

# Spinal Flexibility And Musculoskeletal Health In Adolescents: A Conceptual Synthesis Of Yogic Sukshma Vyayama

Lata<sup>1</sup>, Priti<sup>2</sup>, Dr. Gurneet Kaur<sup>3</sup>

<sup>1</sup>Research scholar, University of Patanjali, Haridwar, Orchid ID: <https://orcid.org/0009-0006-7127-2507>,  
Email ID: pathaklata42@gmail.com

<sup>2</sup>Research Scholar, University of Patanjali, Haridwar, Orchid ID: <https://orcid.org/0009-0002-6085-561X>  
Email ID: Ch.priti1310@gmail.com

<sup>3</sup>Assistant Professor, University of Patanjali, Haridwar, Email ID: gurneetkaur221@gmail.com

---

## Abstract

The position of adolescent spinal discomfort and postural dysfunction is increasingly recognized as a predisposing factor to chronic musculoskeletal illnesses. Epidemiological data show that low back pain often begins during adolescence and can persist into adulthood, underscoring the need to prioritize preventive measures. The progression of the spine at such a rate, along with alterations in biomechanical loading and the development of neuromuscular control, makes the adolescent spine both very flexible and easy to damage. This narrative review summarizes evidence on developmental biomechanics, normative flexibilities, and randomized controlled trials of yoga programs to explore the potential of Sukshma Vyayama as an intervention to improve spinal flexibility and musculoskeletal well-being. The adult clinical trials consistently show the enhancement of spinal mobility, functional capacity, and neuromuscular coordination after the planned yoga practices. Theoretically, the micro-motions of Sukshma Vyayama, which are low-load, segmental, and breath-coordinated, are in agreement with developmental spinal mechanisms. The evidence is convergent, though adolescent-specific trials are few, suggesting that structured micro-movement protocols can be an effective school-based preventive strategy. These mechanistic and clinical implications should be proven by further longitudinal studies.

**Keywords:** adolescent spine, spinal flexibility, musculoskeletal health, Sukshma Vyayama, yoga therapy, biomechanics, school-based intervention

**How to cite this article:** Lata, Priti, Kaur G. Spinal Flexibility And Musculoskeletal Health In Adolescents: A Conceptual Synthesis Of Yogic Sukshma Vyayama. *Int J Drug Deliv Technol.* 2026;16(59s): 1603-1607. DOI: 10.25258/ijddt.16.59s.180

**Source of support:** Nil

**Conflict of interest:** None

---

## Introduction

The pain in the lower back is no longer considered a problem of adults. Empirical research shows that many children and adolescents complain of the presence of low back pain during their school age. A meta-analysis has indicated that low back pain is highly prevalent among this age group and it grows with age (Calvo-Muñoz et al., 2013). Similarly, school-based studies have found a significant prevalence of nonspecific low back pain in adolescents aged 13-15 years of age (Masieri et al., 2008). The findings are indicative of the fact that spinal discomfort begins at an early age, and it ought to be regarded as a relevant public healthcare issue.

There is also longitudinal evidence suggesting that low back pain in adolescence can carry into adult life. A follow-up study of eight years showed that teenagers affected by back pains are inclined to develop chronic symptoms in adulthood (Hestbaek et al., 2006). This continuity emphasizes the role that early preventive measures play, as opposed to preventing the emergence of chronic conditions.

This is also increasing due to modern lifestyle issues. Often, computers, long sitting, and poor digital posture were linked with high levels of neck, shoulder, and low

back pains among adolescents (Hakala et al., 2002). Inactive lifestyles and the underlying rapid rate of spinal development at puberty may increase the mechanical stress of developing the spine.

Although yoga has revealed an evident impact on the spinal health of adult patients, its direct mechanistic use on the spinal flexibility of adolescents, especially regarding soft micro-movements like Sukshma Vyayama, has not been properly investigated. In this paper, developmental biomechanics evidence will be synthesized with clinical yoga evidence to suggest a conceptual model of the relationship between Sukshma Vyayama and adolescent spinal flexibility and musculoskeletal health.

## Methodological Approach

The methodological approach used in this manuscript is the narrative review because it incorporates interdisciplinary evidence relating to adolescent spinal flexibility and musculoskeletal health. A systematic search of peer-reviewed articles was conducted in various areas such as adolescent spinal epidemiology, developmental biomechanics, sensorimotor control, and

randomized controlled trials assessing the use of yoga-based interventions. Specific attention was paid to the studies that are registered in the main scientific databases and published in the high-impact periodicals. The accumulated evidence was synthesized in a conceptual manner to create a mechanistic model, which would connect Sukshma Vyayama to spinal conditioning in adolescence.

