UNIVERSIDAD DE MURCIA

FACULTAD DE MEDICINA

Relación entre las Curvaturas Sagitales de Raquis y el Nivel de Función Motora Gruesa

D. José Manuel Sanz Mengíbar

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de la Universidad de Murcia

AUTORIZA:

La presentación de la tesis doctoral titulada: **"Relación entre las curvaturas sagitales del raquis y el nivel de función motora gruesa"**, realizada por **D. José Manuel Sanz Mengíbar**, bajo mi inmediata dirección y supervisión, y que presenta para la obtención del Grado de Doctor por la Universidad de Murcia.

Y, para que surta los efectos oportunos al interesado, firmo la presente en Murcia, a once de marzo de dos mil siete.

Dr. Fernando Santonja Medina

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Dra. Dª. Mª Paloma Sánchez de Muniain y Sabater

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Dra. Mª Paloma Sánchez de Muniain y Sabater

Dedicado a Alberto. Dedicado a las innumerables dificultades que he encontrado en el camino. Me avisaron que tendría que empujar una piedra pesada por una colina cuesta arriba. Jamás pensé que habría viento en contra. Gracias a tanta resistencia hoy siento que ni un solo segundo de este proyecto ha sido debido a la inmerecida fortuna del "pan de la vergüenza", sino al incansable esfuerzo de mis directores de tesis y yo mismo.

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INTRODUCCIÓN

INTRODUCTION

INTRODUCCIÓN E HILO CONDUCTOR DE LA PRESENTE TESIS DOCTORAL

La esencia de esta Tesis Doctoral es investigar la relación entre las curvaturas del raquis en el plano sagital y la función motora gruesa alcanzada por los sujetos. De esta manera se podría entender el impacto sobre la posición del raquis en dicho plano cuando la función motora gruesa se ve afectada por una patología determinada. Por tanto, son varias los puntos que abrieron las diferentes líneas de investigación incluidas en este trabajo:

- ¿Cuál es la mejor manera de medir la función motora gruesa?
- ¿Está la función motora gruesa de un sujeto determinada en parte por la capacidad de enderezamiento de su raquis en el plano sagital?
- ¿Se da esta relación tanto en condiciones de función motora gruesa normal (desarrollo ontogénico), como en la función motora gruesa reducida (niños con parálisis cerebral), y así mismo en niños con desarrollo de funciones superiores al desarrollo ontogénico (marcha sobre los miembros superiores en Gimnasia Artística)?
- ¿Cuál puede ser el efecto en el raquis del entrenamiento de una función por encima de las capacidades ontogénicas adquiridas por el sujeto? ¿Es este efecto similar en niños con una lesión cerebral y por tanto con función motora gruesa reducida (marcha asistida con los miembros superiores a través de un andador en niños con parálisis cerebral) a aquellos que a pesar de tener un Sistema Nervioso Central intacto, entrenan un función superior al nivel ontogénico (Marcha sobre los miembros superiores en Gimnasia Artística)?

La tabla 1 muestra los diferentes estudios que se han desarrollado para poder obtener y relacionar los datos en todos los rangos de las variables: función motora gruesa, edad, sistema nervioso central intacto y parálisis cerebral. Los campos sombreados son los artículos incluidos en la presente Tesis por compendio de Publicaciones.

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<tr><td colspan="7">Se muestran de forma esquemáticas los diferentes estudios para relacionar las curvaturas sagitales de la columna vertebral con la función motora gruesa. GMFCS= Gross Motor Function Classification System. EL = Estadios de Locomoción según el Dr. Vojta</td></tr>
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En un primer momento se demostró la validez relativa de criterio y la fiabilidad de la medición de la función motora gruesa mediante los "Estadios de Locomoción". Esto nos permitió comparar la función motora gruesa de los niños con desarrollo sano y aquellos niños con parálisis cerebral en sucesivos pasos. Para ello, se realizó una correlación con la escala de referencia aceptada internacionalmente que es la Gross Motor Function Classification System (GMFCS), pero que únicamente clasifica niños con parálisis cerebral (PC).

Por otro lado, la medición de la disposición sagital de la columna vertebral se estudió en niños con parálisis cerebral, dinámicamente durante la ejecución del patrón de marcha bípeda humana. El laboratorio de análisis tridimensional del movimiento nos permitió medir la columna lumbar en niños con parálisis cerebral de gravedad GMFCS III, II y I. A continuación, los datos obtenidos de la disposición sagital del raquis se relacionaron con los valores de la función motora de la escala GMFCS.

