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Relationship between radiographic patella-alta pathology and walking dysfunction in children with bilateral spastic Cerebral Palsy

Matthias Hösl[a,*], Harald Böhm[b], Michaela Seltmann[c,d], Chakravarthy Ugandhar Dussa[b], Leonhard Döderlein[b]

[a] Schön Klinik Bad Aibling, Hospital for Neurology and Neurological Rehabilitation, Kolbermoorer Str. 72, 83043, Bad Aibling, Germany
[b] Orthopaedic Hospital for Children, Behandlungszentrum Aschau GmbH, Bernauer Str. 18, 83229, Aschau im Chiemgau, Germany
[c] Department of Sport and Health Sciences, Technische Universität München, Uptown München-Campus D, Georg-Brauchle-Ring 60/62, 80992, München, Germany
[d] Schön Klinik München Harlaching, Harlachinger Straße 51, 81547, München, Germany

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ABSTRACT

Background: Patella-alta is very common in patients with Cerebral Palsy (CP). While several diagnostic x-ray indices have been developed for patella-alta in general, the specific relationship with walking dysfunction in CP is only partly understood.

Methods: 33 participants with bilateral spastic CP between 4 and 20 years (GMFCS I–II without previous surgery) that underwent 3D gait analysis as well as a radiographic exam within 0.8 (SD 1.2) months were retrospectively included. The Caton-Deschamps, the Insall-Salvati and the Koshino-Index, as well as the moment-arms of the quadriceps, the pattelar-tendon length and patellar tilt angle were analyzed from x-rays. During gait, tempo-spatial parameters, the knee flexion kinematics, the knee moments and the moment impulse were calculated and correlated to x-ray parameters.

Results: Smaller quadriceps moment-arms were related to slower walking speed ($r = 0.48$, $P = 0.005$) and less knee extension during stance ($r = 0.68$ $P < 0.001$). Smaller quadriceps moment arms and longer patellar-tendons were also significantly related to a larger knee flexion moment impulse in the second half of the stance phase ($r = -0.36$, $P = 0.045$ and $r = 0.39$, $P = 0.028$) and hence to more abnormal knee loads. Yet, none of the traditional indices was related to any parameter of gait.

Interpretation: Traditional radiographic indices for patella-alta possess little to no informative value for walking dysfunction in individuals with CP suspected to have knee pathology. Smaller moment-arms are a key feature of patellofemoral pathology in CP reducing the knee extensor mechanism, an aspect which is not sufficiently picked up by traditional indices.

1. Introduction

Many children with CP depict progressive skeletal abnormalities [1]. Amongst others, patella-alta, a vertically displaced kneecap, has been reported in 61–93% of ambulatory children with CP [2,3]. It is probably caused by elongated patellar-tendons and is often observed in children with crouch gait, a walking pattern during which knee loads are large [4]. Patella-alta appears to be critical since it reduces retro-patellar contract areas [5] and supposedly causes excessive retro-patellar stress. Although exact links have not been established, approximately every 5th child with CP complains about knee pain [6] and about every 8th child locates the pain anterior at the knee [2].

In symptomatic knees or in functionally very limited walkers, the patello-femoral joint congruency is restored by surgical shortening of the patellar-tendon. The ultimate goal of such treatment is to increase function. This is frequently done together with femur osteotomies [7–9] and in combinations these approaches are able to improve crouch gait. However, as a side effect shortening the patellar-tendon may also risk anterior pelvic tilt [7,8] and reduction in swing phase knee flexion [8,9], which may perhaps be induced by increased tension within the rectus femoris muscle. Yet, the biomechanical trade-offs need to be disentangled further and an exact identification of the relevance of skeletal deformities for gait is thus warranted.

Patella-alta is typically diagnosed from x-rays indices relating the

Abbreviations: KI, Koshino Index; ISI, Insall-Salvati Index; CDI, Caton-Deschamps Index; CP, Cerebral Palsy; d_{PT}, Patella-tendon moment-arm; d_{QD}, Quadricpes moment-arm; L_{PT}, Patella-tendon length; ICC, intra-class correlation coefficient; SEM, standard error of measurement

* Corresponding author.
E-mail addresses: mhoesl@schoen-kliniken.de, matthias.hoesl@gmx.de (M. Hösl).

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position of the patella to the tibia or femur [10]. Whether this is functionally meaningful in CP is not known. Notably, the majority of indices were developed for adults and typically developing children without associated crouch gait pathology. Nevertheless, 3 common indices may be practical in children with CP: The Insall-Savati Index (ISI) [11] showed high validity with MRI measures of patellar-tendon length in healthy children [12]. The Koshino index (KI) [13] had been already frequently used in CP [7,8,14], e.g. as an outcome after patella-tendon shortening procedures [7]. Yet, as the KI is a rather complex geometric construct, the Caton-Deschamps index (CDI) has been proposed as a simpler alternative [15].

Since specific knowledge about patella-alta and its relations to walking dysfunction is vague, missing success of interventions could be partly related to an incomplete understanding of the etiology. As the patella usually functions as a fulcrum to the femoral condyles, it should provide a mechanical advantage for knee extensor torque generating capacity. In this context, patella-alta is thought to decrease the muscular moment arms close to full knee extension and hence contribute to functional weakness during gait [16]. Yet, recent simulations pointed out that a moderate patella alta may in fact act to reduce knee extensor muscle loadings when walking in crouch [33]. In addition, the theory about moment arm reductions was also derived from simulations and could not be confirmed in CP patients [17]. Aspects of moment arm reductions could therefore be separate features of patellofemoral pathology in CP.