### **Developmental Anatomy and Biomechanics of the Adolescent Spine**

Adolescence is a specific stage of spinal development, which is characterized by intensive somatic growth and simultaneous structural remodeling. There are complex morphological changes in the vertebral bodies, intervertebral discs, and the nearby soft tissues during this period. Biomechanical modelling has shown that changes in the geometry of the vertebra with growth may modulate the segmental stiffness, load distribution, and the motion pattern in the spinal unit (Meijer et al., 2010). The elongation of the spine and its reformation also lead to a change in mechanical behavior and make it unique compared to the spinal structure in children and adults.

Not all parts of the spinal constituents grow at the same rate. Vertebral body and posterior element growth may alter the segmental loading, which may temporarily reduce mechanical stability and predispose instability to imbalance, especially when external loading (such as prolonged sitting, sustained poor postures) is placed. In the period of puberty, the skeletal lengthening can proceed faster than muscular adaptation, resulting in relative muscular tightness, asymmetry or weakness. These neuromuscular disproportions may change the spinal positioning and decrease the flexibility.

Normative information about the lumbar range of motion indicates a changing spinal mobility during childhood and adolescence, and these changes are associated with the current maturation of joint apparatus and neuromuscular control systems (Kondratek et al., 2007). Though the teenage spine is highly adaptable and has got a good level of motion ability, the flexibility is regulated by the growth dynamics and activity.

A combination of these factors can be described as a mechanically loose and vulnerable adolescent spine. It has the capacity of positive conditioning with the use of suitable movement but it has been sensitive to sustained sedentary loading and postural strains. This duality is critical to be understood in designing preventive and remedial measures that will help protect the spinal health in adolescence.

### **Spinal Flexibility and Sensorimotor Development in Adolescence**

Spinal flexibility in adolescence is a multidimensional concept that goes beyond being a simplistic concept of range of motion. ROM lumbar measurement (ROM) provides objective information on the spinal mobility, and it indicates the functional potential of vertebral joints and the surrounding soft tissues. The normative data show that spinal mobility changes during childhood and adolescence, which depend on the skeletal development, the levels of physical activity, and the maturation of the

neuromuscular system. Population assessments of the sit and reach test also indicate age- and sex-specific differences in flexibility at different stages of development (He et al., 2023), which highlights the idea that the flexibility changes simultaneously with the general development of the musculoskeletal system.

Structured interventions of stretching are also found to have adaptive responses in adolescent populations. Surveys that have compared the effects of prepubertal and pubertal boys in stretching in comparison to strength training have reported significant improvements in flexibility, which implies that the maturing musculoskeletal system is still open to intensive mobility interventions (Zakas et al., 2002). However, the flexibility cannot be diminished only to passive extensibility.

In this regard, sensorimotor determinants are at the center stage. The lumbar repositioning studies show that the proprioceptive accuracy of adolescents with low back pain is worse compared to that of their asymptomatic peers (Astfalek et al., 2013), which underlines the significant level of importance of joint-position sense to spinal health. Research studies also show that proprioceptive accuracy is enhanced by age as the neuromuscular control is better developed (Goble et al., 2005).

Overall, these results suggest that adolescent spinal plasticity is a combination of joint, muscle and proprioceptive plasticity. Flexibility therefore should not be interpreted as simply an increase in the range of motion, but a complex consequence of the neuromuscular coordination as well as sensorimotor refinement.

### **Clinical Evidence of Yoga for Spinal Function**

There is a considerable amount of randomized controlled trials which have investigated the effects of yoga on the spinal function, especially in chronic low back pain patients. It has been shown that yoga-based interventions may enhance spinal mobility, decrease pain and increase functional capacity. A brief, intensive program in yoga led to a considerable increase of flexibility of the spine in a controlled trial with lessening pain and disability (Tekur et al., 2008). The research is especially topical since objective measurements of the motion range of the spine were involved, which proves that yoga can affect the mechanical mobility of the lumbar spine positively.

The clinical evidence has also been enhanced by large randomized trials. A pragmatic trial showed that yoga resulted in significant back pain reduction and functional outcome improvement as compared to standard care (Tilbrook et al., 2011). On the same note, a comparative study involving yoga, stretching, and self-care education using randomized controlled trial concluded that yoga was as effective as a traditional stretching program in relieving back-related functionality (Sherman et al., 2011). A second trial carried out in a spine-specialty setting demonstrated that Iyengar yoga had a profound impact on the reduction of the degree of pain and disability among patients with persistent back pain (Williams et al., 2009).

