Effects of massage on the mechanical behaviour of muscles in adolescents with spastic diplegia: a pilot study

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Calf muscles of five adolescents aged 12 to 15 years (three males, two females) with spastic diplegia were massaged for 14 minutes twice a week for 5 weeks in a controlled sequence, stretching the muscles transversely rather than longitudinally, without eliciting pain. Slow, passive test stretches were applied before and after massage. After massage, the range of movement was not consistently increased but, on average, greater force was needed to stretch the muscle than before massage. However, after massage the resting ankle angle sometimes changed so that the calf muscles were either shorter or longer. We suggest that these phenomena could be explained if massage resets sarcomere lengths which corrects for thixotropic effects (i.e. previous use modifies a muscle's mechanical behaviour). A redistribution on sarcomere lengths within muscles could also have reset proprioceptive feedback. The incidence of abnormal stretch reflexes during test stretches fell from 40 to 22%, comparing the first five sessions with the last five sessions. The amplitude of voluntary alternating ankle rotation increased in three participants. Motor skills were assessed with the Gross Motor Function Measure-66 (GMFM-66) 1 week before the test period, during the 5th week, and 12 weeks later. Our participants in Gross Motor Function Classification System (GMFCS) Levels I and II made sustained improvements in GMFM-66 scores (6.4% at 5 weeks falling to 5.5% at 17 weeks), one increase being significant. One participant in GMFCS Level III improved significantly only after massage of all leg muscles for 30 weeks.

Current therapy for muscles with spasticity in cerebral palsy (CP; intrathecal baclofen, botulinum toxin, and selective dorsal rhizotomy), targets neural mechanisms. It has been proposed, however, that abnormal physiological properties of the muscle itself could contribute to disability.[1–4] This study tested whether massage could change these properties.

The resistance of muscles with spasticity to stretching has reflex and intrinsic components.[5,6] In CP, the stiffness of muscles with spasticity was thought to be because the muscle fibres are shorter than the population norm, based on indirect evidence.[7] In fact, the muscle fibres themselves are stiffer,[8] though their length may be comparable with the population norm.[2,9] However, connective tissue between the muscle fibres is excessively compliant,[10] although there is an abnormally large quantity of it.[11] The weakness of this connective tissue may throw a greater part of the tensional load on the molecular spring titin within the sarcomeres of the muscle fibres. Possibly the titin in these muscles is stiffer than the population norm.[10] The relationship between muscle bundles and tendon is also severely disturbed because muscle fibres are thinner[9] by as much as one-third compared with the population norm.[10]

The massage given in our study was designed to stretch muscles with spasticity transversely, gradually, and gently to avoid eliciting pain. We tested whether massaging calf muscles could increase the range of passive and voluntary movement at the ankle joint and improve motor skills. We restricted participants to adolescents because their gross motor ability is not expected to improve spontaneously. Gross motor ability in children with CP reaches a plateau around the age of 7 years.[12] In fact, adolescents often become wheelchair-bound as the effort of moving their increasing body weight fails to match the demand for fast transfer.[13] We included only patients with spastic diplegia as the neuropathology (periventricular leucomalacia) is more uniform.[14]

Method

PARTICIPANTS

Five adolescents (three males, two females; mean age 14y, age range 12–15y) with spastic diplegia, recruited from a special needs school in Glasgow, UK, gave written, informed consent to participate in the study in accordance with the Declaration of Helsinki. Permission for the study was obtained from the Ethics Committee of Yorkhill Hospitals NHS Trust, Glasgow, participants' parents, general practitioners, and hospital consultants. Glasgow City Council Education Services and the senior management team of the school gave their approval for the study to be conducted at school. Only five pupils met both inclusion criteria (i.e. they were adolescents with spastic diplegia) and could accommodate participation in our study with their curricular activities.

MASSAGE

Calf muscles were gently stretched transversely rather than longitudinally with a standardized sequence of Swedish massage strokes lasting 14 minutes, twice a week for 5 weeks. Each sequence involved seven timed changes of stroke, beginning and ending with effleurage, with five variations of petrissage in between. Participants lay prone during the sequence with their knee extended and ankle supported on a cushion to allow the joint to adopt its natural rest position. The right calf muscle was always massaged first. Non-allergenic grapeseed oil was used for lubrication. Each session lasted 50 minutes, including tests.

