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Supported Standing in Boys With Duchenne Muscular Dystrophy

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Abstract

Purpose—To evaluate the safety, tolerability, and efficacy of supported standing in a small sample of boys with Duchenne muscular dystrophy (DMD).

Methods—Four 12- to 15-year-old boys with DMD engaged in a home-based supported standing program for 6 to 12 months. A single-subject design was employed to examine muscle length. Bone mineral density was assessed at 4-month intervals using dual-energy x-ray absorptiometry.

Results—Upright, sustained supported standing was tolerated in 3 of the 4 boys. Mean weekly stand times ranged from 1.3 to 3.3 hours. Improved hip or knee flexor muscle length was seen in 3 of the 4 boys. No boys showed improved plantar flexor muscle length or increased lumbar bone mineral density.

Conclusions—Findings offer preliminary empirical evidence addressing the safety, tolerability, and efficacy of standing in boys with DMD. Additional research with an emphasis on better program adherence is indicated.

Keywords

adolescence; bone mineral density; Duchenne muscular dystrophy; exercise therapy; exercise tolerance; patient safety; physical therapy methods; range of motion; standing position; weight-bearing

INTRODUCTION AND PURPOSE

Duchenne muscular dystrophy (DMD), the most common dystrophinopathy affecting children, is an X-linked, progressive neuromuscular disease. Myofibril degeneration and extensive fibrosis give rise to progressive weakness, calf muscle pseudohypertrophy and contracture, and gradual loss of functional mobility across childhood. Because no cure currently exists, interventions are aimed at slowing the rate of disease progression,

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maintaining functional abilities, and optimizing participation in age-appropriate home, school, and community activities. Current pharmacological management includes long-term glucocorticoid therapy (prednisone/prednisolone or deflazacort), now a reference standard treatment for boys who are ambulatory.¹ Glucocorticoid therapy has been shown to slow loss of ambulation and slow progression of scoliosis, and is associated with improved strength and pulmonary function.^{2–5} Therapeutic benefits are offset by side effects that include enhanced loss of already impaired bone mineral density (BMD) and weight gain.⁶ Significantly impaired BMD, along with weakness and an increased body mass index (BMI), renders boys with DMD at high risk for fall-related fractures.^{7,8}

Physical therapy (PT) management includes active and passive stretching programs to help maintain range of motion of the hip, knee, and ankle,⁹ which permits a more stable base of support in standing and sitting. Goals for PT include maintaining postural symmetry and delaying or limiting the development and progression of contractures, particularly of ankle plantar flexor, knee flexor, and hip flexor muscles. Resting ankle foot orthoses (AFOs) may be prescribed to deter the development of plantar flexion contractures, which can limit stability with walking, standing and sitting. Supported standing has also been recommended, both historically¹⁰ and as part of published clinical care guidelines for DMD.⁹ Supported standing programs have been shown to improve lower extremity range of motion and BMD in children with cerebral palsy^{11,12} and have also been recommended for children with neuromuscular diseases on the basis of expert opinion.^{13,14} Despite potential benefits and common clinical use, no empirical studies evaluating standing in boys with DMD have been reported and no evidence-based clinical recommendations currently exist. Therefore, this study sought to describe the safety, tolerability, and efficacy of supported standing in a small sample of boys with DMD.

METHODS

Participants

Participants were 4 boys (aged 12–14 years) with DMD who met the following inclusion criteria: ability to attain a supported standing position, sufficient cognitive and upper extremity motor abilities to safely navigate a powered mobility device, and wheelchair-accessible home environment. Exclusion criteria included weight greater than 155 lb (device limit). The study was approved by the Institutional Review Board. Informed consent was given by the participants and their parent(s). Data collection occurred between 2009 and 2011. Demographic characteristics of participants are presented in Table 1. Baseline functional level, on the basis of the grading system developed by Vignos et al,¹⁵ ranged from 5 (walks unassisted but cannot rise from a chair or climb stairs) to 8 (in chair: sits erect and performs bed and wheelchair aids for daily living with assistance). All boys were receiving daily, long-term glucocorticoid therapy and were at or above the 95th percentile of age-predicted BMI and at or below the sixth percentile for height. Two boys (P1 and P4) received school-based PT in the form of stretching 1 day per week with occasional (not daily) home stretching by family, and wore no resting AFOs. Two boys (P2 and P3; twins) did not receive regular PT services, did not engage in a home stretching program, had a

history of bilateral tendo achilles lengthening 6 months before enrollment, and wore custom-resting AFOs for 3 to 4 hours per day.

Design

The single-subject design included an initial safety and tolerability trial, followed by 3 phases: A1 (baseline, 1 month); B1 (supported standing intervention, 8 months); and A2 (withdrawal of standing, 4 months). Intervention phase length was extended if a participant expressed concern about withdrawal and wished to continue supported standing.