Notably, yoga has also been compared with proven medical procedures. The study of yoga in comparison

with physical therapy revealed that yoga was not any worse in the treatment of back-related functionality (Saper et al., 2017), and thus it can be regarded as a clinically viable alternative. According to dosing research, 1 and 2 classes of yoga per week may demonstrate results, which means that the design of the program is flexible (Saper et al., 2013). In modern times, virtual yoga delivery has been proven to be effective, which points to the possibility and availability for a wide range of people (Tankha et al., 2024).

Despite the fact that the majority of evidence is based on the adult population, the identified improvements in the range of motion, muscle endurance, and neuromuscular coordination bring mechanistic information. The mechanisms can be conceptually applied to adolescents, especially when modified to the developmental requirements and implemented using age-adequate protocols.

### **Conceptual Integration: Sukshma Vyayama as a Micro-Mobilization Strategy**

The exercise can be said to be Sukshma Vyayama, which can be outplayed as a structured low-load, segmental, and repetitive joint mobilization which can take place alongside regulated breathing. Unlike the high-intensity stretching or intensive movements of the spine, in this method, special emphasis is placed on the smooth flexion, extension, lateral bending, and rotation of the spine under an easy scale of motion. Biomechanically, such a controlled mobilization can be seen to be especially appropriate to the growing spine.

Three-dimensional structural changes in the vertebral development process of adolescents contribute to changes in stiffness and load distribution within segments of the spinal motion (Meijer et al., 2010). It is in this context that mild forms of spinal flexion and extension may help in promoting patterns of physiological loading that promote the nutrition of intervertebral discs through cyclic compression and decompression. Similarly, segmental rotational movements can be used to increase the circulation of the synovial fluid in facet joints, which could increase joint lubrication and maintain its mobility.

Monotonous micro-motions can also cause an action on the mechanoreceptors of the spinal tissues, which can enhance proprioceptive feedback. The lumbar repositioning studies indicate that the adolescents with disturbed proprioceptive accuracy experience impaired spinal control (Astfalck et al., 2013). Therefore, low-amplitude, repetitive movements can be helpful in terms of the fine sensorimotor integration. Also through clinical trials on adults, it has been more suggested that structured yoga practices can enhance spinal flexibility and functional capacities (Tekur et al., 2008), which implies that mobility-based interventions can have a positive impact on musculoskeletal functioning.

These movements can also facilitate the autonomic regulation when coordinated with rhythmic breathing, with neuromuscular relaxation, and coordinated activation patterns. Collectively, Sukshma Vyayama can be considered a developmentally relevant, low-impact spinal conditioning protocol, which complies with the

mechanical and sensorimotor properties of the teenage spine.

### **School-Based Application and Preventive Potential**

School settings are a feasible and modifiable setting in which structured movement-based interventions may be applied to improve the spinal health of adolescents. Randomized controlled trials show that yoga programmes could be implemented in schools without the interference with the academic periods. To illustrate, a case of yoga intervention in schools improved the well-being of students and showed high participation rates, which justified its applicability to a regular educational routine (Frank et al., 2017). Similarly, research with high-risk teenagers has demonstrated that the organized yoga programs were well acceptable and yielded psychophysiological results, hence making them safe and acceptable (Fishbein et al., 2016).

Among younger school-going groups, yoga programs have been conducted throughout regular lessons with minimal negative incidences, which suggests that the risk of injury is minimal when the activities are well monitored and tailored to the age (Hagins et al., 2013). This safety profile is consistent with the gentle nature of Sukshma Vyayama, a low-load exercise. More so, short, scheduled sessions will facilitate compliance because it can be integrated into physical education programs with the least physical demands. Therefore, the introduction of the so-called micro-movement protocols into school-based programmes can become a preventive measure to maintain flexibility of the spine and musculoskeletal health during adolescence.

### **Research Gaps and Future Directions**

Despite the current theoretical evidence on Sukshma Vyayama as a strategy of spinal conditioning, there are some fundamental gaps in research. Most clinical evidence relating to yoga and spinal mobility has been based on adult population and there is conspicuous gap in the literature on adolescent-specific randomized controlled trials, measuring the effect of yoga on spinal range of motion changes after a practice of Sukshma Vyayama. There is insufficient information assessing objective biomechanical outcomes in school-aged cohorts in existing literature.

