Pinch Strength Measurements in Adolescents With Pediatric Multiple Sclerosis

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ABSTRACT

BACKGROUND: Multiple sclerosis (MS) is a degenerative disease with typical onset between 20 and 50 years of age. An increase in MS cases has been found in the adolescent US population. Adolescents require fine motor manipulation skills for their functional and academic performance. Deficits in the major components of manipulation skills may result in insufficient function. This study examined the 2-point, 3-point, and lateral pinch strength of adolescents diagnosed as having MS.

METHODS: Seventy-four adolescents, 37 with a diagnosis of relapsing-remitting MS and a control group of 37 age-matched peers, participated in this study. Data on 2-point, 3-point, and lateral pinch strength in both hands were collected using a pinch meter. Analyses of covariance were used to describe differences across the 2 groups, and effect sizes (Cohen *d*) were calculated by finding the mean difference between the study groups divided by the pooled SD.

RESULTS: A significant difference was found in the 2-point pinch strength of the right hand of participants with pediatric MS compared with age- and sex-matched control participants. There were no significant differences in 2-point pinch strength of the left hand or in 3-point or lateral pinch strength of the right and left hands.

CONCLUSIONS: Pinch grasp strength was differentially affected in adolescents with MS. Pinch strength should be assessed and considered in adolescents with MS for a better understanding of their functional performance of fine motor tasks in activities of daily living and academics.

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Multiple sclerosis (MS) is an immune-mediated disorder in which there is an attack on the myelin sheath that protects the central nervous system's neurons.[1] It presents with diverse symptoms, including weaknesses, spasticity, ataxia, fatigue, pain, depression, speech and swallowing disorders, and cognitive delays. The result of this complex presentation can be adverse effects in the ability to accurately perform functional tasks such as activities of daily living (ADLs).

Currently, 2.2% to 5.0% of all MS cases have onset before 16 years of age.[2] Rarely, individuals younger than 10 years may be diagnosed.[3-5] Patients diagnosed as having pediatric MS frequently relapse multiple times early in the disease progression, and this inflammatory lesion burden places patients at increased risk for cognitive and physical difficulties as they age, including functional deficits.[6-8] Those with pediatric MS transition to a progressive phase more gradually than adults, but they may reach any given impairment level at a younger age.[9] In pediatric MS, recovery between relapses seems to be more complete than in adults with MS.[10]

Weaknesses may not be reported by adolescents in the early stages of MS because when they find themselves without sufficient endurance and strength during fine motor task performance, they turn to compensatory strategies to accomplish their ADLs. Thus, sensory and cognitive deficiencies, including grip pinch weakness, are often overlooked and reported later in the disease process.[11,12] Because deficits in fine motor control may predict the future severity of MS in a younger population, addressing this issue early may avoid disease complications related to function and quality of life.

Neural degeneration in MS leads to deficits in the major components of motor manipulation skills, such as speed, strength, and coordination, resulting in insufficient functional performance.[13] Sufficient digital muscle strength is required to initiate and maintain appropriate grasp patterns while pinching and grasping. An inability to coordinate fine motor movements and forces may lead to difficulty with common ADLs that require fine motor strength and precision.[14] Daily

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TABLE 1. Number of Participants by Age, Sex, and Handedness

Age, y	Boys, No.		Girls, No.		EDSS score
	MS status	Handedness, R/L	MS status	Handedness, R /L	
13	MS: 0	0/0	1	1/0	0.0-2.5
	Control: 2	0/0	1	1/0	
14	MS: 2	1/0	3	3/0	0.0-0.0
	Control: 1	1/0	3	3/0	
15	MS: 3	2/1	5	5/0	1.0-3.0
	Control: 2	2/0	5	4/1	
16	MS: 4	4/0	10	9/1	0.0-3.5
	Control: 4	4/0	10	9/1	
17	MS: 4	4/0	5	5/0	1.0-4.0
	Control: 4	4/0	5	5/0	
Total	MS: 13	11/1	24	23/1	
	Control: 13	11/0	24	22/2	

EDSS, Expanded Disability Status Scale; L, left; MS, multiple sclerosis; R, right.
Note: MS group n = 37; control group n = 37. The mean EDSS score was 1.5 (range, 0.0-4.0).

living tasks, such as buttoning or zipping, turning a key, or eating with utensils, require the strength and precision of a 2-point pinch grasp using the intrinsic muscles of the hands.[15] These movements require rapid, repetitive action without fatigue, and weakness can affect these fine motor movements. The combination of fatigue and digital muscle weakness may also affect the occupational functional skills needed during the high school years, which require digit speed and strength. Adolescents may have vocational coursework, must master keyboard manipulation, and have increased note-taking and written work that demands skilled manipulation of writing tools. Delays in these higher-functioning hand abilities may result in loss of productivity, decreased ability to manage schoolwork, and insufficient ADL skills required for appropriate social, postsecondary, and community integration.