Outcome Measures

The primary outcome measures for evaluating efficacy were lower extremity muscle length of ankle plantar flexors (with knee maximally extended), knee flexors (popliteal angle), and hip flexors (Thomas test position) measured using standard goniometry, a reliable tool in boys with DMD.^{16,17} Measurements were taken weekly during A1, and monthly during B1 and A2. One examiner experienced in DMD standardized testing (ELT) performed all goniometric measurements, with a second examiner providing limb stabilization and recording data. A single set of all lower extremity measurements was completed during each session, followed 5 to 10 minutes later by a second set of measurements for assessment of intrarater reliability. Evaluators did not review data from previous evaluations before measurement.

Lumbar spine areal BMD, a secondary outcome measure for efficacy, was assessed at 4-month intervals (end of A1, midpoint of B1, end of B1, and end of A2) using dual-energy x-ray absorptiometry (DXA; Hologic Discovery A, Hologic Corporation, New Bedford, MA). Dual-energy x-ray absorptiometry and anthropometric measurements performed by ISCD-Certified Bone Densitometry Technicians at the hospital's Clinical Research Center. Dual-energy x-ray absorptiometry is the preferred method for assessing bone density in pediatric populations,^{18,19} including DMD.^{9,20} Hologic normative values based upon age and sex were used to produce lumbar spine Z-scores. Given technical feasibility and clinical relevance, recent reports identify distal femur as an anatomical location of choice for assessing BMD in children with limited or no ambulation,²¹ including boys with DMD.²² However, at the time of data collection for this study, reference curves for evaluation of distal femur BMD in children were under development²³ and lumbar spine was 1 of the 2 most widely used, accurate and reproducible sites.^{18,24} Therefore, total lumbar BMD was selected as the DXA outcome measure for this preliminary investigation.

Supported Standing Intervention

The device used for the supported standing intervention was a powered wheelchair (model C400 Stander Jr, Permobil Inc, Lebanon, TN) that transforms from a chair to a stander electrically and can be driven in both sitting and standing positions using a joystick. Devices were either loaned by a vendor (P1 and P4) or newly acquired by the participant through insurance (P2 and P3). An inclinometer was mounted on the seat frame to measure chair angle in the standing position. The aim was to identify a supported standing posture that maximized weight bearing using as upright a position as possible, ideally the device maximum of -15° from vertical. Fitting, adjustments, and participant/caregiver instruction

for safe device use were conducted before the B1 phase in conjunction with a certified Assistive Technology Professional. As part of the initial safety and tolerability trial, boys and their primary caregivers were required to demonstrate safe operation of the device including use of safety supports and belts, use of electronic controls, driving in/outdoors, and transferring in/out of the device safely.

The initial safety and tolerability trial included (1) modeling of knee and chest pad set-up by the therapist; (2) transferring to the maximally tolerated upright (vertical) stand position with therapist guidance using the “tight sit to stand” device sequence; (3) sustaining standing as tolerated; (4) returning to seated position; and (5) after a brief rest, evaluation of parent/child ability to set up and demonstrate the standing sequence to and from the optimized position, without therapist cues. If sustained standing proved challenging, trial of heel/foot support and/or a chest strap was provided to improve standing tolerance. On the basis of the safety and tolerability trial, an initial daily standing duration was prescribed (maximal time tolerated), with a recommended daily increase of 5 minutes until the target stand time of 60 minutes was reached. Two to 3 shorter bouts of standing per day were suggested as an alternative if fatigue or discomfort made 60-minute bouts of standing challenging. Participants were asked to begin the standing program 5 to 7 days per week with an aim of 5 to 7.5 hours per week, on the basis of previously reported standing programs with children.^{12,13,25} A stopwatch attached to the armrest was used by participants to monitor standing duration. A written log was used by participants and caregivers to document standing time of day, duration, seat back angle, location, and description of any discomfort associated with standing and new functional activities that the standing position allowed. Weekly phone calls were made to families to (1) provide a reminder to complete logs, (2) encourage program adherence, and (3) provide an opportunity to report and resolve difficulties.

Data Analysis

Total standing duration across the intervention phase was calculated for each participant, along with weekly and daily standing time means. Intrarater reliability for goniometric measurements was evaluated by calculating inter-class correlation coefficients ($ICC_{3,3}$) using a 2-way mixed model repeated measures analysis of variance²⁶ and SPSS Version 18.

Muscle length data of ankle, knee, and hip were graphed for visual analysis. The 2-standard deviation band method (2SDBM)²⁷ was used to assess for significant change in muscle length between baseline and intervention phases for each participant. The 2SDBM involves calculation and graphing means and standard deviations of baseline data. Two consecutive data points falling outside the baseline 2-SD bands during the intervention phase indicate statistically significant change from baseline.

Within-participant change in total lumbar (L1–L4) BMD was assessed by comparing change scores between times of measurement to an anatomical location, scanner, and tester-specific least significant change precision score of 0.026 g/cm^2 . Change in BMD was considered significant if the change score exceeded the least significant change.^{18,19}

RESULTS

Safety

All participants were able to safely move into and out of the supported standing position during the initial safety and tolerability trial. Caregivers were able to demonstrate proper knee and chest support bar placement and adjustment following physical therapist modeling. No participant injuries or adverse events associated with the standing program were reported across the study intervention phase.