Future studies should use standardized and measurable variables, including lumbar goniometry to determine segmental range of motion, three-dimensional motion capture to determine movement quality, electromyography of paraspinal muscles to assess neuromuscular activation pattern, and lumbar repositioning error test to assess proprioceptive control. Such objective tools would be used to support mechanistic information regarding the effects of micro-movement interventions in modulating spinal functioning.

The longitudinal, school-based trials are particularly necessary to test the preventive potential in the long run. A 10 -15-minute Sukshma Vyayama protocol used as an 8-12-week randomized sample intervention program in physical education programs would produce practical, ecologically valid data. These study designs are capable

of explaining short term biomechanical adaptations and long term musculoskeletal benefits in adolescents.

### Conclusion

The most common issues that have been mentioned in adolescents include spinal pain and postural problem which are manifestations of a change in lifestyle and the increased sedentary tendency. At this critical stage of development, the vertebral development and the maturation of neuromuscular coordination make the spine both flexible and susceptible to mechanical forces. Premature dysfunctions in mobility and posture can be continued in adulthood, thus the urgent need to develop preventive measures that are non-invasive, accessible, and developmentally favorable.

In adult populations, it has been shown by clinical methods that yoga-based programs increase spinal mobility, functional capacity, and neuromuscular control. The biomechanical and sensorimotor processes of these advantages provide a solid conceptual framework for adapting to younger populations, although few trials have been conducted in adolescents. Yogic Sukshma Vyayama, characterized by the micro-movements that are gentle, segmented, and accompanied by breath movements, is in line with the mechanical and developmental qualities of the adolescent spine.

Through the combination of developmental biomechanics and evidence-based yoga philosophy, Sukshma Vyayama can become a promising low-impact form of conditioning. Potentially one of the cost-effective, developmentally-consistent ways to maintain musculoskeletal health throughout the lifespan could be early spinal conditioning through organized micro-movement yogic practice.

### REFERENCES

1. Astfalck, R. G., O'Sullivan, P. B., Smith, A. J., Straker, L. M., & Burnett, A. F. (2013). Lumbar spine repositioning sense in adolescents with and without non-specific chronic low back pain—An analysis based on sub-classification and spinal regions. *Manual Therapy*, 18(5), 410–417. <https://doi.org/10.1016/j.math.2013.02.005>
2. Calvo-Muñoz, I., Gómez-Conesa, A., & Sánchez-Meca, J. (2013). Prevalence of low back pain in children and adolescents: A meta-analysis. *BMC Pediatrics*, 13, 14. <https://doi.org/10.1186/1471-2431-13-14>
3. Fishbein, D., Miller, S., Herman-Stahl, M., Williams, J., Lavery, B., Markovitz, L., Johnson, M., & Sussman, S. (2016). Behavioral and psychophysiological effects of a yoga intervention on high-risk adolescents: A randomized controlled trial. *Journal of Child and Family Studies*, 25(2), 518–529. <https://doi.org/10.1007/s10826-015-0231-6>
4. Frank, J. L., Kohler, K., Peal, A., & Bose, B. (2017). Effectiveness of a school-based yoga program on adolescent mental health and school performance: Findings from a randomized controlled trial. *Mindfulness*, 8(3), 544–553. <https://doi.org/10.1007/s12671-016-0628-3>
5. Goble, D. J., Lewis, C. A., Hurvitz, E. A., & Brown, S. H. (2005). Development of upper limb proprioceptive accuracy in children and adolescents. *Human Movement Science*, 24(2), 155–170. <https://doi.org/10.1016/j.humov.2005.05.004>
6. Hagins, M., Haden, S. C., & Daly, L. A. (2013). A randomized controlled trial on the effects of yoga on stress reactivity in sixth-grade students. *Evidence-Based Complementary and Alternative Medicine*, 2013, Article 607134. <https://doi.org/10.1155/2013/607134>
7. Hakala, P. T., Rimpelä, A. H., Saarni, L. A., & Salminen, J. J. (2002). Frequent computer-related activities increase the risk of neck–shoulder and low back pain in adolescents. *BMJ*, 325(7367), 743. <https://doi.org/10.1136/bmj.325.7367.743>
8. He, H., Pan, L., Wang, D., Du, J., Pa, L., Wang, H., Zhao, J., Peng, X., & Shan, G. (2023). The normative values of vertical jump and sit-and-reach in a large general Chinese population aged 8–80 years: The China National Health Survey. *Global Transitions*, 5, 141–148. <https://doi.org/10.1016/j.glt.2023.08.003>
9. Hestbaek, L., Leboeuf-Yde, C., Kyvik, K. O., & Manniche, C. (2006). The course of low back pain from adolescence to adulthood: Eight-year follow-up of 9,600 twins. *Spine*, 31(4), 468–472. <https://doi.org/10.1097/01.brs.0000199958.04073.d9>
10. Kondratek, M., Krauss, J., Stiller, C., & Olson, R. (2007). Normative values for active lumbar range of motion in children. *Pediatric Physical Therapy*, 19(3), 236–244. <https://doi.org/10.1097/PEP.0b013e3180f61c43>
11. Masiero, S., Carraro, E., Celia, A., Sarto, D., & Ermani, M. (2008). Prevalence of nonspecific low back pain in schoolchildren aged between 13 and 15 years. *Acta Paediatrica*, 97(2), 212–216. <https://doi.org/10.1111/j.1651-2227.2007.00603.x>
12. Meijer, G. J. M., Homminga, J., Hekman, E. E. G., Veldhuizen, A. G., & Verkerke, G. J. (2010). The effect of three-dimensional geometrical changes during adolescent growth on the biomechanics of a spinal motion segment. *Journal of Biomechanics*, 43(8), 1590–1597. <https://doi.org/10.1016/j.jbiomech.2010.01.028>
13. Saper, R. B., Boah, A. R., Keosaian, J., Weinberg, J., Sherman, K. J., & Davis, R. B. (2013). Comparing once- versus twice-weekly yoga classes for chronic low back pain in predominantly low-income minorities: A randomized dosing trial. *Evidence-Based Complementary and Alternative Medicine*, 2013, Article 658030. <https://doi.org/10.1155/2013/658030>

