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Letter to the Editor

Letter to the editor regarding: Effects of cerebral palsy on Achilles tendon moment arm length – Do children with CP have larger or smaller moment arms than typically developing children? Commentary on: Alexander et al.

In children with cerebral palsy (CP), secondary musculo-skeletal deformities can cause lever-arm dysfunction. Common deformities such as increased femoral anteversion and excessive tibial torsion can compromise respectively the hip abductor moment arm and the external moment arm around the ankle (Theologis, 2013). A recent paper in Journal of Biomechanics by Alexander et al. (2019) reports Achilles tendon moment arm (MA_{AT}) to be bigger in children with CP compared to typically developing (TD) children. This contradicts findings from our group, published in the same journal two years earlier (Kalkman et al., 2017) showing that MA_{AT} is smaller in children with CP. Some possible reasons for the difference have been suggested by Alexander et al., namely the heterogeneity of the participant groups and the methodology used (2D vs. 3D). Further, there are differences in the angle at which the MA_{AT} is measured, so with this letter we seek to provide a further discussion to examine the possible effects of these on the comparisons.

Given the heterogeneity of musculoskeletal presentation associated with CP and that authors only report those participant characteristics that they were aware of, a risk exists when generalizing results between studies. The patient groups in Kalkman et al. and Alexander et al. (Table 1) seem comparable in terms of age, diagnosis and the Gross Motor Function Classification Scale (with the children in Kalkman et al. possibly being slightly more functional). One notable difference is that all but one child in the study of Alexander et al. had received intramuscular injections with Botulinum NeuroToxin-A (BoNTA) within the past six months. In contrast, Kalkman et al. defined BoNTA injections in the past 6 months as an exclusion criterion. In addition, the location of the study (Belgium and the UK in Kalkman et al. and Australia in Alexander et al.) may have led to differences in the patients' treatment histories. On further analysis (unpublished), in the patient group included in Kalkman et al., subjects received on average 2.3 injections (range 0–11) > 6 months before the study date. While it seems unlikely that MA_{AT} will be affected by BoNTA, there is evidence that long term use of BoNTA affects muscle structure in CP (Schless et al., 2018). Nevertheless, while heterogeneity of study groups will always be a challenge when working with a CP population, the relatively small differences in patient presentation are unlikely to explain the contrasting findings, which are more likely caused by methodological factors.

The moment arm of a tendon is defined as the perpendicular distance from the tendon line of pull to the axis of rotation of the joint the tendon crosses, and has been calculated using either 2D or 3D methods (Clarke et al., 2015; Fath et al., 2010). The problem with a 2D approach to measure MA_{AT} at the ankle joint, is that the orientation of the axis of rotation is not orthogonal to the sagittal plane, in which the MA_{AT} is measured. Furthermore, due to tibial torsion, this could be even more altered in children with CP. Alexander et al. argue that this source of error might explain the differences found between the two studies. Indeed this error does alter moment arm measurements, however a rotation of the tibiotalar joint axis would lead to an overestimation of the moment arm length when measured in 2D (Hashizume et al., 2012; Maganaris, 2004), as illustrated in Fig. 1. Due to possible greater tibial torsion in children with CP, the effect of this error in the study of Kalkman et al., would be to overestimate MA_{AT} more in CP compared to TD. Therefore, the difference found by Kalkman et al. would be even more pronounced if this error was taken into account. However, even though the method is important and could definitely impact between group differences it cannot completely explain the between study findings.

Another important difference in methodology is related to the ankle joint angle at which the MA_{AT} was measured. In Kalkman et al., MA_{AT} was measured at multiple joint angles. Between group comparisons were presented at −20° (negative angles refer to plantarflexed position) because all participants could achieve this ankle angle. In Alexander et al., MA_{AT} was measured at one position, which differed between participants and groups (CP: mean: −32°, min: −15°, max: −54°; TD: mean: −19°, min: −7°, max: −29°). Therefore to make a valid between group comparison, they estimated the MA_{AT} at −20° by extrapolating over a relationship obtained from the Opensim lower limb model (Arnold et al., 2010). The shape of this moment arm-ankle angle curve is of paramount importance when estimating the moment arm at a common angle and could completely determine the direction of the between group difference observed. Experimental studies have reported varying ankle angle-moment arm relationships, with mostly a decrease in moment arm length towards more dorsiflexed angles (Maganaris et al., 2000; Rugg et al., 1990) while others report that MA_{AT} does not change with ankle angle (Fletcher and MacIntosh, 2018). However, Arnold et al. report a parabolic relationship with a peak around −20°. An illustration of the data can be found in Fig. 2. The parabolic relationship, is only validated between ankle angles of −30° and 20° (Arnold et al., 2010). Similarly, experimental measurements are usually not extended beyond ~−20° or ~30°. While we do not know about the accuracy of the extrapolated relationship, if a flat or even a decreasing relationship, would have been used by Alexander et al. to calculate MA_{AT} at −20°, the results in the CP group would have been smaller, while in the TD group the influence would have been limited since MA_{AT} was measured at an angle close to −20°. Therefore, when comparing the two groups, the difference would have been much smaller or even in the opposite direction.

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Table 1
Comparison of patient characteristics.