RANGE OF PASSIVE AND VOLUNTARY MOVEMENT

Before and after massage, ankles were passively dorsiflexed from the resting position three times at a controlled rate with the knee at a right angle while the participant lay prone (Fig. 1a). Changes in ankle angle were measured with a goniometer positioned with one axis aligned parallel to the long axis of the fibula and the other parallel to the long axis of the fifth metatarsal bone.[15] The ankle was dorsiflexed with a pressure pad 7cm in diameter applied to the sole of the foot over the metatarso-phalangeal joints. Force was applied at a controlled rate (around 8N/s) by matching the force trace on a computer screen with a linearly increasing template. Dorsiflexion was terminated when resistance to movement was judged to be rising steeply. The resting ankle position was not controlled in any way, but as the goniometer was not removed during massage, any change in angle was recorded.

Immediately following three passive stretches participants flexed and extended their ankle voluntarily in time with a metronome set at 40 beats/min. To avoid causing participants stress, possibly affecting supraspinal control,[16] they were not specifically encouraged to make maximum movements.

Electromyography (EMG) signals were collected with paired surface silver electrodes 6mm in diameter and 12mm apart following standard skin preparation. They were placed over the soleus muscle 2.5cm distal to the lower limit of the gastrocnemius muscle belly in line with the Achilles tendon, removed during massage, and replaced in the same marked position for tests following massage. EMG signals were amplified (x1000), analogue to digital converted (sampling rate of 2kHz) using a 1401 Micro (Cambridge Electronic Design, Cambridge, UK) and stored in a personal computer, together with signals from the goniometer and pressure pad. They were band-pass filtered (50–300Hz) offline, rectified, and filtered (time constant 1ms or 100ms) with Spike2 software (version 5; Cambridge Electronic Design, Cambridge, UK). Data in Spike2 were transferred to Excel for further analysis.

MOTOR SKILLS

Motor skills were assessed with the Gross Motor Function Measure-66 (GMFM-66)[17] by an independent physiotherapist (NT; see Table I for goal areas). Two weeks before starting massage, participants were familiarized with the items that they would be asked to attempt. They were assessed 1 week before beginning massage, after nine massage sessions, and 12 weeks later.

Results

RANGE OF MOVEMENT

Analysis of tests of passive dorsiflexion of the ankle before and after massage (Fig. 1a) showed that only two of the 10 ankles dorsiflexed consistently further after massage, even though, overall, the force applied to all ankles after massage was greater (compare force applied in Fig. 1b and c). This could imply that massage had made the calf muscles stiffer, as, on average, greater force moved the ankles to the same degree. However, how far an ankle extended depended on the resting ankle angle, which could change appreciably after massage (compare initial joint angle in Fig. 1b and c, and Fig. 2). If the

Table I: Gross Motor Function Measure (GMFM) assessments of participants before and after massage sessions

Participant Sex/Age (y:m)	*GMFCS level*	*Goal area*	*1wk before massage sessions* GMFM-66 score	SEM	Item 87	*5th wk after massage* GMFM-66 score	SEM	Item 87	*17th wk after massage* GMFM-66 score	SEM	Item 87
1. M/15:0	I	E	84.05	2.7	3	89.7	4.12	3	89.7	4.12	3
2. F/13:1	I–II	E	74.16	1.88	2	81.93	2.53	3	78.28	2.23	3
3. F/12:11	II	E	66.33	1.41	0	71.22	1.58	0	70.81	1.58	0
4. M/14:9	II	E	64.98	1.41	0	72.16[a]	1.7	2	72.63[a]	1.7	3
5. M/14:1[b]	III–IV	C,D	45.91	1.05	–	46.09	1.05	–	46.09	1.05	–

[a]Significant difference from initial score. [b]Hamstrings lengthened 3 years earlier; receiving physiotherapy twice weekly. Item 87, walking down four steps with alternating feet and hands free. Goal areas: E, walking, running, and jumping; C, crawling and kneeling; D, standing. Orthoses: ankle, participants 3 and 5; foot, participant 1. GMFCS, Gross Motor Function Classification System; SEM, standard error of measurement.