14. Saper, R. B., Sherman, K. J., Delitto, A., et al. (2017). Yoga, physical therapy, or education for chronic low back pain: A randomized noninferiority trial. *Annals of Internal Medicine*, 167(2), 85–94. <https://doi.org/10.7326/M16-2579>
15. Sherman, K. J., Cherkin, D. C., Wellman, R. D., Cook, A. J., Hawkes, R. J., Delaney, K., & Deyo, R. A. (2011). A randomized trial comparing yoga, stretching, and a self-care book for chronic low back pain. *Archives of Internal Medicine*, 171(22), 2019–2026. <https://doi.org/10.1001/archinternmed.2011.524>
16. Tankha, H., Keosaian, J. E., & Saper, R. B. (2024). Effectiveness of virtual yoga for chronic low back pain: A randomized clinical trial. *JAMA Network Open*, 7(11), e2442339. <https://doi.org/10.1001/jamanetworkopen.2024.42339>
17. Tekur, P., Singphow, C., Nagendra, H. R., & Raghuram, N. (2008). Effect of short-term intensive yoga program on pain, functional disability, and spinal flexibility in chronic low back pain: A randomized control study. *Journal of Alternative and Complementary Medicine*, 14(6), 637–644. <https://doi.org/10.1089/acm.2007.0815>
18. Tilbrook, H. E., Cox, H., Hewitt, C. E., Kang'ombe, A. R., Chuang, L. H., Jayakody, S., Aplin, J. D., Semlyen, A., Trewhela, A., Watt, I., & Torgerson, D. J. (2011). Yoga for chronic low back pain: A randomized trial. *Annals of Internal Medicine*, 155(9), 569–578. <https://doi.org/10.7326/0003-4819-155-9-201111010-00003>
19. Williams, K. A., Petronis, J., Smith, D., Goodrich, D., Wu, J., Ravi, N., Doyle, E. J., Juckett, R. G., Munoz Kolar, M., Gross, R., & Steinberg, L. (2009). Effect of Iyengar yoga therapy for chronic low back pain. *Spine*, 34(19), 2066–2076. <https://doi.org/10.1097/BRS.0b013e3181b315cc>
20. Zakas, A., Galazoulas, C., & Grammatikopoulou, M. G. (2002). Effects of stretching exercise during strength training in prepubertal, pubertal and adolescent boys. *Journal of Bodywork and Movement Therapies*, 6(3), 170–176. [https://doi.org/10.1016/S1360-8592\(01\)90275-X](https://doi.org/10.1016/S1360-8592(01)90275-X)