Tolerability of Standing

All boys were able to attain a supported standing position at or near the device maximum angle (Figure 1), and 3 of the 4 were able to maintain an upright trunk and sustain the position during the initial trial. Two of the 4 participants (P1 and P3) consistently attained and sustained the maximal device position during standing across the intervention phase. Regular and sustained use of the maximum stance angle was limited by low back discomfort in P2 and by plantar flexion contractures that increased anterior knee pressure in P4. P4's standing position and tolerance was improved after the initial trial, with the modifications of wedge support under heels to support plantar flexion contractures and a chest strap to support a more upright trunk. However, he remained unable to sustain an upright standing position for longer than 3 minutes across the intervention period. When his ability to tolerate the upright standing position was reached within a given standing bout, he transitioned to a semisquat position (seat angle 45°). P4 and his family were provided the option to withdraw from the study, given difficulty sustaining an upright standing position, but chose to continue to see whether changes in tolerance for the upright position could be achieved over time. No improvement in tolerance for the upright position was achieved, and the participant chose to end the standing program 6.5 months into the planned 8-month intervention phase.

Standing dose by means for days per week, minutes per day, and hours per week, as well as total intervention stand time, are presented in Table 2. The duration of the standing intervention ranged from 13 months (P1) to 6.5 months (P4). Total standing dose ranged from 192 hours (P1) to 47 hours (P2). Maximum hours of standing in a given week by participants were 7.3 (P1), 3.9 (P2), 3.6 (P3), and 7.4 (P4), all achieved in the first 12 weeks of the intervention period. Mean weekly standing duration ranged from 3.3 hours (P1) to 1.3 hours (P2).

Factors reported to have limited standing tolerance within a given session were plantar foot paresthesia (P1), anterior knee/shin discomfort related to pressure from support pads (P2, P3, and P4), low back pain (P2), excessive forefoot pressure (P4), and leg fatigue (P4). Factors reported by the child or caregivers to have limited adherence across intervention weeks included device malfunction (P1 and P3), vacation (P1), back pain (P2), ankle pain (P3), limited time for standing along with homework and personal care at the end of long school days (P2 and P3), and overall motivation for the standing program (P1, P2, P3, and P4). Despite identified limiters, 3 of the 4 boys chose to extend the length of the standing intervention beyond the planned 8 months and reported that positive benefits of standing (eg, legs feeling better, and being up tall) outweighed negatives. Reported new functional

activities that supported standing allowed included standing to eat at the breakfast bar with siblings (P1), accessing freezer for frozen snacks (P2, P3, and P4), accessing higher shelves in refrigerator (P1), standing to urinate (P3), putting clean utensils away in kitchen drawers (P3), and playing tennis ball catch with dog outside using a higher loft throw (P1).

Efficacy

Lower Extremity Muscle Length—Intrarater reliability for muscle length measurements was excellent for the ankle ($ICC_{3,3} = 0.99$, 95% confidence interval = 0.98–0.99), knee ($ICC_{3,3} = 0.97$, 95% confidence interval = 0.93–0.97), and hip ($ICC_{3,3} = 0.98$, 95% confidence interval = 0.98–0.99). Patterns of stability and change were similar on left and right limbs; therefore, muscle length data for the side with the most stable baseline are presented (Figure 2). All boys had impaired muscle length at baseline for hip flexors (range -10° to -45°), knee flexors (range -20° to -55°), and ankle plantar flexors (range 2° to -20°). Individual muscle length data for baseline, intervention, and withdrawal are provided in Table 3.

P1: For P1, ankle plantar flexor, knee flexor, and hip flexor muscle length all decreased significantly during the intervention phase. The significant decreases were observed between weeks 16 and 36, which coincided with loss of functional ambulation. Muscle length remained low or decreased further during the withdrawal phase.

P2: For P2, who was status post surgical tendo achilles lengthening, plantar flexor muscle length remained stable across phases. Knee flexor muscle length improved significantly mid-intervention and returned to baseline during late intervention and withdrawal. Hip flexor muscle length showed a nonsignificant trend toward improvement with intervention that became significant during withdrawal.

P3: For P3, also status post surgical tendo achilles lengthening, plantar flexor muscle length remained stable across phases. Knee and hip flexor muscle length improved significantly during the intervention, and decreased to or toward baseline levels with withdrawal.

P4: For P4, who had 20° ankle plantar flexor muscle contractures at baseline, plantar flexor muscle length showed a nonsignificant trend toward decline during the intervention phase that became significant during withdrawal. Knee flexor muscle length declined significantly during the intervention phase, whereas hip flexor muscle length improved significantly.

Summary: Improved hip flexor muscle length was observed in 3 of the 4 boys (P2–P4) during or immediately after the standing intervention. Improved knee flexor muscle length was seen in 2 of the 4 boys (P2 and P3). Ankle plantar flexor muscle length was stable (P2–P4) or declined (P1) in all 4 boys.

