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Effect of Proprioceptive Neuromuscular Facilitation Stretching vs Passive Stretching on Pain and Hamstring Flexibility in Mechanical Low Back Ache among Female College Students

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Abstract: ***Background: Mechanical low back pain is a common musculoskeletal condition associated with hamstring tightness, altered lumbopelvic movement and sedentary behaviour. Stretching interventions may improve hamstring flexibility and reduce pain. Aim: To compare the effectiveness of Proprioceptive Neuromuscular Facilitation (PNF) stretching and passive stretching on pain and hamstring flexibility among female college students with mechanical low back pain. Methodology: A comparative experimental study was conducted among 40 female college students divided into two groups (n=20 each). Group A received PNF stretching, while Group B received passive stretching. Both groups received Interferential Therapy (IFT) and a standardized home exercise programme for four weeks. Pain was assessed using the Numerical Pain Rating Scale (NPRS), and bilateral hamstring flexibility using the Active Knee Extension Test (AKET). Pre- and post-intervention data were analysed using paired and independent t tests. Results: Both groups showed significant improvements ($p < 0.001$). Group A demonstrated a greater reduction in NPRS scores (6.35 to 1.75) compared with Group B (6.25 to 3.55). Similarly, right AKET improved from 31.25° to 10.75° in Group A and from 31.35° to 19.10° in Group B. Left AKET improved from 30.55° to 9.95° in Group A and from 30.35° to 18.10° in Group B. Intergroup analysis revealed significantly greater improvements in Group A across all outcomes ($p < 0.001$). Conclusion: Both PNF and passive stretching were effective in reducing pain and improving hamstring flexibility. However, PNF stretching demonstrated superior outcomes and may be considered a more effective intervention for female college students with mechanical low back pain.***

Keywords: Mechanical Low Back Pain, PNF Stretching, Passive Stretching, Hamstring Flexibility, NPRS, AKET, Physiotherapy.

1. Introduction

Low back pain is one of the leading causes of disability worldwide, affecting individuals across different age groups. Mechanical low back pain is commonly associated with postural stress, repetitive mechanical loading, restricted mobility and reduced physical activity. Its occurrence among young adults and university students has gained increasing attention, particularly due to prolonged sitting, academic workload and sedentary lifestyles (1–7, 24–26).

Hamstring flexibility plays an important role in maintaining normal lumbopelvic biomechanics. The hamstring muscle group, comprising the biceps femoris, semitendinosus and semimembranosus, contributes to hip extension, knee flexion and pelvic movement. Restricted hamstring flexibility may alter pelvic rotation and lumbar movement during functional activities such as forward bending, potentially influencing mechanical loading of the lumbar spine (8–10, 29).

Stretching exercises are commonly incorporated into physiotherapy programmes to improve muscle extensibility and joint range of motion. Passive stretching involves applying an external force to lengthen the muscle, whereas Proprioceptive Neuromuscular Facilitation (PNF) stretching combines passive stretching with active muscle contraction and relaxation. The hold-relax technique of PNF stretching is widely used to improve flexibility through neuromuscular and sensory mechanisms (18–23,31–34).

Previous research has demonstrated the effectiveness of stretching interventions in improving hamstring flexibility and range of motion. However, evidence regarding the comparative effectiveness of PNF stretching and passive

stretching remains variable. Furthermore, limited research has specifically investigated their comparative effects on pain and hamstring flexibility among female college students with mechanical low back pain (31–34,38).

Therefore, the present study was undertaken to compare the effectiveness of PNF stretching and passive stretching on pain intensity and bilateral hamstring flexibility among female college students with mechanical low back pain. Pain was assessed using the Numerical Pain Rating Scale (NPRS), while hamstring flexibility was evaluated using the Active Knee Extension Test (AKET). The findings aim to contribute to evidence-based physiotherapy management of mechanical low back pain.

Aim

To compare the effects of proprioceptive neuromuscular facilitation stretching and passive stretching on pain and hamstring flexibility in female college students with mechanical low back ache.

Objectives

- To evaluate the effect of proprioceptive neuromuscular facilitation (PNF) stretching vs passive stretching on pre and post value of pain intensity by using numerical pain rating scale (NPRS) in subjects with mechanical low back ache in female college students.
- To evaluate the effect of proprioceptive neuromuscular facilitation (PNF) stretching vs passive stretching on pre and post value of hamstring flexibility by using active knee extension test (AKET) in subjects with mechanical low back ache in female college students.