Para poder obtener datos de sujetos con una capacidad motora gruesa por encima del desarrollo típico ontogénico se estudió a los gimnastas de la disciplina de Gimnasia Artística. Se eligió esta población por su entrenamiento en capacidades más altas a la ontogénesis básica humana, y entre ellas la marcha con los miembros superiores. Además esta población permitía una medición estática y estandarizada mediante el inclinómetro de la disposición sagital del raquis.

Nuestra hipótesis de partida es: "Existe una relación entre la función motora gruesa humana y la disposición sagital de la columna vertebral en los sujetos con parálisis cerebral, y de forma adaptativa al entrenamiento en sujetos sanos".

Todo ello nos ha hecho comprender cómo un entrenamiento mediante factores externos de patrones motores superiores a las capacidades independientes de niños con parálisis cerebral (marcha asistida con andador), se relaciona con las adaptaciones sufridas por el raquis de deportistas sanos con este tipo de entrenamiento por encima del desarrollo postural ontogénico.

LA PARÁLISIS CEREBRAL

DEFINICIÓN

La Parálisis Cerebral (PC) fue descrita por primera vez por Little en 1861, quien relacionó la espasticidad que la caracteriza con la anoxia y el traumatismo del parto. Sin embargo, Sigmund Freud sugirió que la causa eran disfunciones cerebrales prenatales que se demostraban con asfixia al nacimiento (consecuencia y no causa) (Pountney, 2007).

La definición europea es "una alteración permanente pero no incambiable de neurodesarrollo causada por una lesión no progresiva de localización única o múltiple en un cerebro inmaduro. Los defectos o lesiones pueden ocurrir in útero, durante o en un breve periodo después del nacimiento, causando alteraciones motoras y posibles déficits sensoriales que son evidentes desde etapas tempranas" (Bax et al, 2005).

Por tanto la parálisis cerebral es un término que engloba un grupo de trastornos del movimiento, la postura y del tono muscular (Mutch et al, 1992) y la causa de las lesiones neurológicas, aunque el desorden sea permanente, no es inmutable, ya que las características del mismo podrán cambiar evolutiva o involutivamente. Pero no aumenta, ni disminuye, ni tampoco constituye un trastorno de tipo degenerativo. Todo ello condiciona una limitación en la capacidad y en la función motora gruesa.

Según el Comité Ejecutivo para la Definición de Parálisis Cerebral (Bax et al, 2005) "La parálisis cerebral describe a un grupo de alteraciones del desarrollo del movimiento y de la postura, causadas por alteraciones no progresivas del cerebro durante el desarrollo fetal o en la infancia, y que provocan una limitación de la actividad. Las alteraciones motoras de la parálisis cerebral se acompañan con frecuencia de alteraciones sensoriales, cognitivas, de la comunicación, de la percepción, y/o del comportamiento, y/o de crisis convulsivas" (Bax et al, 2005).

Aunque el trastorno motor es el factor que define "sine qua non" de la parálisis cerebral, los trastornos asociados son frecuentes y a menudo asociados a la gravedad del cuadro. Entre ellos se han descrito: apraxia, agnosia, alteraciones sensoriales (visuales, auditivas), problemas del habla y lenguaje (disartria), estrabismo, déficit de funciones cognitivas (discapacidad intelectual) y trastornos psiquiátricos como labilidad emocional, déficit atencional, rasgos obsesivos compulsivos, trastorno de espectro autista, frustración y baja autoestima. Además pueden existir trastornos de alimentación, retraso de crecimiento, reflujo esófago-gástrico, trastornos respiratorios, trastornos del sueño, epilepsia, dificultades en el aprendizaje, en la comunicación y de tipo comportamental.

INCIDENCIA Y PREVALENCIA

A partir de los años 60 se produjo una disminución de parálisis cerebral debido a la mejora en los cuidados perinatales, aunque aumentó a partir de los 70 por la mayor supervivencia de los prematuros extremos (<1500 gr.) en los que la incidencia es 70 veces superior a las de los niños de peso >a 2500 gr. (Hurtado, 2007). En los años 80 los rangos de prevalencia de parálisis cerebral eran estables entre los niños nacidos vivos y particularmente entre los sujetos prematuros. Está prevalencia se vió aumentada junto a los rangos de supervivencia, mientras que la incidencia en niños de bajo peso al nacer (inferior a 2500 gr) permanecían estables (Hagberg et al, 2001). Estudios recientes sugieren que la incidencia de parálisis cerebral se está reduciendo en niños de bajo peso al nacimiento y en niños prematuros (Hagberg et al, 2001 y Topp et al, 2001). La incidencia en los países desarrollados es de 2-3 por mil recién nacidos vivos en Europa (SCPE, 2000; Johnson, 2002) y en América (MAADDSP 2002; Lorente, 2007). En España y según la Encuesta sobre Deficiencias, Discapacidades y Estados de Salud de 1999, el

número de personas con parálisis cerebral se acerca a 78.000 (Jiménez Lara, 2003). Datos procedentes de Reino Unido, Australia y Suecia muestran una tendencia al aumento de la parálisis cerebral cuanto menor es el peso al nacer. Dentro de la población de bajo peso al nacer, hay un aumento de la parálisis cerebral con la reducción de la mortalidad (Shore et al, 2012).
La esperanza de vida ha aumentado a partir de los años 90, incluso en personas con problemas funcionales severos, alcanzando la edad adulta con normalidad.