Bone Mineral Density—BMD data were graphed using Hologic software-generated curves on the basis of sex and age at baseline (Figure 3).

P1: Total lumbar spine BMD of P1 was within 1 standard deviation of age-predicted mean at baseline (Z -score = -0.6), decreased significantly mid-intervention, and remained stable, yet

significantly below baseline, through withdrawal. P1 was the only subject that was ambulatory at study start, and the significant loss of BMD corresponded to the period immediately after loss of functional ambulation.

P2 to P3: Baseline total lumbar spine BMDs of P2 to P3 (both non-ambulatory) were more than 2 standard deviations below age-predicted means at baseline (Z -scores = -2.9 ; -2.8). P2 showed a significant BMD decrease mid-intervention that recovered to baseline by intervention end and remained level through withdrawal. P3 showed stable lumbar BMD across baseline, intervention, and withdrawal phases.

P4: Baseline total lumbar spine BMDs of P4 (also non-ambulatory) was nearly 2 standard deviations below age-predicted means at baseline (Z -score = -1.9), decreased significantly mid-intervention, recovered to baseline by late intervention, and remained at baseline level through withdrawal.

Summary: A significant decrease in lumbar BMD between baseline and early to mid-intervention was seen in 3 of the 4 boys. This decrease in BMD was transient in P2 and P4, and sustained in P1. Stable lumbar BMD across study phases was observed in P3. No boy showed increased BMD during or poststanding intervention.

DISCUSSION

The purpose of this study was to assess the safety and tolerability of a supported standing program in 4 boys with DMD and describe effects of standing on lower extremity muscle length and BMD before, during, and after an extended standing program. Although standing programs have been described and studied in several samples of children with impaired movement and mobility,¹² this report is the first to provide empirical evidence related to supported standing programs in boys with DMD. Current evidence-based recommendations for PT intervention during the late ambulatory and nonambulatory phases include stretching, positioning, and orthoses (AFOs).⁹ Supported standing offers the possibility of an additional approach for targeting contracture management, with the potential for added positive effects on spinal and/or lower extremity BMD, and function and participation in home, school, and community settings.

Our findings support the safety of supported standing for boys with DMD. No injuries or serious adverse events related to the standing program were reported, and physical discomfort that occurred with supported standing did not last beyond daily standing times. The sample included boys aged 12 to 15 years at a typical height in the setting of long-term glucocorticoid therapy, but with elevated BMI for age compared with that of a recently described DMD cohort.²⁸ Increased body weight may have provided better longitudinal axis bone loading in a standing position, but may also have had a negative effect on standing tolerance.

Maintenance of an upright standing position for 20 to 60 minutes at the maximum device angle (-15° from vertical) was achieved and tolerated by 75% of participants (P1, P2, and P3), despite mild to moderate hip, knee, and/or ankle range-of-motion restrictions. The

maximum device angle position was tolerated across the intervention phase by 50% of participants (P1 and P3). P4 was the only participant who did not tolerate an upright position at the device maximum for more than 3 minutes at any point in the intervention phase. Comparative analysis of lower extremity muscle lengths across participants revealed that the only joint at which P4 showed more than 10° greater deficit than other participants at baseline was the ankle. P4's chief physical complaint when standing (and his reason for preferring a squat position) was increased anterior knee/shin pressure and forefoot/toe pressure, both clearly linked to redistribution of forces from plantar flexion contractures. This finding suggests supported standing programs may be less feasible in boys with plantar flexor contractures more than 15° to 20° and highlights the importance of vigilant preventive management of ankle plantar flexor muscle length to allow sustained supported standing as a viable intervention option. Other PT interventions targeting plantar flexor muscle length of boys with DMD have also noted 15° of plantar flexion as a cut-off point guiding clinical decision making,²⁹ in this case related to the effectiveness of serial casting. P2's tolerance of the upright position across the intervention phase was most limited by low back pain that began mid-intervention and occurred as an intermittent complaint approximately 50% of intervention weeks. He adjusted his stand position to -25° to ameliorate physical discomfort or did not stand on days he was experiencing back pain more than 3/10.

Target standing times of 60 minutes per day were reached by 75% of participants (P1, P2, and P3), but target numbers of days (5) and hours (5) per week were not consistently achieved or were not sustained, making the overall dose of standing across the intervention period markedly less than prescribed. Program adherence was affected by both practical factors (device malfunction, family vacations, long school days limiting home time) and motivational factors ("I just didn't feel like standing") for all boys, as well as by physical factors for P2 and P4. More frequent monitoring (>1 times/month), implementation of standing programs in school-based settings, and identification of incentives that motivate program commitment may help improve adherence in future standing studies.