Chen et al[16] found that in adults with MS, motor skills involving pinch strength and pinch grip are correlated with manual ability due to the essential need for finger strength and dexterity to perform most ADL. In a study examining a simple manipulation requiring precision grip to lift an object, individuals with mild MS displayed weakened grip and load coordination and a deteriorated ability to accurately apply the load force needed for manipulation tasks.[17] During typical development, the central nervous system matures so that it can regulate the appropriate isometric forces needed to create a stable pinch force.[18] However, interference in this developmental motor process, due to demyelination of the motor neuron, may result in impaired neural network functioning and lead to decreased coordination of grasp and pinch in adolescents with MS. In a preliminary study, Squillace et al found that there were no significant differences in gross grasp strength between adolescents with MS and age-matched peers. However, difficulty with coordination was noted and was attributed to the intrinsic weaknesses of the hands affecting pinch strength and not solely gross grasp strength. The present study aimed to determine whether pinch grasp weakness is present in adolescents with MS and whether the use of objective measures of muscle strength of the digits and hands could help determine early signs of deficits in adolescents with MS.

METHODS

Research Design

In a quantitative descriptive study, we examined and compared 3 types of pinch strength—2-point, 3-point, and lateral—in adolescents with MS and age- and sex-matched peers without MS.

Participants

The institutional review board of Stony Brook University approved this study. All participants provided assent, with informed consent provided by parents or legal guardians. The adolescents with MS had an established diagnosis for at least 1 year; met the diagnostic criteria for pediatric MS[19]; had an Expanded Disability Status Scale[20] score of 4 or less; was aged 13 to 17 years; was enrolled in school; had no history of neurologic or physical impairment that might affect testing results; had sufficient visual ability to perform testing; and did not take any disease-modifying therapy or other medications. Control participants were recruited to match the age and sex of the participants with MS and were excluded only if they had orthopedic or neurologic conditions that prevented completion of the tasks (TABLE 1). Of the participants with MS, 34 were right-handed and 2 were left-handed (1 girl and 1 boy). Of the control group, 33 were right-handed and 2 were left-handed (both girls).

Instruments

The level of neurologic impairment was screened by a neurologist using the Expanded Disability Status Scale.[20] The Baseline Mechanical Pinch Gauge (model 12-0200; Baseline Instruments, 2009) was used to assess 3 types of pinch

PRACTICE POINTS

Clinicians should routinely evaluate the strength of 3 functional pinch grasps in adolescents with multiple sclerosis, with particular emphasis on evaluating 2-point pinch.

Pinch grasp strength is differentially affected in adolescents with multiple sclerosis. Impairments in pinch strength could affect academic performance and activities of daily living in this population.

Unaddressed pinch weakness in adolescents with multiple sclerosis may limit their participation in daily-life, vocational, and academic activities as they transition to adulthood. ■

strength: 2-point, 3-point, and lateral pinch (**FIGURE 1**). The units of measure for the pinch gauge are pounds per pressure. The pinch gauge has been shown to be a valid and reliable measure of the 3 types of pinch and was chosen due to its accuracy.[21]

Procedures

During a scheduled appointment with a neurologist at a pediatric MS center, participants with MS were seen by a licensed and registered occupational therapist familiar with pinch gauge equipment. The participants without MS were seen in their homes or at a local community center following an after-school program. Data were collected by a single rater, and assessment took approximately 15 minutes per participant, with rest given as needed between each pinch assessment.