2. Methodology

Materials: Couch / Plinth, Stepper, Stopwatch in smart phone,180° Goniometer, Numerical Pain Rating Scale, Interferential therapy Machine, Sand bag, Pillows, Drape sheet, Consent forms

Study Design

A randomized experimental study was conducted to compare the effects of proprioceptive neuromuscular facilitation (PNF) stretching and passive stretching on pain and hamstring flexibility in female college students with mechanical low back pain.

Study Setting

The study was conducted at the College of Physiotherapy, Sri Venkateswara Institute of Medical Sciences (SVIMS), Tirupati, Andhra Pradesh.

Study Duration:

The duration of the study was 4 weeks.

Sample Size

A total of 40 female college students meeting the inclusion and exclusion criteria participated in the study.

Sampling Technique

Participants were selected using purposive sampling, they were randomly allocated into two groups (PNF and Passive Stretching).

Inclusion Criteria

- Age between 18–25 years
- Gender – female
- Diagnosed with mechanical low back ache (LBA)
- Presence of hamstring tightness, defined by - OR Active Knee Extension (AKE) deficit ≥ 20°
- Written informed consent obtained

Exclusion Criteria

- History of trauma and spinal surgery.
- Any other musculoskeletal disorders.
- Any neurological disorders.
- Dysmenorrhea during assessment period.
- Limb length variations.
- Sport persons.

3. Interventional Protocol

The intervention was administered for four consecutive weeks, with three supervised treatment sessions per week, resulting in a total of 12 sessions for each participant. Participants were randomly allocated into two groups of 20 each. Both groups received their respective hamstring stretching intervention, followed by Interferential Therapy (IFT). A standardized Home Exercise Programme (HEP) was prescribed to all participants.

Group A: Proprioceptive Neuromuscular Facilitation (PNF) Stretching

Participants in Group A received the Hold–Relax PNF stretching technique for the hamstring muscles. The participant was positioned comfortably in supine lying, with the non-test lower limb maintained in extension. The therapist passively flexed the hip while maintaining knee extension until a mild hamstring stretch was perceived. This position was maintained for 10 seconds. The participant was then instructed to perform an isometric contraction of the hamstrings against the therapist's resistance without producing joint movement. The contraction was maintained for 6–10 seconds, followed by approximately 2–3 seconds of relaxation. Immediately after relaxation, the therapist gently increased hip flexion until a new comfortable stretch was achieved and maintained this position for 15 seconds. This sequence constituted one repetition and was repeated 3–5 times for each lower limb.

Group B: Passive Hamstring Stretching

Participants in Group B received therapist-assisted passive hamstring stretching. The participant was positioned in supine lying, with the non-test lower limb maintained in extension. The therapist gently raised the test limb using the Straight Leg Raise technique while maintaining the knee in full extension until a comfortable stretch was felt in the hamstring muscles. The stretch was maintained for 15 seconds, after which the limb was slowly returned to the starting position. A brief rest period was provided between repetitions. The procedure was repeated 3–5 times for each lower limb. Care was taken to maintain pelvic stability and avoid compensatory lumbar movement.

Common Intervention: Interferential Therapy (IFT)

Following the stretching intervention, participants in both groups received IFT over the lumbar region. Participants were

positioned comfortably in prone lying, and four electrodes were placed around the painful lumbar region in a quadripolar arrangement.

The treatment parameters were standardized as follows:

- Carrier frequency: 4000 Hz
- Beat frequency: 90 Hz
- Mode: Continuous
- Electrode placement: Quadripolar
- Treatment duration: 15 minutes

The intensity was gradually increased until a strong but comfortable tingling sensation was experienced without visible muscle contraction. Participants were monitored throughout the treatment to ensure comfort and safety.

Home Exercise Programme (HEP)

Both groups received a standardized home exercise programme consisting of:

1) **Seated hamstring stretch:** Participants sat at the edge of a chair with one knee extended and the heel resting on the floor. They were instructed to bend forward from the hips while maintaining a neutral lumbar position until a mild stretch was felt along the posterior thigh.
2) **Standing hamstring stretch:** Participants stood facing a stable chair or step, placed one heel on the elevated surface with the knee extended, and gently leaned forward from the hips until a comfortable hamstring stretch was felt.