ETIOLOGÍA

Existen muchas especulaciones sobre las causas de la parálisis cerebral, sobre todo debido a que las mejoras en los cuidados obstétricos no han reducido su incidencia como se postulaba. Algunos autores indican una mayor correlación con trastornos durante el embarazo que con problemas durante el nacimiento. Sólo el 10% de los casos de parálisis cerebral se debe a asfixia perinatal, y de entre ellos pocos se pueden achacar a un déficit del manejo obstétrico (Rosenbloom, 1995 y Stanley et al, 2000), existiendo sospechas de trastornos preexistentes que incrementan la vulnerabilidad.

Existen múltiples causas que pueden originar el daño cerebral y que podrán tener lugar en diferentes momentos:

1. **Prenatal:** Genéticos, hemorragia maternal, hipertiroidismo de la madre, fiebre, procesos vasculares, accidentes cerebrovasculares, infecciones (intrauterinas, sífilis, VIH, rubeola, toxoplasma, cytomegalovirus, herpes) corioamnionitis, infarto placentario, toxicidad / drogas.
2. **Perinatal**: Encefalopatía hipóxico-isquémica, infecciones (meningitis), prematuridad, hiperbilirrubinemia.

3. **Postnatal**: Infecciones (meningitis, sepsis graves), Encefalitis, Accidentes cerebrovasculares, hidrocefalia, neoplasias y traumatismos craneoencefálicos.

DISFUNCIÓN MOTORA Y DISCAPACIDAD

La parálisis cerebral es la causa de discapacidad motora más importante en la infancia (Escobar et al, 2011). Los mayores problemas funcionales de los niños con parálisis cerebral son el bloqueo del desarrollo motor, alteraciones de la marcha y demás patrones de movimiento anormal que suponen un mayor desgaste energético y deformidades. Los patrones de reclutamiento muscular y de locomoción normales no se desarrollan en niños con parálisis cerebral, asemejándose por el contrario a patrones inmaduros. El aparato locomotor se deforma de forma secundaria al uso de estos patrones de postura y movimiento.

CLASIFICACIÓN CLÁSICA DE LA PARÁLIS CEREBRAL

Topográfica

La clasificación topográfica ha sido la más utilizada clásicamente y probablemente es la más conocida en la actualidad. Esta clasificación considera las zonas anatómicas afectadas. Cuando la parálisis afecta por igual a las cuatro extremidades se denomina una tetraparesia (o tetrapléjia). Si el mayor nivel de afectación se localiza en las extremidades inferiores, estando las superiores claramente mucho menos comprometidas, se habla entonces de diparesia (o diplejia). Si la afectación es de un hemicuerpo se denomina hemiplejía (o hemiparesia), que podrá ser derecha o izquierda. Cuando sólo un miembro es el afectado, se habla de la existencia de una monoplejía (o monoparesia). En ocasiones es difícil delimitar la afectación, por lo que en la actualidad se han establecido dos grupos: afectación bilateral o unilateral (Ruiz, 2006).

El Surveillance of Cerebral Palsy in Europe (SCPE, 2000) define los siguientes Subtipos de parálisis cerebral según los hallazgos neurológicos predominantes:

- PC espástica
    - bilateral
    - unilateral (hemiparesia)
- PC discinética
    - distónica
    - coreoatetósica
- PC atáxica

Tipo de trastorno de movimiento

Esta clasificación describe el tipo de tono muscular y trastorno de movimiento predominante en cada grupo. Por tanto se habla de:

- Espasticidad: lesión del tracto piramidal (corticospinal directo)
- Discinésia: lesiones en los circuitos de los de los ganglios de la base (extrapiramidales)
- Ataxia: lesiones en circuitos cerebelosos

Grado de severidad

Esta clasificación se caracteriza por la subjetividad y se describen grados leve, moderado y grave o severo de acuerdo a las capacidades funcionales.