First, informed consent was obtained, the medical record was reviewed, and a health history form was completed. Then the participants were given oral and demonstrative descriptions of the testing procedures and the purpose of the testing. Each participant was tested individually in a quiet room seated upright with their upper extremities adducted against their body and elbows flexed at 90°. Participants started with the right hand and were asked to squeeze as hard as possible for 3 trials of each pinch type in the following order: 2-point, 3-point, and lateral. The trials were then repeated with the left hand. The average of the 3 trials for each pinch type was calculated and used for analysis.[22]

FIGURE 1. Testing Grip Patterns

Retrieved with permission from Pinch Gauge Norms and Testing Protocols (prohealthcareproducts.com, 2021)

Data Analysis

Statistical software (IBM SPSS Statistics for Windows, version 22.0; IBM Corp) was used to generate a 1-way analysis of covariance for each of the 3 pinch grasps to look for group differences between adolescents with and without MS using age and sex as covariates. Means and SDs of strength for the 3 pinch types on the pinch meter were recorded. Significance was set at $P < .05$. Because no difference was found for dominance, right- and left-handed participants were combined for all reported analyses. Effect size (Cohen *d*) was found by calculating the mean difference between the study and control groups and dividing by the pooled SD.[23] Salkind and Frey[23] define effect size ranges as small (0-0.2), medium (>0.2-0.8), and large (>0.8).

RESULTS

Seventy-four individuals aged 13 to 17 years agreed to participate and were included in the study: 37 participants with MS and 37 age- and sex-matched control participants. Analysis of covariance did not reveal age as a significant contributor; sex significantly affected the results of all comparisons except 2-point pinch of the right hand.

2-Point Pinch

Adolescent participants with MS displayed deficits in 2-point pinch strength of the right hand compared with their peers without MS. Participants with MS generated approximately 0.5 lb less force (mean ± SD, 3.5 ± 1.2 lb) than those without MS (mean ± SD, 4.0 ± 1.1 lb) ($F = 4.1$; $P = .04$) during 2-point right hand pinch grasp performance, demonstrating a strength difference with a moderate effect size ($d = 0.43$) (**TABLE 2**). Similar to the right hand, participants with MS produced less force during 2-point pinch with the left hand (mean ± SD, 3.4 ± 1.2lb) compared with the control group (mean ± SD, 3.7 ± 0.91), but this did not reach significance ($F = 2.3$; $P = .13$) despite a moderate effect size ($d = 0.28$) (Table 2).

3-Point Pinch

Between the participants with MS and the control group, there was no significant difference in mean ± SD 3-point pinch strength for either hand (right hand: MS—5.1 ± 1.5; control—5.1 ± 1.3; $F = .18$; $P = .67$ and left hand: MS—4.7 ± 1.5; control—4.9 ± 1.0; $F = .09$; $P = .90$) (Table 2). Although average force generation on the right was the same (ie, no effect size), the adolescents with MS averaged 0.2 lb of pressure less on the left hand with a small effect size ($d = 0.15$), further suggesting that the difference is not clinically meaningful.

TABLE 2. Adjusted Mean ± SD Performance on 2-point, 3-point, and Lateral Pinch

Pinch type	Right hand, lb of pressure					Left hand, lb of pressure				
	MS group (n = 37)	Control group (n = 37)	*F*	*P* value	Cohen *d*	MS group (n = 37)	Control group (n = 37)	*F*	*P* value	Cohen *d*
2-point	3.5 ± 1.2[a]	4.0 ± 1.1[a]	4.1[a]	.04	0.043	3.4 ± 1.2	3.7 ± .91	2.3	.13	0.28
3-point	5.1 ± 1.5	5.1 ± 1.3	.18	.67	0.00	4.7 ± 1.5	4.9 ± 1.0	.09	.90	0.15
Lateral	6.2 ± 1.8	6.1 ± 1.4	.03	.86	0.06	6.0 ± 2.1	6.0 ± 1.6	.10	.75	0.00

[a]Mean values significant at $P \leq .05$.

Lateral Pinch

Similar to 3-point pinch, lateral pinch showed no significant difference between the participants with MS and the control group for the right hand (mean ± SD: MS, 6.2 ± 1.8; control, 6.1 ± 1.4; F = .03; P = .86) and left hand (mean ± SD: MS, 6.0 ± 2.1; control, 6.0 ± 1.6; (F = 0.10; P = .75) (Table 2). Effect size was negligible for lateral pinch (d = 0.06 for right and d = 0.00 for left).