Each exercise was performed for three repetitions, with a 30-second hold and a 10-second relaxation period between repetitions, for both lower limbs. The complete programme was prescribed twice daily, preferably in the morning and evening, throughout the four-week intervention period. Each session lasted approximately 10–15 minutes. Participants were instructed to avoid bouncing movements, maintain normal breathing and perform the exercises within a comfortable range without provoking pain. Compliance was monitored during supervised treatment visits.

Statistical Analysis

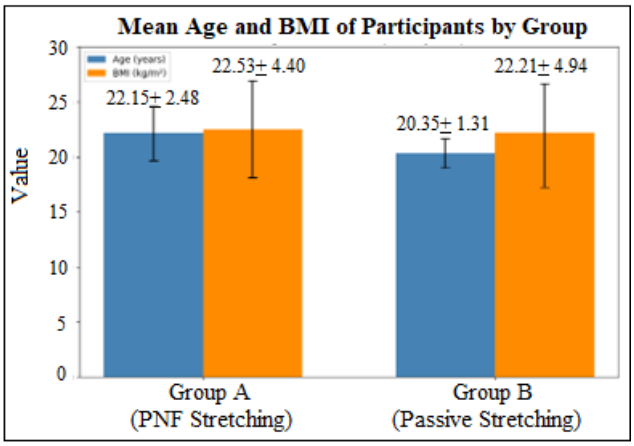
Data were analysed using IBM SPSS Statistics Version 25.0 and expressed as mean ± standard deviation. Normality was assessed using the Shapiro–Wilk test. Paired-samples t-tests were used for within-group comparisons, while independent-samples t-tests compared mean change scores between groups. A 95% confidence interval was calculated, and $p < 0.05$ was considered statistically significant.

4. Results

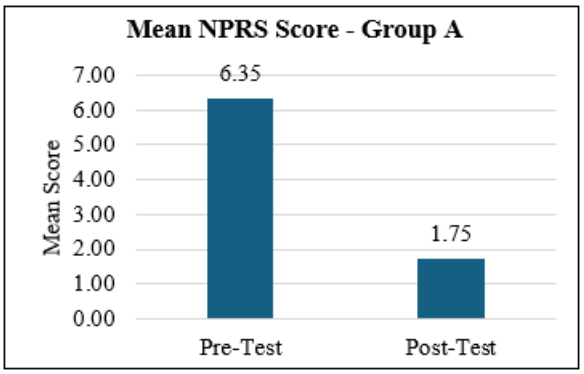
Descriptive Statistics of Demographic Data

Table 1: Demographic Data of Participants

Variable	Group	Count	Min	Max	Mean	SD
Age (years)	Group A (PNF Stretching)	20.00	18.00	25.00	22.15	2.48
	Group-B (Passive Stretching)	20.00	18.00	23.00	20.35	1.31
BMI (kg/m²)	Group A (PNF Stretching)	20.00	16.40	30.04	22.53	4.40
	Group-B (Passive Stretching)	20.00	15.60	38.30	22.21	4.94



Graph 1: Mean Age and BMI of Participants by Group



Graph 2: Mean NPRS Score - Group A

Inferential Statistics

Intra-Group Analysis (or Within-Group Analysis)

Intra-Group Analysis of NPRS Score:

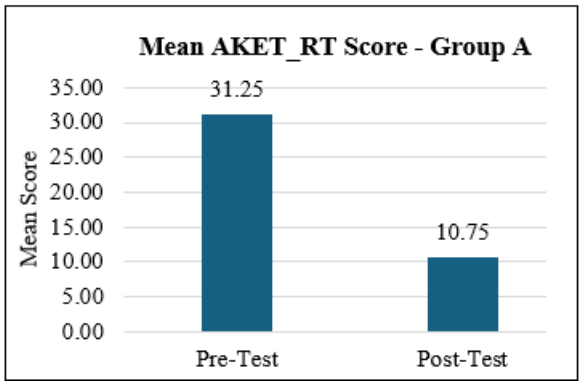
Table 2: Paired-Samples t-test for NPRS Score - Group A

Variable	Pre-test Mean ± SD	Post-test Mean ± SD	t-value	p-value
NPRS Score	6.35 ± 0.75	1.75 ± 0.64	-25.06	<0.001