The pattern of stability and change seen in lower extremity muscle length with supported standing was not uniform across the 4 participants, or across muscle groups. However, our findings support the idea that improvements in hip and knee flexor muscle length are possible for boys in the early nonambulatory phase, even with standing times less than 7.5 hours per week. Significant improvements ranged from 15° to 16° in hip flexors and 10° to 12° in knee flexors, both beyond the 5° to 10° of measurement error expected for joint range of motion.³⁰ The clinical relevance of the improvements at the hip and knee is not clear, particularly given the nonambulatory status of the boys. At the ankle, clinical relevance for DMD has been based upon achieving and maintaining a neutral (plantigrade) position, which supports ambulation.^{29,31} Much needed are studies that more closely examine the association between hip and knee extension ROM and the ability to attain and sustain a supported standing position.

The natural history of contracture development in DMD predicts a progressive decline in muscle length, particularly once the ability to ambulate has been lost.¹⁴ Evidence supports improved ankle dorsiflexion ROM with serial casting in boys with DMD in the early ambulatory stage of the disease.³¹ However, nonsurgical interventions for contracture

management in boys *not ambulating* (eg, orthotics and stretching) have mainly been effective at slowing contracture progression.³² Therefore, the possibility of improvement in muscle length with supported standing in boys who are not ambulating warrants further exploration, particularly if improved muscle length relates to improved tolerance of supported standing. Importantly, boys with DMD not participating in regular stretching programs (all participants in this study) show increased variability in range of motion,³³ which may increase “noise” in baseline muscle length measurements in some subjects.

The significant loss of hip flexor, knee flexor, and ankle plantar flexor muscle length seen in P1, who was ambulatory at study start, is characteristic of the transition to the non-ambulatory phase,³⁴ and suggests that supported standing programs of less than 3 to 4 hours per week may be insufficient to counteract the expected loss of lower extremity muscle length that comes with loss of the ability to walk. One unexpected finding was the continued improvement in P2’s hip flexor muscle length in the withdrawal phase. A possible explanation is that P2 continued with sporadic supported standing beyond the end of the intervention phase, despite withdrawal phase instructions. His back pain tempered during the withdrawal phase and he reported occasional standing “helped his legs feel better.” Thus, he may have continued to benefit from the stretch provided by supported standing and gained a few more degrees of motion. Alternatively, because all hip flexor measurements after mid-intervention were relatively stable (within 5°), the significant change in withdrawal might merely reflect maintenance of the improvements from intervention.

Given low baseline bone density and high risk of fractures in boys with DMD,^{7,8} BMD was chosen as a secondary outcome measure. Dual-energy x-ray absorptiometry requires exposure to small amounts of ionizing radiation and only detects changes in BMD within 4 to 6 months in children older than 10 years,³⁵ rendering the typical, repeated baseline testing of a single-subject design untenable. Compared with a single baseline BMD, only P1, who lost ambulation in the course of the intervention phase, showed a significant and sustained loss of BMD with supported standing. This finding suggests that a dose of 3 to 4 hours of supported standing per week may not be sufficient to counteract the loss of BMD associated with loss of ambulation in boys with DMD.²² Of perhaps greater interest is the finding of relative stability in BMD in 3 of 3 boys who were not ambulating, particularly in the setting of ongoing glucocorticoid therapy. Given increased risk of vertebral and lower limb fractures, particularly for boys receiving long-term glucocorticoids,³⁶ a PT intervention that stabilizes or slows loss of BMD and, potentially, lowers risk of fracture is desirable. Although both cross-sectional and 2-time-point longitudinal data describing bone changes in DMD have been reported,^{7,37,38} a detailed, longitudinal natural history of BMD within and across disease stages in glucocorticoid-treated boys with DMD is not yet available, making more in-depth interpretation of stable BMD findings a challenge.

Limitations

This study had a number of limitations. First, the single-subject A-B-A design used for muscle length, while experimental, is challenging to interpret when a return to baseline does not occur during withdrawal. In our study, we saw both patterns of stability and continued decline from intervention through withdrawal phases, making evaluation of the treatment

effects difficult. A second intervention period (eg, an A-B-A-B design) with comparable study phase lengths might better characterize treatment effects. Second, our sample of 4 boys with DMD was heterogeneous with respect to functional level at baseline. Loss of ambulation in 1 participant, with the associated loss of muscle length and bone density, confounded interpretation of individual and group treatment effects. Third, lower extremity joint angles were not measured in a supported standing position, which limits the ability to evaluate the relationship between hip, knee, and ankle contracture and standing tolerance, a finding that would guide clinical decision making when initiating supported standing programs. In particular, measurement of standing knee flexor muscle length, rather than popliteal angle, may have more clinical relevance for predicting standing tolerance. Finally, daily standing times were based on self or parental report, which may have introduced bias and/or inaccuracy related to intervention dose.

Future Research

The findings from this study can serve as a foundation for future studies of supported standing in boys with DMD. A randomized controlled trial or cohort study with a larger sample is warranted to more fully explore outcomes and potential benefits of supported standing. Strategies for increasing adherence and maintaining motivation to achieve longer standing duration are needed. Better adherence to a standing program could also allow a comparison of multiple dosing regimens. Katz et al²⁵ demonstrated benefits of standing on BMD in children with cerebral palsy with 10 weekly hours, but not with less than 7.5 hours. Optimal dosing in boys with DMD may be different than in children with other developmental disabilities, but this study provides a starting point for exploring various standing durations. Finally, weight-bearing load in supported standing (eg, percent body weight) should be measured alongside the postural alignment/stand angle to more clearly quantify standing dose.