DISCUSSION

The corticospinal tract is the major pathway responsible for sending motor-related information from the brain to the spinal cord. Although this tract is involved with gross motor movements such as reaching, it is specifically engaged during individual digit movement.[24] If damage occurs to the corticospinal tract, the ability to regain full digit motor movements may be lost.[24] Thickbroom et al[25] found that corticomotor conduction is related to dexterity tasks, suggesting that a block in the corticospinal tract conduction may play a role in fine motor disability for those with MS.

Adults and adolescents with MS have physical impairments associated with muscle weakness.[4] Hojjatollah et al[26] found that reduced activity levels for this population may lead to muscle weakness and atrophy, and adults with MS show a 30% to 70% difference in muscle strength compared with a healthy adult population. In adults with MS, difficulties in ADLs have been linked to manual dexterity issues,[27] and the present findings suggest that similar issues may be present in adolescents with MS.

This study sought to determine whether digit muscle weakness is present in adolescents with MS and might partially explain this population's reported coordination deficits. The results indicated that adolescents show early deficits in 2-point pinch strength but maintain 3-point and lateral pinch strength at a similar level to their peers. A 2-point grasp requires precision matching of the index finger and thumb, and loss of this ability affects functional skills that apply to academics, ADL, and social behaviors.[28] This is especially important for adolescents who are developing prevocational skills and transitioning to adulthood, where higher-level skills are required for independence, postsecondary education, instrumental ADL, and health management.[28]

Interestingly, strength differences in 2-point pinch for adolescents with MS were not significantly explained by differences in age or sex. Although sex was a significant covariate for all other pinch variables tested, the significant effect for 2-point pinch strength seems to be the disease itself. In addition, the moderate effect size suggests that this difference is meaningful and may represent an important marker of disease in adolescence. There is evidence that fine motor concerns tend to emerge later in disease progression in pediatric MS than in adult-onset MS.[5,9,29] Yet impaired fine motor control is an important predictor of a diagnosis of MS in the younger population.[30] Adolescents with MS experience generalized muscle weakness, but little evidence had been found regarding a possible relationship between fine motor ability and pinch muscle strength in this population. Although adolescents with MS may be accomplishing functional ADLs, the outcome of these skills may be less efficient due to weakness.[31]

This study showed no differences in 3-point and lateral pinch strengths, which may suggest that participants are using bilateral vs unilateral hand movements as compensatory strategies to achieve good pinch strength in these pinch postures. Alternatively, the participants in this study may have compensated for impaired pinch grasp strength by using hand and wrist muscles. When the extrinsic muscles of the hand substitute for the intrinsic muscles that are designed for small repetitions, fatigue may occur. An interesting finding of the 3-point and lateral pinch tests showed that force production in the MS group was equivalent to or greater than that in the control group (Table 2). These differences were not statistically significant, but the trends are in the opposite direction of the 2-point findings. This may indicate that the participants with MS can incorporate the use of more proximal musculature and that their control peers isolated the intrinsic muscles. The 3-point and lateral pinch types are designed for sustained grasp. If an adolescent experiences fatigue during a prolonged functional task, substitutions of alternate muscle groups may occur to avoid a slower rate of manipulation. It is common for those with weakness to use a compensation to attempt to generate sufficient pinch strength to accurately perform the task, altering the grip configuration to increase power.[15,32] This likely accounts for the differences found in 2-point pinch strength and the other grasp postures.

Prehensile strength contributes to the ability of the intrinsic muscles of the hands to engage in coordinated movements. Krishnan and Jaric found a relationship between digital dexterity and grasp strength, but these findings were in adults with advanced stages of MS.[21] In adults with MS, grip and pinch strength are significantly decreased compared with age-matched non-MS peers. In addition, self-reported manual

skills are closely related to pinch strength needed for clinical assessment tasks.[16]

Fine motor manipulation deficits for adolescents with MS have been shown in previous studies that highlighted fine motor control and manipulation weaknesses, but not pinch strength.[5,33] The purpose of this study was to examine grasp patterns in adolescents with MS and determine whether they demonstrate impairments compared with adolescents without MS. Although this is a preliminary study, the findings suggest that 2-point pinch of the dominant hand may be a sensitive measure of disease. In addition, it may be clinically important to address intrinsic muscle strength in relation to functional performance for adolescents with MS.