Intra-Group Analysis of AKET (Right) Score:

Table 3: Paired Samples t-test for AKET Right Score – Group A

Variable	Pre-test Mean ± SD	Post-test Mean ± SD	t-value	p-value
AKET Right (°)	31.25 ± 2.20	10.75 ± 1.92	-120.49	<0.001

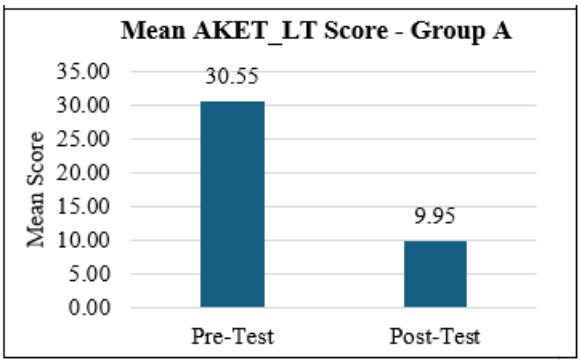


Graph 3: Mean AKET_RT Score – Group

Intra-Group Analysis of AKET (Left) Score: Group - A

Table 4: Paired-Samples t-test for AKET_LT Score – Group A

Variable	Pre-test Mean ± SD	Post-test Mean ± SD	t-value	p-value
AKET_LT Score	30.55 ± 2.14	9.95 ± 1.79	-153.99	0.000*



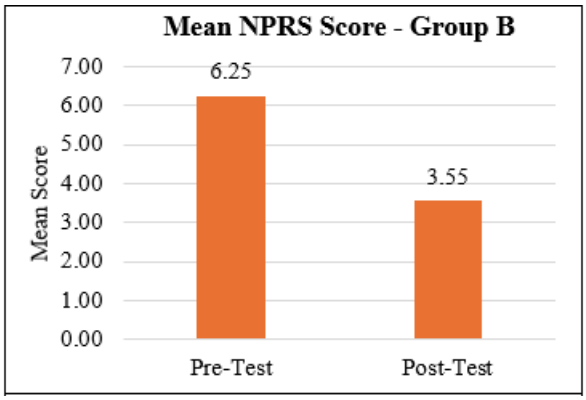
Graph 4: Mean AKET_LT Score - Group A

Intra-Group Comparison of NPRS and AKET Scores in Group B (Passive Stretching) Using Paired-Samples t-test

Intra-Group Comparison of NPRS Score: Group - B

Table 5: Paired-Samples t-test for NPRS Score - Group B

Variable	Pre-test Mean ± SD	Post-test Mean ± SD	t-value	p-value
NPRS Score	6.25 ± 0.72	3.55 ± 0.51	-21.14	0.000*

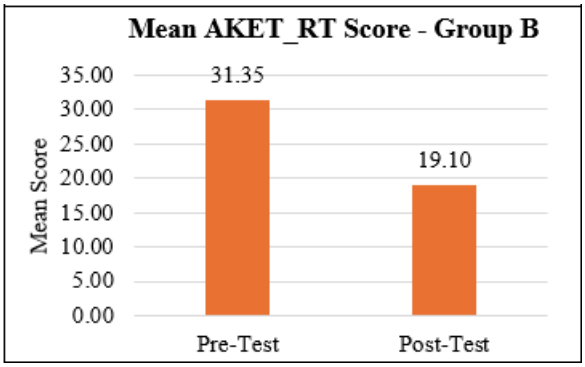


Graph 5: Mean NPRS Score - Group B

Intra-Group Comparison of AKET (Right) Score: Group - B

Table 6: Paired Samples t-test for AKET Right Score – Group B

Variable	Pre-test Mean ± SD	Post-test Mean ± SD	t-value	p-value
AKET-RT Score (°)	31.35 ± 2.28	19.10 ± 2.07	-69.66	0.000*

