tightness (17,21). Birinci et al. (21) showed an additional contract-relax PNF stretching to ischemic compression on PM muscle was more effective compared to static stretching and myofascial release to decrease PM tightness. Lai et al. (17) indicated that PNF pattern of shoulder extension, abduction, internal rotation would increase PM length index. Different from the aforementioned studies, the present study results revealed that PM tightness did not differ following scapular patterns of PNF application. A direct comparison of our results with the previous study results would be difficult because different PNF patterns was used and, we performed the PNF stretching on scapular muscles not on the PM muscle.

Previous findings indicated variable results of the effects of PNF stretching on LSST results (20,35). Balcı et al. [20] applied PNF stretching as two diagonals, anterior elevation, and posterior depression in patients with adhesive capsulitis and found no difference in LSST results. Differently, Başkurt et al. (35) found a significant difference in LSST results following a 6-week home-based scapular stabilization exercise combined with scapular exercises in several PNF patterns in subacromial impingement syndrome patients. The LSST results of the present study did not differ following PNF training. This may be because our strengthening program does not include stretching and functional exercises.

One of the limitations of the present study was we did not compare the effects of PNF training with scapular stabilization exercises or self-exercises of PNF patterns. Adding an exercise group would improve our understanding if a manually resistive application such as PNF was effective or not compared to only exercises. But the primary aim of this study was to compare a 6-week application of PNF to another 6-week with no application and the results showed that PNF training was reversible such as exercise training. Another limitation of our study was we evaluated asymptomatic individuals, and these results cannot be interpreted directly according to the patients with scapular dyskinesis.

In conclusion, this study demonstrates that a 6-week scapular patterns of PNF training would improve scapular muscle balance between trapezius and SA via increasing LT and SA muscle strength in asymptomatic individuals with scapular dyskinesis. But these beneficial effects did not continue when the PNF training ended. Clinicians and health professionals might implement PNF scapular patterns when designing the rehabilitation programs of individuals with scapular dyskinesis.

Acknowledgements: None.
Author contributions: Idea/concept: NBC, HGD; Design: PH, EU, FT, HEK; Supervision/Advisory: HGD, HEK; Resources and Funding: HGD, HEK; Materials: NBC, EU, PH, FT; Data Collection and Processing: NBC, HGD, EU; Analysis and Interpretation: NBC, PH, FT; Literature Screening: NBC, EU, HEK; Article Writing: NBC, HGD, EU, PH; Critical Review: HGD, HEK.
Conflict of Interest: None
Ethical Approval: The study was registered to Clinical Trials with the ID of NCT04622800.
Funding: None
Peer-review: Externally peer-reviewed.

REFERENCES

1. Akodu AK, Akinbo SR, Young QO. Correlation among smartphone addiction, craniovertebral angle, scapular dyskinesis, and selected anthropometric variables in physiotherapy undergraduates. J Taibah Univ Med Sci. 2018;13(6):528-534.
2. Christiansen DH, Møller AD, Vestergaard JM, Mose S, Maribo T. The scapular dyskinesis test: Reliability, agreement, and predictive value in patients with subacromial impingement syndrome. J Hand Ther. 2017;30(2):208-213.
3. Kibler WB, Sciascia A. Evaluation and Management of Scapular Dyskinesis in Overhead Athletes. Curr Rev Musculoskelet Med. 2019;12(4):515-526.
4. Panagiotopoulos AC, Crowther IM. Scapular Dyskinesia, the forgotten culprit of shoulder pain and how to rehabilitate. SICOT J. 2019;5:29.
5. Burn MB, McCulloch PC, Lintner DM, Liberman SR, Harris JD. Prevalence of Scapular Dyskinesis in Overhead and Nonoverhead Athletes: A Systematic Review. Orthop J Sports Med. 2016;4(2):2325967115627608.
6. Yeşilyaprak SS, Yüksel E, Kalkan S. Influence of pectoralis minor and upper trapezius lengths on observable scapular dyskinesis. Phys Ther Sport. 2016;19:7-13.
7. Provencher MT, Kirby H, McDonald LS, Golijanin, P., Gross, D., Campbell, K. J. et al. Surgical Release of the Pectoralis Minor Tendon for Scapular Dyskinesia and Shoulder Pain. Am J Sports Med. 2017;45(1):173-178.
8. Umehara J, Nakamura M, Nishishita S, Tanaka H, Kusano K, Ichihashi N. Scapular kinematic alterations during arm elevation with decrease in pectoralis minor stiffness after stretching in healthy individuals. J Shoulder Elbow Surg. 2018;27(7):1214-1220

9. Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. J Orthop Sports Phys Ther. 2005;35(4):227-238.
10. Voss DE, Ionta MK, Myers BJ, Knott M. Proprioceptive neuromuscular facilitation: patterns and techniques. 3th edition Philadelphia: Paul B Haeber; 1985.
11. Adler SS, Beckers D, Buck M. PNF in practice: an illustrated guide. 3th edition. Springer; 2007.
12. Westwater-Wood S, Adams N, Kerry R. The use of proprioceptive neuromuscular facilitation in physiotherapy practice. Physical Therapy Reviews. 2010;15(1):23-8.
13. Anjum H, Amjad I, Malik AN. Effectiveness of Proprioceptive Neuromuscular Facilitation Techniques as Compared to Traditional Strength Training in Gait Training Among Transtibial Amputees. J Coll Physicians Surg Pak. 2016;26(6):503-506.
14. Areeudomwong P, Wongrat W, Neammesri N, Thongsakul T. A randomized controlled trial on the long-term effects of proprioceptive neuromuscular facilitation training, on pain-related outcomes and back muscle activity, in patients with chronic low back pain. Musculoskeletal Care. 2017;15(3):218-229.
15. Areeudomwong P, Buttagat V. Proprioceptive neuromuscular facilitation training improves pain-related and balance outcomes in working-age patients with chronic low back pain: a randomized controlled trial. Braz J Phys Ther. 2019;23(5):428-36.
16. Kofotolis N, Vrabas IS, Vamvakoudis E, Papanikolaou A, Mandroukas K. Proprioceptive neuromuscular facilitation training induced alterations in muscle fibre type and cross sectional area. Br J Sports Med. 2005;39(3):e11.
17. Lai CC, Chen SY, Yang JL, Lin JJ. Effectiveness of stretching exercise versus kinesiotaping in improving length of the pectoralis minor: A systematic review and network meta-analysis. Phys Ther Sport. 2019;40:19-26.
18. Lempke L, Wilkinson R, Murray C, Stanek J. The Effectiveness of PNF Versus Static Stretching on Increasing Hip-Flexion Range of Motion. J Sport Rehabil. 2018;27(3):289-94.
19. Marek SM, Cramer JT, Fincher AL, Massey LL, Dangelmaier SM, Purkayastha S, et al. Acute Effects of Static and Proprioceptive Neuromuscular Facilitation Stretching on Muscle Strength and Power Output. J Athl Train. 2005;40(2):94-103.
20. Balcı NC, Yuruk ZO, Zeybek A, Gulsen M, Tekindal MA. Acute effect of scapular proprioceptive neuromuscular facilitation (PNF) techniques and classic exercises in adhesive capsulitis: a randomized controlled trial. J Phys Ther Sci. 2016;28(4):1219-27.
21. Birinci T, Razak Ozdincler A, Altun S, Kural C. A structured exercise programme combined with proprioceptive neuromuscular facilitation stretching or static stretching in posttraumatic stiffness of the elbow: a randomized controlled trial. Clin Rehabil. 2019;33(2):241-52.
22. Kibler WB, Uhl TL, Maddux JW, Brooks PV, Zeller B, McMullen J. Qualitative clinical evaluation of scapular dysfunction: a reliability study. J Shoulder Elbow Surg. 2002;11(6):5506.
23. Borstad JD. Measurement of pectoralis minor muscle length: validation and clinical application. J Orthop Sports Phys Ther. 2008;38(4):169-74.
24. Odom CJ, Taylor AB, Hurd CE, Denegar CR. Measurement of scapular asymetry and assessment of shoulder dysfunction using the Lateral Scapular Slide Test: a reliability and validity study. Phys Ther. 2001;81(2):799-809.
25. Michener LA, Boardman ND, Pidcoe PE, Frith AM. Scapular muscle tests in subjects with shoulder pain and functional loss: reliability and construct validity. Phys Ther. 2005;85(11):1128-38.
26. Bruton A, Conway JH, Holgate ST. Reliability: what is it, and how is it measured? Physiotherapy. 2000;86(2):94–99.
27. Eliasziw M, Young SL, Woodbury MG, Fryday-Field K. Statistical methodology for the concurrent assessment of interrater and intrarater reliability: using goniometric measurements as an example. Phys Ther. 1994;74(8):777-788.
28. Hickey D, Solvig V, Cavalheri V, Harrold M, McKenna L. Scapular dyskinesis increases the risk of future shoulder pain by 43% in asymptomatic athletes: a systematic review and meta-analysis. Br J Sports Med. 2018;52(2):102-10.
29. Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. Sports Med. 2009;39(8):663-85.

30. Lee SK, Park DJ. The Effects of Knee Joint and Hip Abduction Angles on the Activation of Cervical and Abdominal Muscles during Bridging Exercises. J Phys Ther Sci. 2013;25(7):857-860.
31. Kofotolis N, Kellis E. Effects of two 4-week proprioceptive neuromuscular facilitation programs on muscle endurance, flexibility, and functional performance in women with chronic low back pain. Phys Ther. 2006;86(7):1001-12.
32. Hall EA, Docherty CL, Simon J, Kingma JJ, Klossner JC. Strength-training protocols to improve deficits in participants with chronic ankle instability: a randomized controlled trial. J Athl Train. 2015;50(1):36-44.
33. Andersen CH, Zebis MK, Saervoll C, Sundstrup E, Jakobsen MD, Sjøgaard G, et al. Scapular muscle activity from selected strengthening exercises performed at low and high intensities. J Strength Cond Res. 2012;26(9):2408-16.
34. Ha SM, Kwon OY, Yi CH, Cynn HS, Weon JH, Kim TH. Effects of scapular upward rotation exercises on alignment of scapula and clavicle and strength of scapular upward rotators in subjects with scapular downward rotation syndrome. J Electromyogr Kinesiol. 2016;26:130-6.
35. Başkurt Z, Başkurt F, Gelecek N, Özkan MH. The effectiveness of scapular stabilization exercise in the patients with subacromial impingement syndrome. J Back Musculoskelet Rehabil. 2011;24(3):173-9.
36. Witt D, Talbott N, Kotowski S. Electromyographic activity of scapular muscles during diagonal patterns using elastic resistance and free weights. Int J Sports Phys Ther. 2011;6(4):322-332
37. Peteraitis T, Smedes F. Scapula motor control training with Proprioceptive Neuromuscular Facilitation in chronic subacromial impingement syndrome: A case report. J Bodyw Mov Ther. 2020;24(3):165-71.
38. Meneghini GO, Adamatti FS, Dhein W. Immediate effect of proprioceptive neuromuscular facilitation on scapular dyskinesia of volleyball players. MTP&RehabJournal 2020;18:1-9.