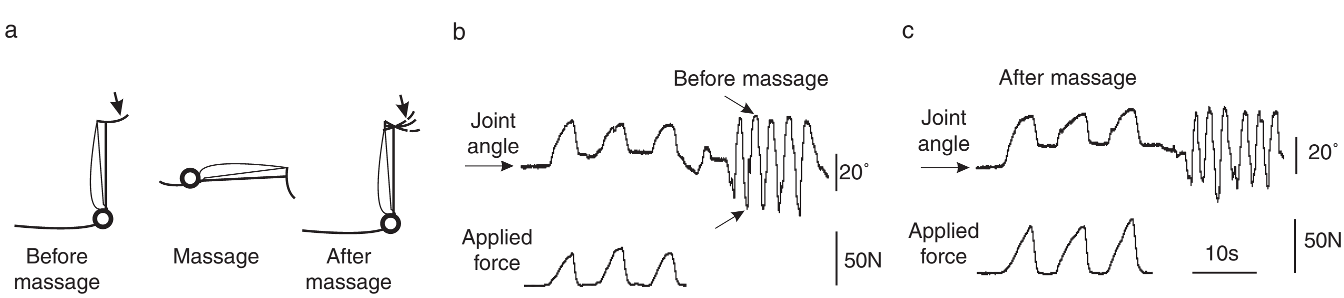

Figure 1: *Testing passive dorsiflexion of ankle and voluntary alternating movements. (a) Limb positions during tests and massage (arrow: force applied during tests). Note that after massage, ankle could assume a different rest angle. (b) and (c) Joint angles during three passive stretches followed by voluntary alternating movements, example from participant 3 during second massage session. In this case, calf muscle was longer after massage. Horizontal arrows indicate rest angles. Sloping arrows in (b) indicate amplitude of a voluntary contraction (see Fig. 4).*

change in resting ankle angle indicated that the calf muscle had shortened, the ankle displacement during stretch was greater than before, and less if the calf muscle had lengthened (the slopes of the trend lines for peak displacement reverse in upper and lower graphs in Fig. 2). Surprisingly, individual calf muscles could either shorten or lengthen when massaged; they did not do this consistently.

The ankles did not spring back exactly to the resting position immediately on release from a test stretch. There was always some residual displacement.[18] The slopes of the trend lines for peak and residual displacements before massage (Fig. 2a) suggest that calf muscles did not extend so far, and sprang back closer to the rest position if they shortened during massage, and vice-versa for those that lengthened.

STRETCH REFLEXES

The incidence of abnormal stretch reflexes was assessed from soleus EMG activity during all test stretches, together with any irregularities in the joint angle record evidencing stretch reflexes in the gastrocnemius muscles. These indications occurred during 40% of passive stretches during the first five massage sessions and only 22% of stretches during the last five sessions. However, the character of the reflexes encountered could change markedly. For example, in the first two sessions a stretch reflex in the soleus muscle of participant 2 began at a more dorsiflexed angle after massage (Fig. 3a), suggesting a reduced responsiveness. However, in subsequent massage sessions, decreasing phasic stretch reflexes were recorded soon after the beginning of stretch (Fig. 3b). Evidence of inhibition of the soleus muscle during stretch (see Discussion) was also seen in participant 1 in sessions 4 and 5 as a diminution of background EMG activity.

VOLUNTARY MOVEMENTS

Participant 1 made striking gains in the freedom of movement of both ankles after the third massage session (Fig. 4a). Participant 2 made a more modest improvement in movement in one limb, also after the third massage session (Fig. 4b). Participant 3 made no clear gains (Fig. 4c), but participant 4 improved, especially in the last session when urged to contract the calf muscle, rather than inverting and everting the foot (Fig. 4d). Participant 5 could not move either ankle voluntarily.