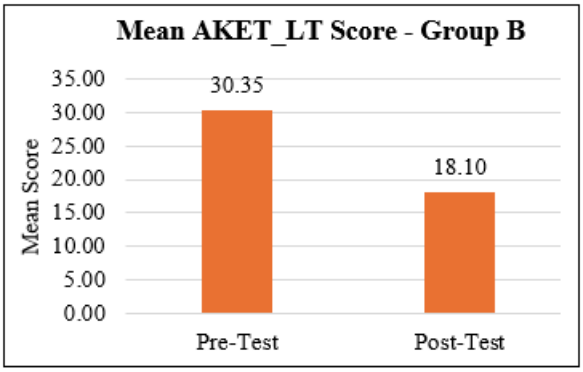


Graph 6: Mean AKET_RT Score - Group B

Intra-Group Comparison of AKET (Left) Score: Group - B

Table 7: Paired-Samples t-test for AKET_Left Score – Group B

Variable Group - B	Pre-test Mean ± SD	Post-test Mean ± SD	t-value	p-value
AKET-LT Score (°)	30.35 ± 2.28	18.10 ± 2.20	-85.78	0.000*



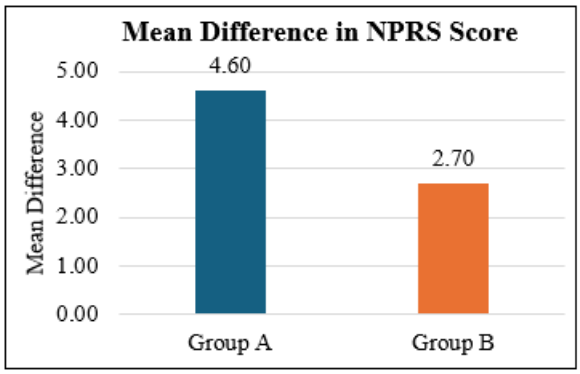
Graph 7: Mean AKET_LT Score - Group B

Inter-Group Analysis (or Between Group Analysis):

Inter-Group Analysis of NPRS Score:

Table 8: Independent Samples t-test for Difference in NPRS Score

Variable	Group A (Mean ± SD)	Group B (Mean ± SD)	t-value	p-value
Difference in NPRS Score	−4.60 ± 0.82	−2.70 ± 0.57	−8.50	0.000*

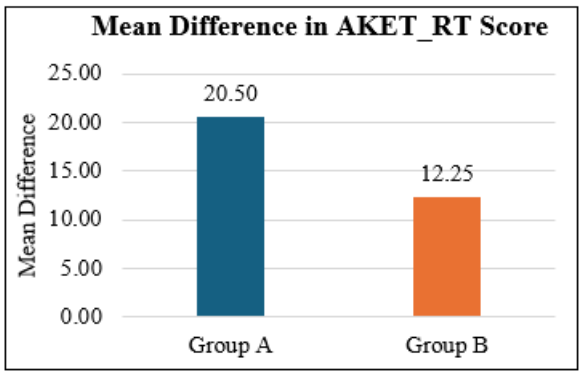


Graph 8: Mean Difference in NPRS Score

Inter-Group Analysis of AKET (Right) Score:

Table 9: Independent Samples t-test for Difference in AKET_RT Score

Variable	Group A (Mean ± SD)	Group B (Mean ± SD)	t-value	p-value
Difference in AKET_RT Score	−20.50 ± 0.76	−12.25 ± 0.79	−33.72	0.000*

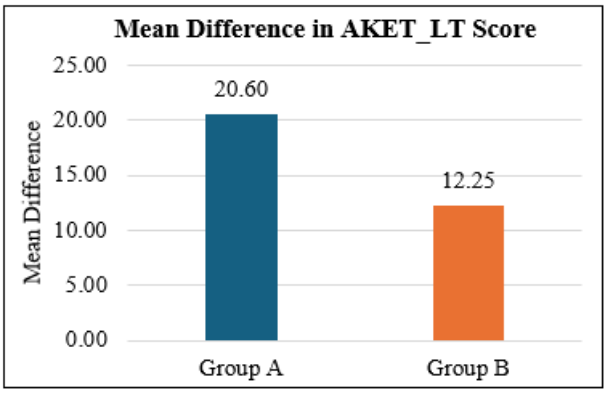


Graph 9: Mean difference of AKET_RT Score

Inter-Group Analysis of AKET (Left) Score:

Table 10: Independent Samples t-test for Difference in AKET_LT Score

Variable	Group A (Mean ± SD)	Group B (Mean ± SD)	t-value	p-value
Difference in AKET_LT Score	−20.60 ± 0.60	−12.25 ± 0.64	−42.67	0.000*



Graph 10: Mean Difference in AKET_LT Score

5. Discussion

The present study compared the effects of Proprioceptive Neuromuscular Facilitation (PNF) stretching and passive stretching on pain and hamstring flexibility among 40 female college students with mechanical low back pain.Both groups showed statistically significant improvements in pain and bilateral hamstring flexibility following the four-week intervention ($p < 0.001$).