Taken together it needs to be determined whether the radiographic patellofemoral pathology in CP patients is a priori related to crouch gait. Therefore our aim was to study the relationship between radiographic measures and walking dysfunction to provide clinically useful assessments. We hypothesized that more abnormal patella-alta x-ray indices, longer patella-tendon lengths and smaller moment arms of the patellar and quadriceps tendon are related to more crouch gait and larger knee loads during walking.

2. Methods

2.1. Participants

Participants were retrospectively included from a gait lab data base in an orthopaedic paediatric hospital from 09/2006-07/2016. They needed to be diagnosed with bilateral spastic CP, aged 4–20 years, classified in GMFCS I–II and have no history of surgery and no botulinum-toxin Injections within 6 months. All performed a 3D gait analysis and they needed to have a sagittal plane knee x-ray taken within less than 4 months. Participants were excluded if 1) the patella was not clearly ossified; 2) the radiograph was not taken during lying; 3) the x-ray was taken during knee flexion < 20° to avoid that the patellar-tendon buckled [18]. If an x-ray of both knees was available, only the more affected side was included based on gait pathology (greater magnitude of crouch). In case no clear distinction could be made, the side with an x-ray closer to 30° knee flexion was chosen. All parents and patients signed a free and informed consent statement.

33 bilaterally affected CP patients with a mean age of 12.0 years (SD 3.7, range 4–20), at a height of 145.2 cm (SD 18.9) and a weight of 39.2 kg (SD 13.9) were included. 6 were classified in GMFCS I, 27 in GMFCS II. Mean time between x-ray and 3DGA was 0.8 months (SD 1.2). 6 of 33 reported knee pain (18.2%). As part of the clinical routine, the presence of knee pain was assessed by a standardized questionnaire. As a reference group for 3D gait analysis only, 35 typically developing participants (18 female) served as reference for walking. Their age was 11.6 years (SD 3.5), at a height of 149.9 cm (SD 17.1) and a weight of 40.7 kg (SD 14.2). This reference group will give an indication about the degree of gait pathology in the sample with CP. No x-ray was taken from this reference group.

2.2. Gait-analysis

A Vicon Nexus system (Vicon, Oxford, UK) with 8 MX-Cameras was used to capture barefoot gait at a self-selected, comfortable speed. Markers were placed according to the Plug-In gait Model. Only two raters performed application of reflective markers during the course of 3D gait analysis.

Marker data were sampled at 200 Hz and force data at 1000 Hz via two force plates (AMTI, Watertown, USA). 3 or more consistent trials were averaged, as only data with a clear foot strike on an individual force plate were selected. As outcomes we selected the non-dimensional speed: v/√(g x leg length), step length: step length/leg length and cadence: cadence x √(g x leg length); with g representing gravitational acceleration [19]. Concerning joint kinematics, we selected the minimum knee flexion in stance, as well as the peak knee flexion in swing. Concerning joint kinetics, knee flexion moments were normalized to body mass (kg). We extracted the peak knee flexion moment in the first and second half of stance, as well as the minimal moment in midstance [Nm/kg]. Next to that, we calculated the angular moment impulse as the integral of moment with respect to time [Nm x sec./kg] in the first and second half of stance [20].

2.3. Radiography

Lateral x-rays were taken while subjects were lying. Radiographs were reviewed using Gemed-Pacs software (Allgeier Medical IT GmbH, Freiburg, Germany). 3 indices were used: the Koshino (KI) [13], the Insall-Salvati (ISI) [11] and the Caton-Deschamps Index (CDI) [21]. Methods are visualized in Fig. 1. Normative scores (z-values) for the CDI, ISI and KI were created with respect to the reference values in [15,35,13]. For the CDI and ISI we provided age-dependentscores and for the KI we created z-scores depending on the knee flexion angle. We looked for the closest match between the participants' age or knee flexion angle and the normative reference values.

Patellar-tendon length (L_{PT}) was measured from the distal tip of the patella to the most anterior point at the tibial tuberositas. The geometrical centre of the femoral condyles was determined as the midpoint of a straight line between the centres of two circular profiles fitted to the posterior condyles [22] (Fig. 1). The moment arm of the patellar tendon (d_{PT}) was equal to the perpendicular distance of the patellar-tendon and the geometrical centre of rotation. The Quadriceps moment arm (d_{QD}) was measured as the perpendicular distance between the line of the quadriceps tendon and the geometrical centre. The quadriceps tendon was assumed to be aligned parallel to the femur long axis. d_{QD} was quantified in two ways: First, the line of the quadriceps tendon was assumed to run through the proximal tip of the patella. Second, the line of the quadriceps tendon was placed such that it tangentially meets the most anterior aspect of the patella (Fig. 1). Moreover, the patellar tilt angle was quantified between patellar joint surface and the femur long axis [5]. Tendon length and moment-arms were normalized to shank segment length, extracted from the PIG-model from gait analysis, to account for different skeletal growth.

2.4. Clinical examination

Passive knee extension was determined with ruler based goniometry. The Medical Research Council [MRC] Scale [0–5] was used to manually evaluate knee extensor strength [23].

2.5. Statistical analysis

Data were analyzed with custom written MatLab scripts (Mathworks, Natick, USA). First, to give an indication about the degree of gait pathology, we referenced the gait parameters of children with CP to a group of typically developing peers and performed independent *t*-tests. Second, in 10 randomly selected participants the intra- and inter-