GROSS MOTOR FUNCTION MEASURE SCORES

By the 5th week of the intervention the ambulant participants had improved their GMFM-66 scores by an average of

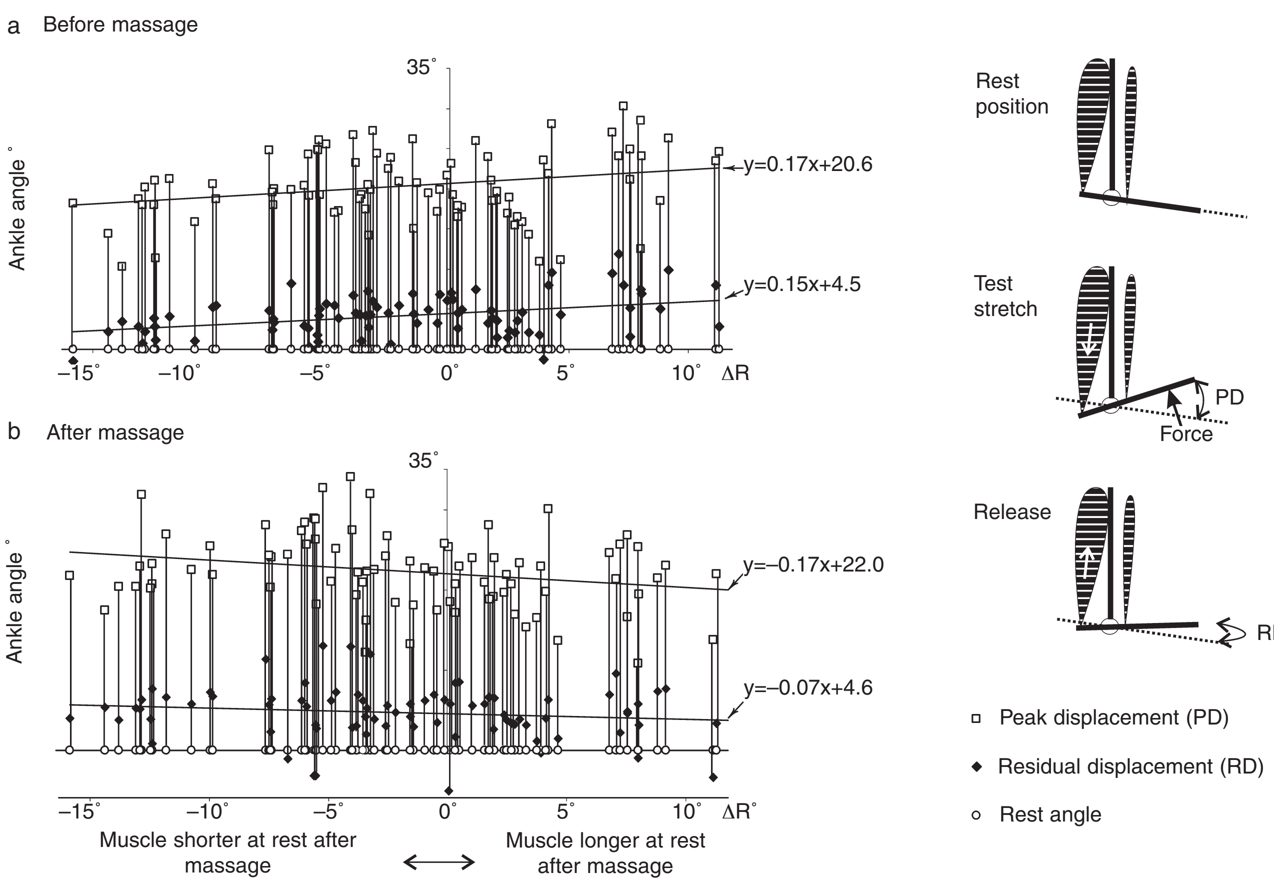

Figure 2: *Changes in passive mechanical behaviour of spastic calf muscles after massage. (a) Ankle extension in first test stretch before massage plotted against change in resting ankle angle after massage (ΔR°). Data are from all participants in all massage sessions. (b) Ankle extension in the first stretch after massage plotted from new resting position. We suggest that trend line slopes reverse between (a) and (b) because massage reset sarcomere lengths in calf muscles. If a large proportion of sarcomeres were initially over-long (left side of graphs) muscles extended less before massage, whereas if sarcomeres were mainly over-short (right side of graphs) they extended more easily before massage.*

6.4% but the score of the non-ambulant participant (participant 5) was unchanged (Table I). The change was statistically significant only for participant 4. In general, scores improved in items testing coordination and balance (e.g. stepping over a stick at knee height) rather than muscle strength like jumping vertically and hopping. Surprisingly, gains were largely maintained 12 weeks later (Table I). Scores for GMFM-66 item 87 (walking down four steps with alternating feet and hands free) are quoted in Table I because of the special relevance to the control of calf muscles (see Discussion). To find out if participant 5 could improve, all leg muscles were massaged twice a week in three blocks of 10 weeks; that participant's score increased significantly from 45.91 (SEM 1.05) to 50.85 (SEM 1.23).