In Group A, which received PNF stretching, the mean NPRS score decreased from 6.35 ± 0.75 to 1.75 ± 0.64. Group B, which received passive stretching, showed a reduction from 6.25 ± 0.72 to 3.55 ± 0.51. The greater reduction in Group A suggests that PNF stretching was more effective in reducing pain. This may be attributed to the active contraction and subsequent relaxation involved in the hold-relax technique, which may improve muscle relaxation and stretch tolerance.

Hamstring flexibility also improved significantly in both groups. Group A demonstrated greater improvement in right and left AKET scores (20.50° and 20.60°, respectively) compared with Group B (12.25° on both sides). These findings support the effectiveness of PNF stretching in improving hamstring flexibility.

The results are consistent with Hindle et al. and Sharman et al., who reported improvements in range of motion following PNF techniques. Findings from Gou et al. also support the potential benefits of hamstring stretching in reducing pain and improving function in individuals with low back pain.

The greater improvements observed in Group A indicate that PNF stretching may provide additional benefits over passive stretching. However, since both groups received IFT and a home exercise programme, the improvements should be interpreted in the context of the combined interventions.

Overall, the study suggests that both stretching techniques are beneficial; however, PNF stretching produced significantly greater improvements in pain reduction and bilateral hamstring flexibility among female college students with mechanical low back pain.

6. Conclusion

Both PNF stretching and passive stretching, when combined with IFT and a home exercise programme, were associated with significant improvements in pain and bilateral hamstring flexibility over four weeks. PNF stretching produced significantly greater improvements than passive stretching in this sample of female college students with mechanical low back pain. PNF may therefore be considered a useful component of conservative physiotherapy management, while the findings should be interpreted within the limits of the study design.

7. Future Scope and Limitations

The study was limited by its small sample, single-institution recruitment, inclusion of only female students, four-week intervention and absence of long-term follow-up. Functional disability, quality of life, pelvic tilt, lumbar range of motion

and psychosocial factors were not assessed. Future multicentre studies with larger and more diverse samples should include longer follow-up, validated disability measures and objective biomechanical outcomes. Further comparisons may evaluate PNF alongside core stabilization and other stretching or manual therapy approaches.

Ethics, Consent and Declarations

Ethics approval: Institutional Ethics Committee, SVIMS, IEC No. 1954. Informed consent: Written informed consent was obtained from all participants.

References

[1] GBD 2021 Low Back Pain Collaborators. Global, regional, and national burden of low back pain, 1990–2020, its attributable risk factors, and projections to 2050: a systematic analysis of the Global Burden of Disease Study 2021. Lancet Rheumatol. 2023;5(6):e316-e329. doi:10.1016/S2665-9913(23)00098-X.

[2] World Health Organization. Low back pain [Internet]. Geneva: World Health Organization; 2023.

[3] Hoy D, Bain C, Williams G, March L, Brooks P, Blyth F, et al. A systematic review of the global prevalence of low back pain. Arthritis Rheum. 2012;64(6):2028-2037. doi:10.1002/art.34347.

[4] Vos T, Lim SS, Abbafati C, Abbas KM, Abbasi M, Abbasifard M, et al. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet. 2020;396(10258):1204-1222.

[5] Smith DR, Leggat PA. Back pain in the young: a review of the epidemiology and associated factors. Work. 2007;28(1):69-74.

[6] AlShayhan FA, Saadeddin M. Prevalence of low back pain among health sciences students. Eur J Orthop Surg Traumatol. 2018;28(2):165-170.

[7] Alshagga MA, Nimer AR, Yan LP, Ibrahim IA, Al-Ghamdi SS, Radman Al-Dubai SA. Prevalence and factors associated with neck, shoulder and low back pains among medical students in a Malaysian medical college. BMC Res Notes. 2013; 6: 244.