For evaluation of changes in BMD with supported standing, lateral distal femur should be included as an anatomical DXA site in future studies. Normative reference data are now available,²³ and current consensus identifies lateral distal femur as a target scan in boys with DMD.^{19,22} Because glucocorticoid-treated boys with DMD have reduced stature, areal BMD should also be adequately corrected for bone size and skeletal maturity using 1 of several existing methods.²⁴

As part of a 2010 systematic review, Glickman et al¹¹ concluded that supported standing clinical investigations should seek to include functional, behavioral, and cognitive outcomes, alongside physiological measures. Therefore, future studies of supported standing in boys with DMD should include outcomes across all 3 components of the International Classification of Functioning, Disability and Health model, particularly those that reflect activity and participation components. Participants in this study reported a host of new functional abilities associated with supported standing, including accessing higher height shelves, cabinets, and counters. These abilities were reported to enhance both independence and social interaction. Social engagement was recently identified as a limitation in older boys with DMD.³⁹ The ability to engage in a supported standing program after the loss of functional ambulation may well have implications beyond any potential effect on muscle

length and bone density. Identifying measurement tools that can capture the effect of supported standing in the activity and participation levels of the ICF should be an important priority.⁴⁰ Current work by the Cooperative International Neuromuscular Research Group includes a longitudinal study of the relationships among impairment, activity, participation, and quality of life in boys with DMD,⁴¹ and may inform our understanding of key outcomes to include in future studies of supported standing in boys living with what is, for now, a progressive neuromuscular disorder.

CONCLUSIONS

This is the first study exploring the safety and tolerability of supported standing for a subset of boys with DMD in the late ambulatory and non-ambulatory disease stages. Findings provide initial evidence that supported standing is safe and, in the absence of marked ankle equinovarus contractures, may be well tolerated and have positive effects on lower extremity hip and knee flexor muscle length in boys with DMD who are not ambulating.

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References

1. Bushby K, Bourke J, Bullock R, Eagle M, Gibson M, Quinby J. The multidisciplinary management of Duchenne muscular dystrophy. *Curr Paediatr*. 2005; 15(4):292–300.
2. Biggar W, Harris V, Eliasoph L, Alman B. Long-term benefits of deflazacort treatment for boys with Duchenne muscular dystrophy in their second decade. *Neuromuscul Disord*. 2006; 16(4):249–255. [PubMed: 16545568]
3. Bach JR, Martinez D, Bilal S. Duchenne muscular dystrophy: the effect of glucocorticoids on ventilator use and ambulation. *Am J Phys Med Rehabil*. 2010; 89(8):620–624. [PubMed: 20647779]
4. Kinali M, Messina S, Mercuri E, et al. Management of scoliosis in Duchenne muscular dystrophy: a large 10-year retrospective study. *Dev Med Child Neurol*. 2006; 48(06):513–518. [PubMed: 16700946]
5. Yilmaz O, Karaduman A, Topaloglu H. Prednisolone therapy in Duchenne muscular dystrophy prolongs ambulation and prevents scoliosis. *Eur J Neurol*. 2004; 11(8):541–544. [PubMed: 15272899]
6. Angelini C. The role of corticosteroids in muscular dystrophy: a critical appraisal. *Muscle Nerve*. 2007; 36(4):424–435. [PubMed: 17541998]
7. Larson CM, Henderson RC. Bone mineral density and fractures in boys with Duchenne muscular dystrophy. *J Pediatr Orthop*. 2000; 20(1):71–74. [PubMed: 10641693]
8. McDonald DGM, Kinali M, Gallagher AC, et al. Fracture prevalence in Duchenne muscular dystrophy. *Dev Med Child Neurol*. 2002; 44(10):695–698. [PubMed: 12418795]
9. Bushby K, Finkel R, Birnkrant DJ, et al. Diagnosis and management of Duchenne muscular dystrophy, part 2: implementation of multidisciplinary care. *Lancet Neurol*. 2010; 9(2):177–189. [PubMed: 19945914]