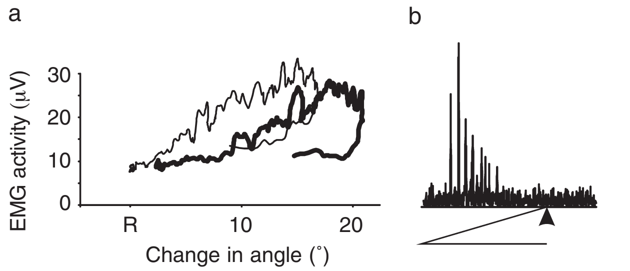

Figure 3: *Changing reflex responses to stretch of soleus muscle. (a) Averaged electromyography (EMG) recorded from participant 2 during sessions 1 and 2 before (thin line) and after massage (thick line). Each trace is an average of six EMG responses to stretch. Before massage, EMG activity increased almost immediately ankle began to move. After massage, EMG activity started to increase later, and although muscle extended further, maximum EMG activity was about the same as before massage. (b) In session 4, EMG activity did not increase as in (a). Instead, phasic stretch reflexes decreased during first stretch before massage. Period of stretch is indicated by ramp below EMG trace with an arrow at peak of stretch. This suggests that reflexes were being progressively inhibited as muscle stretched. Calibration: vertical: 60mV; horizontal: 1s. R, resting.*

Discussion

After massage the ankles could not be dorsiflexed consistently any further than before massage. Instead the resting ankle angle sometimes changed so that the calf muscles were either longer or shorter. Muscles that shortened after massage extended further when they were passively stretched, while those that lengthened extended less (Fig. 2). Surprisingly, muscles that would shorten tended to spring back further immediately after stretch even before massage was applied. These observations can be explained using the concept of thixotropy, meaning that a muscle's mechanical state can be changed by previous activity. One explanation for thixotropy is that it is caused by resting bonds between the contractile filaments in sarcomeres.[19] These bonds are broken during contractions, but quickly reform once contraction stops, fixing sarcomere length.[20] We suggest that repeated local stretching during massage would break these bonds. Before massage, the muscles of our participants probably contained a mixture of over-long and over-short sarcomeres. Resetting sarcomere lengths to intermediate, functionally more optimal values would change overall muscle length. The outcome –