CONCLUSIONS

This study examined whether there were differences in the 3 types of pinch strength in adolescents diagnosed as having MS compared with control participants. The results demonstrated that 2-point pinch strength was decreased bilaterally in the pediatric MS group, whereas 3-point and lateral pinch remained intact.

The findings of this study add to the current understanding of the status of grasp and potential compensations in adolescents with MS. Furthermore, the use of a standardized functional assessment tool to address specific areas of difficulty provides a better understanding of ADL, social, and academic deficits in individuals with MS. The results of this study indicate that specific weaknesses in the hand may affect functional skills and inform clinicians on the importance of functional interventions that incorporate fine motor strength when working with adolescents with MS. ■

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REFERENCES

1. Taylor DC, Davis CP. Multiple sclerosis (MS). Medicine Net. Accessed September 23, 2019. https://www.medicinenet.com/multiple_sclerosis_ms/article.htm#multiple_sclerosis_ms_facts
2. Ekmekci O, Yuceyar N, Sagduyu AK. Clinical features and course in pediatric onset multiple sclerosis. *J Neurol Sci*. 2012;29(4):804-809.
3. 3. Huppke B, Ellenberger D, Rosewich H, Friede T, Gärtner J, Huppke P. Clinical presentation of pediatric multiple sclerosis before puberty. *Eur J Neurol*. 2014;21(3):441-446. doi:10.1111/ene.12327
4. Squillace M, Ray S, Milazzo M. Changes in gross grasp strength and fine motor skills in adolescents with pediatric multiple sclerosis. *Occup Ther Health Care*. 2015;29(1):77-85. doi:10.3109/07380577.2014.967441
5. Ruggieri M, Iannetti P, Polizzi A, Pavone L, Grimaldi LM; Italian Society of Paediatric Neurology Study Group on Childhood Multiple Sclerosis. Multiple sclerosis in children under 10 years of age. *Neurol Sci*. 2004;25(suppl 4):S326-S335. doi:10.1007/s10072-004-0335-z
6. Ghezzi A, Banwell B, Boyko A, et al. The management of multiple sclerosis in children: a European view. *Mult Scler*. 2010;16(10):1258-1267. doi:10.1177/1352458510375568
7. Banwell B, Ghezzi A, Bar-Or A, Mikaeloff Y, Tardieu M. Multiple sclerosis in children: clinical diagnosis, therapeutic strategies, and future directions. *Lancet Neurol*. 2007;6(10):887-902. doi:10.1016/S1474-4422(07)70242-9
8. Boiko A, Vorobeychik G, Paty D, Devonshire V, Sadovnick D; University of British Columbia MS Clinic Neurologists. Early onset multiple sclerosis: a longitudinal study. *Neurology*. 2002;59(7):1006-1010. doi:10.1212/wnl.59.7.1006
9. Renoux C, Vukusic S, Mikaeloff Y, et al. Natural history of multiple sclerosis with childhood onset. *N Engl J Med*. 2007;356(25):2603-2613. doi:10.1056/NEJMoa067597
10. Kramer DR. Deep brain stimulation: a case-based approach. *Neurosurgery*. 2021;88(4):E356-E357.
11. Buchanan RJ, Chakravorty BJ, Tyry T, Hatcher W, Vollmer T. Age-related comparisons of people with multiple sclerosis: demographic, disease, and treatment characteristics. *NeuroRehabilitation*. 2009;25(4):271-278. doi:10.3233/NRE-2009-0525
12. Ness JM, Chabas D, Sadovnick AD, et al. Clinical features of children and adolescents with multiple sclerosis. *Neurology*. 2007;68(16)(suppl 2):S37-S45. doi:10.1212/01.wnl.0000259447 .77476.a9
13. Duff SV. Clinical assessment of dynamic hand control in pediatrics. *Dev Med Child Neurol*. 2010;52(10):888-889. doi:10.1111/j.1469-8749.2010.03728.x
14. Gorniak SL, Plow M, McDaniel C, Alberts JL. Impaired object handling during bimanual task performance in multiple sclerosis. *Mult Scler Int*. 2014;2014:450420. doi:10.1155/2014 /450420