10. Miller G, Dunn N. An outline of the management and prognosis of Duchenne muscular dystrophy in western Australia. *Aust Paediatr J*. 1982; 18(4):277–282. [PubMed: 7165592]
11. Glickman L, Geigle P, Paleg G. A systematic review of supported standing programs. *J Pediatr Rehabil Med*. 2010; 3(3):197. [PubMed: 21791851]
12. Paleg GS, Smith BA, Glickman LB. Systematic review and evidence-based clinical recommendations for dosing of pediatric supported standing programs. *Pediatr Phys Ther*. 2013; 25(3):232–247. [PubMed: 23797394]
13. Stuberger WA. Considerations related to weight-bearing programs in children with developmental disabilities. *Phys Ther*. 1992; 72(1):35. [PubMed: 1728047]
14. McDonald CM. Limb contractures in progressive neuromuscular disease and the role of stretching, orthotics, and surgery. *Phys Med Rehabil Clin N Am*. 1998; 9(1):187–211. [PubMed: 9894140]
15. Vignos PJ Jr, Spencer GE Jr, Archibald KC. Management of progressive muscular dystrophy of childhood. *JAMA*. 1963; 184(2):89. [PubMed: 13997180]
16. Florence JM, Pandya S, King WM, et al. Clinical trials in Duchenne dystrophy: standardization and reliability of evaluation procedures. *Phys Ther*. 1984; 64(1):41. [PubMed: 6361809]
17. Pandya S, Florence JM, King WM, Robison JD, Oxman M, Province MA. Reliability of goniometric measurements in patients with Duchenne muscular dystrophy. *Phys Ther*. 1985; 65(9):1339. [PubMed: 4034668]
18. Gordon CM, Bachrach LK, Carpenter TO, et al. Dual energy x-ray absorptiometry interpretation reporting in children and adolescents: the 2007 ISCD pediatric official positions. *J Clin Densitom Assess Skeletal Health*. 2008; 11(1):43–58.
19. Kecskemethy HH, Harcke HT. Assessment of bone health in children with disabilities. *J Pediatr Rehabil Med*. 2014; 7(2):111–124. [PubMed: 25096863]
20. Biggar WD, Bachrach LK, Henderson RC, Kalkwarf H, Plotkin H, Wong BL. Bone health in Duchenne muscular dystrophy: a workshop report from the meeting in Cincinnati, Ohio, July 8, 2004. *Neuromuscul Disord*. 2005; 15(1):80–85. [PubMed: 15639125]
21. Henderson RC, Berglund LM, May R, et al. The relationship between fractures and DXA measures of BMD in the distal femur of children and adolescents with cerebral palsy or muscular dystrophy. *J Bone Mineral Res*. 2010; 25(3):520–526.
22. Harcke HT, Kecskemethy HH, Conklin D, Scavina M, Mackenzie WG, McKay CP. Assessment of bone mineral density in Duchenne muscular dystrophy using the lateral distal femur. *J Clin Neuromuscul Dis*. 2006; 8:1–6.
23. Zemel BS, Stallings VA, Leonard MB, et al. Revised pediatric reference data for the lateral distal femur measure by Hologic/Delphi dual-energy x-ray absorptiometry. *J Clin Densitom Assess Skeletal Health*. 2009; 12(2):207–218.
24. Bianchi M, Biggar D, Bushby K, Rogol A, Rutter M, Tseng B. Endocrine aspects of Duchenne muscular dystrophy. *Neuromuscul Disord*. 2011; 21(4):298–303.
25. Katz D, Snyder B, Federico A. Can using standers increase bone density in non-ambulatory children? *Dev Med Child Neurol*. 2006; 48(S106):9.
26. Portney, L., Watkins, M. *Foundations of Clinical Research: Applications to Practice*. 3rd. Upper Saddle River, NJ: Pearson/Prentice Hall; 2009. Statistical measures of reliability; p. 593
27. Portney, L., Watkins, M. *Foundations of Clinical Research: Applications to Practice*. 3rd. Upper Saddle River, NJ: Pearson/Prentice Hall; 2009. Single-subject designs; p. 261
28. Davidson Z, Ryan M, Kornberg A, et al. Observations of body mass index in Duchenne muscular dystrophy: a longitudinal study. *Eur J Clin Nutr*. 2014; 68(8):892–897. [PubMed: 24824013]
29. Main M, Mercuri E, Haliloglu G, Baker R, Kinali M, Muntoni F. Serial casting of the ankles in Duchenne muscular dystrophy: can it be an alternative to surgery? *Neuromuscul Disord*. 2007; 17(3):227–230. [PubMed: 17303425]
30. Norkin, CC., White, DJ. *Measurement of Joint Motion: A Guide to Goniometry*. FA Davis; 2009.
31. Glanzman AM, Flickinger JM, Dholakia KH, Bonnemann CG, Finkel RS. Serial casting for the management of ankle contracture in Duchenne muscular dystrophy. *Pediatr Phys Ther*. 2011; 23(3):275–279. [PubMed: 21829124]