	Kalkman et al. (2017)		Alexander et al. (2019)	
	CP (n = 15)	TD (n = 20)	CP (n = 8)	TD (n = 11)
MA (mm)	41.5 (13.4)	48.5 (8.9)	47.1 (3.5)	41.8 (5.85)
MA (% TL)	12.2 (2.3)	14.5 (1.5)	17.2 (2)	15.2 (1.2)
Tibia length (mm)*	333	334.5	275.5	274
Age (year)	11.1 (3)	10.4 (3.4)	9.7 (2.6)	8.7 (2.3)
Gender	10M, 5F	11M, 9F	7M, 1F	5M, 6F
Height (cm)	140.5 (20.6)	141.5 (16.6)	Not reported	
Mass (kg)	34.6 (18)	37 (14)	Not reported	
GMFCS	I (n = 10), II (n = 5)		I (n = 4), II (n = 4)	
	Diplegia (n = 9), Hemiplegia (n = 6)		Diplegia (n = 4), Hemiplegia (n = 4)	
MAS/Tardieu	MAS: 1 (n = 1), 1.5 (n = 6), 3 (n = 1)		Not reported	
	Tardieu: 2 (n = 5), 3 (n = 2)			
Treatment	No previous surgery		No previous surgery	
	No BoNT-A within 6 months		BoNT-A within 6 months (n = 7)	

MA: Moment arm, GMFCS: Gross Motor Function Classification Scale, MAS: Modified Ashworth Scale. BoNT-A: Botulinum NeuroToxin-A, TL: Tibia length.
* Between-study difference in defining tibia length (from tibia plateau to either lateral malleolus (Kalkman et al., 2017) or fibular notch (Alexander et al., 2019)).

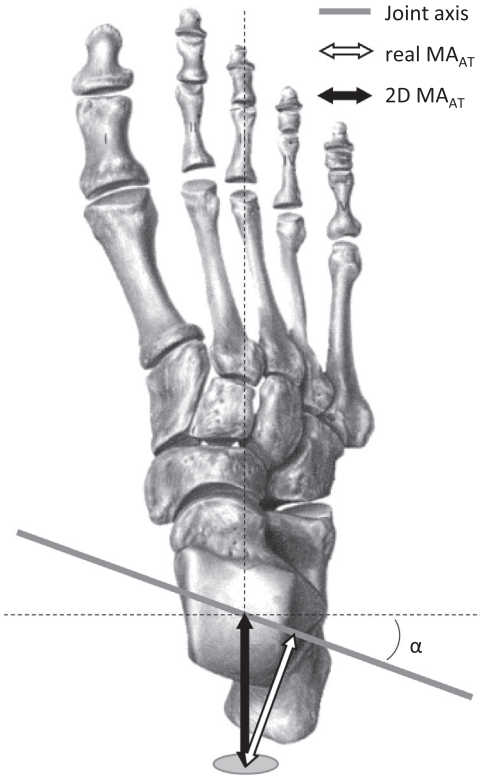

Fig. 1. The grey oval represents the Achilles tendon and the grey line represents the joint axis of rotation. the MA_{AT} measured in a 2D approach in the sagittal plane (black arrow) does not correspond to the 'real' MA_{AT} (white arrow). This 'real' MA_{AT} can be calculated as the product of the 2D MA_{AT} and cosα and is therefore smaller than the 2D measured MA_{AT}. Figure adapted from Hashizume et al. (2012).

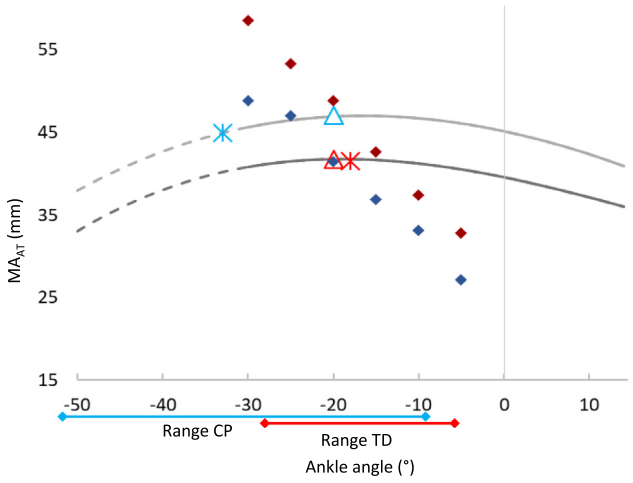

Fig. 2. Achilles tendon moment arm (MA_{AT})-joint angle comparisons from Kalkman et al. and Alexander et al. The Blue (CP) and red (TD) cross represent the average measured MA_{AT} by Alexander et al. The range of angles over which individual MA's are measured is shown by the bar underneath the graph. Consequently, the measured MA was used to estimate its length at −20° using the MA-angle relationship from Arnold et al., which was adjusted such that it runs through this measured value (grey lines, solid: validated range, dashed: non-validated range). The blue and red triangle represent the MA_{AT} extrapolated along this curve for CP and TD respectively. The red and blue diamonds, represent the measured MA_{AT} at 6 joint angles by Kalkman et al. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

At present, one cannot be certain which of the two approaches provides more realistic MA_{AT} values in children with CP. To avoid the pitfalls of each approach and address the issue of how CP affects MA_{AT} unequivocally, future research should firstly focus on measuring the MA_{AT} in children with CP in 3D to account for any rotational deformities. Secondly, MA_{AT} should be measured over the whole range of motion, so that conclusions do not rely on extrapolation of data over a relationship that is not validated. The shape of this MA-angle relationship should be investigated further, especially in pathological cases, since there is a lot of controversy in the literature about the shape of this relationship. Furthermore, MA_{AT} should be investigated under loaded conditions, which has been shown to influence moment arm length (Maganaris et al., 1998; Rasske et al., 2016).

Declaration of Competing Interest

The authors disclose that they have no conflicts of interest.

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