15. Moerchen VA, Lazarus JC, Gruben KG. Task-dependent organization of pinch grip forces. *Exp Brain Res*. 2007;180(2):367-376. doi:10.1007/s00221-007-0864-9
16. Chen CC, Kasven N, Karpatkin HI, Sylvester A. Hand strength and perceived manual ability among patients with multiple sclerosis. *Arch Phys Med Rehabil*. 2007;88(6):794-797. doi:10 .1016/j.apmr.2007.03.010
17. Mathiowetz V, Wiemer DM, Federman SM. Grip and pinch strength: norms for 6- to 19-year-olds. *Am J Occup Ther*. 1986;40(10):705-711. doi:10.5014/ajot.40.10.705
18. Paré M, Dugas C. Developmental changes in prehension during childhood. *Exp Brain Res*. 1999;125(3):239-247. doi:10.1007/s002210050679
19. Krupp LB, Tardieu M, Amato MP, et al. International Pediatric Multiple Sclerosis Study Group criteria for pediatric multiple sclerosis and immune-mediated central nervous system demyelinating disorders: revisions to the 2007 definitions. *Mult Scler*. 2013;19(10):1261-1267. doi:10.1177/1352458513484547
20. Tarver ML. Kurtzke Expanded Disability Status Scale. Multiple Sclerosis Center for Excellence. U.S. Department of Veteran Affairs. 2009. Accessed January 29, 2020. https://www.va.gov/MS/Professionals/diagnosis/Kurtzke_Expanded_Disability_Status_Scale.asp
21. Krishnan V, Jaric S. Hand function in multiple sclerosis: force coordination in manipulation tasks. *Clin Neurophysiol*. 2008;119(10):2274-2281. doi:10.1016/j.clinph.2008.06.011
22. Baseline Instruments. Baseline Hydraulic Hand Pinch Meter Model 12-0200, 2009. Fabrication Enterprises Inc.
23. Salkind NJ, Frey BB. The one-sample *z* test: only the lonely. In: *Statistics for People Who (Think They) Hate Statistics*. Sage Publications Inc; 2020:186-198.
24. Dingman M. Know your brain: corticospinal tract. *Neuroscientifically Challenged* blog. Accessed September 27, 2016. https://www.neuroscientificallychallenged.com/blog/know-your -brain-corticospinal-tract
25. Thickbroom GW, Byrnes ML, Archer SA, Kermode AG, Mastaglia FL. Corticomotor organisation and motor function in multiple sclerosis. *J Neurol*. 2005;252(7):765-771. doi:10.1007/s00415-005-0728-9
26. 26. Hojjatollah NB, Khosrow E, Reza RS, Monireh RM. Effects of selected combined training on muscle strength in multiple sclerosis patients. *HealthMED*. 2012;6(1):96-102.
27. Kierkegaard M, Einarsson U, Gottberg K, von Koch L, Widén Holmqvist L. The relationship between walking, manual dexterity, cognition, and activity/participation in persons with multiple sclerosis. *Mult Scler J*. 2012;18(5):639-646. doi:10.1177/1352458511426736
28. Cahill SM, Beisbier S. Occupational therapy practice guidelines for children and youth ages 5-21 years. *Am J Occup Ther*. 2020;74(4):7404397010p1-7404397010p48. doi:10.5014/ajot .2020.744001
29. Karussis D. The diagnosis of multiple sclerosis and the various related demyelinating syndromes: a critical review. *J Autoimmun*. 2014;48-49:134-142. doi:10.1016/j.jaut.2014.01.022
30. Julian L, Serafin D, Charvet L, et al. Cognitive impairment occurs in children and adolescents with multiple sclerosis: results from a United States network. *J Child Neurol*. 2013;28(1):102-107. doi:10.1177/0883073812464816
31. Goverover Y, Genova H, Deluca J, Chiaravalloti ND. Impact of multiple sclerosis on daily life. In: Chiaravalloti ND, Goverover Y, eds. *Changes in the Brain*. Springer; 2017:165-175. doi:10.1007/978-0-387-98188-8_7
32. Sharp WE, Newell KM. Coordination of grip configurations as a function of force output. *J Mot Behav*. 2000;32(1):73-82. doi:10.1080/00222890009601361
33. Patel Y, Bhise V, Krupp L. Pediatric multiple sclerosis. *Ann Indian Acad Neurol*. 2009;12(4):238-245. doi:10.4103/0972-2327.58281