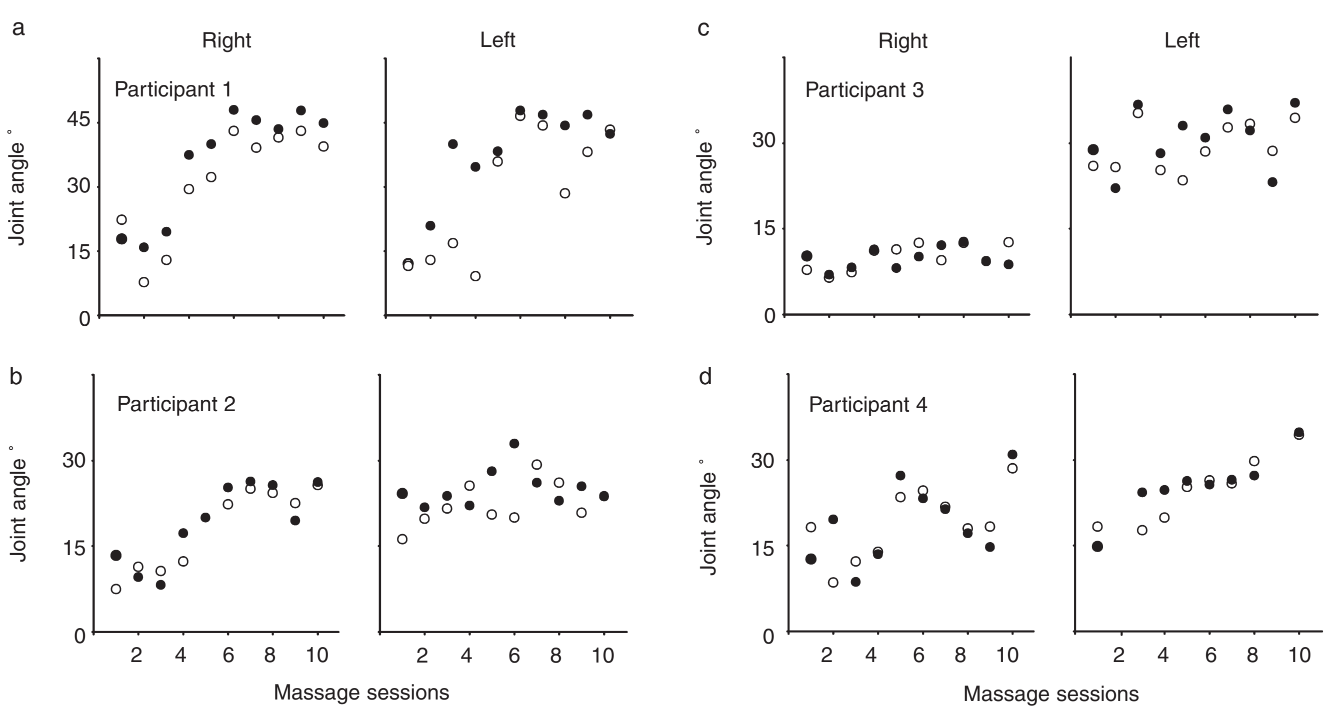

Figure 4: *Amplitude of voluntary alternating movements of ankle of 4 ambulant participants recorded in 10 massage sessions. Each data point is mean amplitude of 3 oscillations. Note different scale for participant 1. It is surprising that amplitudes could improve after massage, especially in participant 1, even though passive ankle extension suggested that muscles were stiffer. Open and filled circles, before and after massage respectively.*

muscle shortening or lengthening – would depend on whether sarcomeres were predominantly over-long or over-short before massage. Muscles with spasticity might be more susceptible to thixotropy because of the physical changes mentioned earlier, and also abnormal patterns of recruitment of motor units.[21] Sarcomeres in muscle fibres of less frequently used motor units might stay long or short, interfering functionally with active units.

The passive mechanical properties of muscle are important as the earliest source of resistance to stretching. Stretch reflexes provide the second defence. The reduced frequency of abnormal stretch reflexes over the 5 weeks of massage could be because regular massage sessions maintained the calf muscles in a functionally better mechanical state.[1,3,4] Resetting sarcomere lengths to functionally more optimal values ought also to improve sensory feedback from muscle spindle stretch receptors. This could be why the range of voluntary alternating ankle movements improved in some limbs – up to three-fold greater (Fig. 4). Alternating limb movements are particularly difficult for children with CP.[14,16] The challenge is to control Ia inhibitory interneurons which receive direct input from muscle stretch receptors.[22] Inhibition of soleus motoneurons via these pathways comes into play especially when descending steps. Soleus motoneurons must be inhibited to allow the muscle to lengthen, counterbalancing automatic resistance to lengthening due to the muscle's mechanical properties. Two pieces of evidence suggest that massage helped participants to gain greater control over these pathways. First, in the two least affected participants, passively stretching the calf initially elicited excitation of soleus motoneurons, but later signs of inhibition developed. Passively stretching normal calf muscles inhibits soleus motoneurons.[23] Second, after the massage sessions, participants 2 and 4 both scored full marks for their ability to walk down four steps with alternating feet and hands free (Table I). It is interesting that the developers of the GMFM regard this test as a benchmark, commenting that it can probably be completed fully only by children classified in GMFCS Level I.[12]

Our hypothesis is that the specific form of massage we tested temporarily improves muscle mechanical properties and sensory feedback by resetting sarcomere lengths in muscles with spasticity. These improvements enable adaptive changes providing that there is some voluntary control over the muscle. This notion also implies that the optimal time for practicing movements, particularly alternating limb movements, is immediately after massage, and that regular massage is required to maintain mobility. Further work including controls is needed to substantiate or refute these ideas. We could not use one ankle as control for the other because limbs are not functionally independent; reflex stiffness of 'unaffected' limbs of adults with hemiplegia is changed reciprocally compared with the limbs with spasticity.[5] Thus the improved mobility of all five of our participants – in four after only 5 weeks – should be viewed with caution until a double-blind controlled trial can be conducted.

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