[8] Gajdosik RL, Lusin G. Hamstring muscle tightness: reliability of an active-knee-extension test. Phys Ther. 1983;63(7):1085-1090. doi:10.1093/ptj/63.7.1085.

[9] Reis FJJ, Macedo AR. Influence of hamstring tightness in pelvic, lumbar and trunk range of motion in low back pain and asymptomatic volunteers during forward bending. Asian Spine J. 2015;9(4):535-540. doi:10.4184/asj.2015.9.4.535.

[10] Kwon YJ, Shim JM. Effects of hamstring stretching on low back pain and lumbar flexibility. J Phys Ther Sci. 2013;25(9):1145-1147.

[11] Decoster LC, Cleland J, Altieri C, Russell P. The effects of hamstring stretching on range of motion: a systematic literature review. J Orthop Sports Phys Ther. 2005;35(6):377-387. doi:10.2519/jospt.2005.35.6.377.

[12] Halbertsma JPK, Göeken LNH. Sport stretching: effect on passive muscle stiffness of short hamstrings. Arch Phys Med Rehabil. 1994;75(9):976-981.

[13] Shahsavari S, Safari A, Mirzaei M, et al. A randomized clinical trial for the effect of static stretching and strengthening exercise on pelvic tilt angle in low back pain patients. J Bodyw Mov Ther. 2020;24(3):1-7. doi:10.1016/j.jbmt.2020.02.001.

[14] Nachemson A. The lumbar spine: an orthopaedic challenge. Spine. 1976;1(1):59-71.

[15] Adams MA, Hutton WC. The effect of posture on the role of the lumbar spine in load bearing. Spine. 1985;10(1):90-98.

[16] McGill SM. Low back stability: from formal description to issues for performance and rehabilitation. Exerc Sport Sci Rev. 2001;29(1):26-31.

[17] Mense S. Nociception from skeletal muscle in relation to clinical muscle pain. Pain. 1993;54(3):241-289.

[18] Freitas SR, Vilarinho D, Rocha Vaz J, Bruno PM, Cordeiro M, Mil-Homens P. Responses to static stretching are dependent on stretch intensity and duration. Clin Physiol Funct Imaging. 2015;35(6):478-484.

[19] Magnusson SP. Passive properties of human skeletal muscle during stretch maneuvers: a review. Scand J Med Sci Sports. 1998;8(2):65-77.

[20] Taylor DC, Dalton JD Jr, Seaber AV, Garrett WE Jr. Viscoelastic properties of muscle-tendon units: the biomechanical effects of stretching. Am J Sports Med. 1990;18(3):300-309.

[21] Weppler CH, Magnusson SP. Increasing muscle extensibility: a matter of increasing length or modifying sensation? Phys Ther. 2010;90(3):438-449. doi:10.2522/ptj.20090012.

[22] Hindle KB, Whitcomb TJ, Briggs WO, Hong J. Proprioceptive neuromuscular facilitation: its mechanisms and effects on range of motion and muscular function. J Hum Kinet. 2012; 31: 105-113. doi:10.2478/v10078-012-0011-y.

[23] Sharman MJ, Cresswell AG, Riek S. Proprioceptive neuromuscular facilitation stretching: mechanisms and clinical implications. Sports Med. 2006;36(11):929-939. doi:10.2165/00007256-200636110-00002.

[24] Wong AYL, Chan LLY, Lo CWT, Lam KCK, Bao JCH, Wong ELY, et al. Prevalence/incidence of low back pain and associated risk factors among nursing and medical students: a systematic review and meta-analysis. PM R. 2021;13(11):1266-1280. doi:10.1002/pmrj.12560.

[25] Damato TM, Christofaro DGD, Pinheiro MB, Morelhao PK, Pinto RZ, De Oliveira Silva D, Tebar WR, Grande GHD, Oliveira CB. Does sedentary behaviour contribute to the development of a new episode of low back pain? A systematic review of prospective cohort studies. Eur J Pain. 2022;26(7):1412-1423. doi:10.1002/ejp.1977.

[26] Oliveira CBS, Damato TM, Tebar WR, Grande GHD, Vidal RVC, Ferrari G, Saraiva BTC, Christofaro DGD. Replacing sedentary time or light physical activity with moderate physical activity is associated with a lower prevalence of back pain: a cross-sectional study using isotemporal analysis. Braz J Phys Ther. 2024;28(5):101123. doi:10.1016/j.bjpt.2024.101123.