32. Hyde SA, Fløytrup I, Glent S, et al. A randomized comparative study of two methods for controlling tendo achilles contracture in Duchenne muscular dystrophy. *Neuromuscul Disord*. 2000; 10(4–5):257–263. [PubMed: 10838252]
33. Barr AE, Diamond BE, Wade CK, et al. Reliability of testing measures in Duchenne or Becker muscular dystrophy. *Arch Phys Med Rehabil*. 1991; 72(5):315–319. [PubMed: 2009048]
34. McDonald CM, Abresch RT, Carter GT, et al. Profiles of neuromuscular diseases: Duchenne muscular dystrophy. *Am J Phys Med Rehabil*. 1995; 74(5):S93. [PubMed: 7576425]
35. Leonard CM, Roza MA, Barr RD, Webber CE. Reproducibility of DXA measurements of bone mineral density and body composition in children. *Pediatr Radiol*. 2009; 39(2):148–154. [PubMed: 19052738]
36. King W, Ruttencutter R, Nagaraja H, et al. Orthopedic outcomes of long-term daily corticosteroid treatment in Duchenne muscular dystrophy. *Neurology*. 2007; 68(19):1607. [PubMed: 17485648]
37. Bianchi ML, Mazzanti A, Galbiati E, et al. Bone mineral density and bone metabolism in Duchenne muscular dystrophy. *Osteoporos Int*. 2003; 14(9):761–767. [PubMed: 12897980]
38. Soderpalm AC, Magnusson P, Ahlander AC, et al. Bone mass development in patients with Duchenne and Becker muscular dystrophies: a 4-year clinical follow-up. *Acta Paediatr*. 2012; 101(4):424–432. [PubMed: 22103559]
39. Bendixen RM, Senesac C, Lott DJ, Vandenborne K. Participation and quality of life in children with Duchenne muscular dystrophy using the international classification of functioning, disability, and health. *Health Qual Life Outcomes*. 2012; 10:43. [PubMed: 22545870]
40. Scott E, Mawson SJ. Measurement in Duchenne muscular dystrophy: considerations in the development of a neuromuscular assessment tool. *Dev Med Child Neurol*. 2006; 48(06):540–544. [PubMed: 16700951]
41. ClinicalTrials.gov. Longitudinal study of the natural history of Duchenne muscular dystrophy (DMD). <http://clinicaltrials.gov/ct2/show/study/NCT00468832>. Updated 2014. Accessed August 14, 2014

Fig. 1.
Typical standing position of participants (P1–P4).

Fig. 2.

Muscle length of hip flexor, knee flexor, and ankle plantar flexor muscles. Baseline, intervention and withdrawal phases are separated by vertical lines. Two standard deviation (SD) bands above and below baseline means (solid horizontal line) are delineated by dotted horizontal lines. Two consecutive data points outside a 2 SD band during the intervention phase indicate statistically significant change from baseline.

Fig. 3. Bone mineral density (g/cm²) for baseline, intervention, and withdrawal phases. Curves represent ± 2 SD from age and sex predicted mean.

TABLE 1

Demographics for Participants 1 to 4 (P1–P4)

	Age, y	Disease Stage at Enrollment	BMI/Height (Percentile)	Glucocorticoid Therapy	Surgical History	Physical Therapy and Orthotics
P1	13	Late ambulatory; Vignos 5	95/3	Deflazacort 45–60 mg/d	None	Stretching 1 time/wk (school), no AFOs
P2	14	Nonambulatory; Vignos 8	96/2	Deflazacort 35 mg/d	Bilateral achilles tenotomy	No regular stretching, solid custom AFOs
P3	14	Nonambulatory; Vignos 8	96/2	Deflazacort 35 mg/d	Bilateral achilles tenotomy	No regular stretching; solid custom AFOs
P4	12	Nonambulatory; Vignos 8	95/6	Prednisone 10 mg/d	None	Stretching 1 time/wk (school), no AFOs

Abbreviations: AFOs, ankle foot orthoses; BMI, body mass index.

TABLE 2

Standing Intervention Times

	Duration of Initial Stance Bout, min	Mean (Range) Standing, d/wk	Mean (Range) Daily Stand Time, min	Mean (Range) Weekly Stand Time, h	Total Stand Time, h
P1	45	4.4 (0–7)	38 (0–62)	3.3 (0–7.3)	192
P2	30	1.6 (0–5)	28 (0–60)	1.3 (0–3.9)	47
P3	30	2.2 (0–5)	32 (0–60)	1.5 (0–3.6)	54
P4 ^a	3	4.6 (0–7)	23 (0–63)	2.1 (0–7.4)	71

^aP4 stand times were in a semisquat position.

TABLE 3

Lower Extremity Muscle Length for Ankle Plantar Flexor, Knee Flexor (Popliteal Angle), and Hip Flexor (Thomas Test Position) Muscles in Degrees

Participant	Baseline (Mean)	Mid Intervention ^a	End Intervention	End Withdrawal
P1				
Ankle PF	−9	−8	−14	−21
Knee flexor	−20	−36	−35	−50
Hip flexor	−10	−8	−26	−26
P2				
Ankle PF	−1	0	−1	0
Knee flexor	−51	−46	−50	−50
Hip flexor	−37	−28	−28	−28
P3				
Ankle PF	2	4	3	2
Knee flexor	−55	−46	−45	−49
Hip flexor	−37	−24	−21	−29
P4				
Ankle PF	−20	−20	−19	−26
Knee flexor	−34	−37	−50	−44
Hip flexor	−45	−35	−30	−30

Abbreviation: PF, plantar flexor.

^aMid-intervention was taken as the fifth intervention data point.