[27] Cuschieri A, Shaw C, Farrugia M, Borg N, Cuschieri S. Low back pain among medical students: a meta-analysis of a growing global public health concern. Eur

J Public Health. 2025;35(Suppl 4):ckaf161.1184. doi:10.1093/eurpub/ckaf161.1184.

[28] Alanazi S, Alruwaili J, Alruwaili M, Alfayyadh A, Alsirhani H, Alowaydhah SM, Alanazi SA, Allam NM, Elsebahy S. Mapping the prevalence and risk factors of low back pain among university populations in Saudi Arabia: a systematic review and meta-analysis. J Clin Med. 2026;15(7):2808. doi:10.3390/jcm15072808.

[29] Nordin M, Frankel VH. Basic Biomechanics of the Musculoskeletal System. 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2012.

[30] Freitas SR, Mendes B, Le Sant G, Andrade RJ, Nordez A, Milanovic Z. Can chronic stretching change the muscle-tendon mechanical properties? A review. Scand J Med Sci Sports. 2018;28(3):794-806. doi:10.1111/sms.12957.

[31] Cai P, Liu L, Li H. Dynamic and static stretching on hamstring flexibility and stiffness: a systematic review and meta-analysis. Heliyon. 2023; 9(8): e18795. doi:10.1016/j.heliyon.2023.e18795.

[32] Konrad A, Alizadeh S, Daneshjoo A, et al. Chronic effects of stretching on range of motion with consideration of potential moderating variables: a systematic review with meta-analysis. J Sport Health Sci. 2024;13(2):186-194. doi:10.1016/j.jshs.2023.06.002.

[33] Behm DG, Alizadeh S, Daneshjoo A, Hadjizadeh Anvar S, Graham A, Zahiri A, Goudini R, Edwards C, Culleton R, Scharf C, Konrad A. Acute effects of various stretching techniques on range of motion: a systematic review with meta-analysis. Sports Med Open. 2023;9:107. doi:10.1186/s40798-023-00652-x.

[34] Cayco CS, Labro AV, Gorgon EJR. Hold-relax and contract-relax stretching for hamstrings flexibility: a systematic review with meta-analysis. Phys Ther Sport. 2019;35:42-55. doi:10.1016/j.ptsp.2018.11.001.

[35] Lim W. Optimal cut-off values of the active knee extension test for diagnosing hamstring tightness. J Bodyw Mov Ther. 2024; 40: 1769-1773.

[36] Olivencia O, Godinez GM, Dages J, Duda C, Kaplan K, Kolber MJ. The reliability and minimal detectable change of the Ely and Active Knee Extension Tests. Int J Sports Phys Ther. 2020;15(5):776-782. doi:10.26603/ijspt20200776.

[37] Williams SA, Sharma S, Cashin AG, Jones MD, Chiarotto A, Hansford HJ, Venter M, Wewege MA, Ferraro MC, Devonshire JJ, Gustin SM, Ostelo RWJG, McAuley JH. Test-retest reliability and measurement error of the numerical rating scale and visual analogue scale in people with low back pain. J Pain. 2025;35:105528. doi:10.1016/j.jpain.2025.105528.

[38] Gou Y, Lei H, Chen X, Wang X. The effects of hamstring stretching exercises on pain intensity and function in low back pain patients: a systematic review with meta-analysis of randomized controlled trials. SAGE Open Med. 2024;12:20503121241252251. doi:10.1177/20503121241252251.

[39] Kang YH, et al. Effect of muscle energy technique on hamstring flexibility: systematic review and meta-analysis. Healthcare (Basel). 2023;11(8):1089. doi:10.3390/healthcare11081089.

[40] Rampazo EP, Luz Júnior MA, Corrêa JB, Oliveira NTB, Santos I, Liebano RE, Costa LOP. Effectiveness of interferential current in patients with chronic non-specific low back pain: a systematic review with meta-analysis. Braz J Phys Ther. 2023;27(5):100549. doi:10.1016/j.bjpt.2023.100549.

[41] Hayden JA, Ellis J, Ogilvie R, Malmivaara A, van Tulder MW. Exercise therapy for chronic low back pain. Cochrane Database Syst Rev. 2021;9:CD009790. doi:10.1002/14651858.CD009790.pub2.