El uso de esta clasificación en el ambiente clínico se asocia a la combinación de las anteriores, intentando describir el diagnóstico funcional más apropiado:

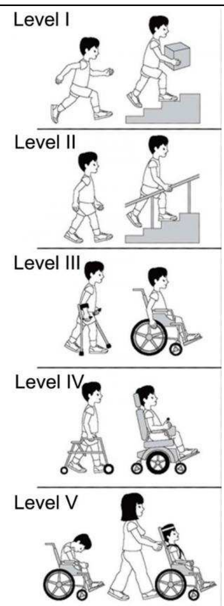
- Parálisis cerebral bilateral (Tetraparesia espástica, Diparesia espástica)
- Parálisis cerebral unilateral (Hemiparesia espástica)

- Parálisis cerebral discinética o distónica
- Parálisis cerebral atáxica
- Formas mixtas

Clasificación según función motora gruesa y la capacidad de locomoción

Gross Motor Function Classification System (GMFCS) se resume en la tabla 2 y es uno de los sistemas de clasificación más conocidos y fiables en rehabilitación pediátrica (Carnahan et al, 2007 y Palisano et al, 2010). Se usa ampliamente en el campo de la investigación, para la clasificación clínica y su uso no requiere mucho tiempo ni costes (Gunel et al, 2009). GMFCS se basa en los componentes de actividad y la participación, así como en los factores ambientales (WHO, 2001) de acuerdo a la movilidad de niños con parálisis cerebral dentro del marco de trabajo de la Clasificación Internacional de la Funcionalidad (CIF).

Tabla 2. Gross Motor Function Classification System (GMFCS) (Palisano et al, 1997)	
Nivel I	Camina sin limitaciones en casa y en la comunidad.
Nivel II	Camina con limitaciones. Puede hacerlo en casa y en la comunidad pero con dificultad en terrenos irregulares o en largas distancias
Nivel III	Camina utilizando un dispositivo manual auxiliar de la marcha
Nivel IV	Automovilidad limitada, es posible que utilice movilidad motorizada
Nivel V	Dependencia completa de otra persona para moverse dentro y fuera de casa. Escaso control de tronco y cefálico. Transportado en silla de ruedas



Clasificación según capacidad manipulativa (Eliasson et al, 2006).

Tabla 3. Manual Ability Classification System (MACS)	
Nivel I	Manipula objetos con facilidad y eficazmente. Puede tener ligera dificultad en movimientos que requieren destreza y rapidez, que no limita su independencia funcional
Nivel II	Manipula la mayor parte de objetos pero con cierta limitación en la eficacia o velocidad. Puede que evite algunas actividades o las consiga con alguna dificultad. Puede que realice actividades buscando vías alternativas, pero la actividad manual habitualmente no limita la independencia en la actividades básicas de la vida diaria
Nivel III	Manipula objetos con dificultad. Necesita ayuda para modificar o preparar actividades. La ejecución es lenta y poco eficaz. Es independiente únicamente si la tarea está preparada o adaptada
Nivel IV	Manipula un número limitado de objetos seleccionados en condiciones adaptadas. Requiere ayuda/adaptación incluso para la ejecución parcial
Nivel V	No manipula objetos y tiene limitación severa para ejecutar incluso actos simples. Requiere asistencia completa

CLASIFICACIÓN FUNCIONAL DE LA PARÁLISIS CEREBRAL EN LA ACTUALIDAD Y SU COMPARACIÓN CON EL DESARROLLO FUNCIONAL TÍPICO.

Los sistemas de clasificación tradicional de la parálisis cerebral de acuerdo a la distribución del patrón de afectación de las extremidades, la severidad del cuadro o el tipo de alteración del movimiento tienen un papel relevante en la práctica clínica actual. Sin embargo, estas herramientas no son indicadores de capacidad motora ni pronóstica (Palisano et al, 1997; Keeratisiroj et al, 2015; Jooyeon et al, 2011). La movilidad durante las actividades de la vida diaria tienen un papel importante como herramientas de clasificación e investigación, categorizando los niños con parálisis cerebral en diferentes niveles funcionales (Mayston, 2008); Wallen et al, 2001). Los actuales sistemas de clasificación como el GMFCS no tienen la capacidad para "valorar cualitativamente", sino que tratan de "discriminar cuantitativamente" (Keeratisiroj et al, 2015) (Gunel et al, 2009), limitando así su uso en la práctica clínica ya que no son capaces de orientar la fisioterapia a corto plazo (Gray et al, 2010).

Los Estadios de Locomoción (EL) descritos por Vojta (Vojta, 1987; Vojta, 1986) se usan en la valoración clínica y en la cuantificación de resultados terapéuticos en pacientes con parálisis cerebral (Schulz et al, 1994; Sánchez de Muniain, 1992; Luna, 2006). Estos estadios de la locomoción patológica están basados en del desarrollo postural humano, que describe los patrones motores desde el punto de vista de la cinesiología (Vojta, 1987; Schulz et al, 1994; Vojta, 2005). Los EL incluyen los componentes de función postural corporal y de actividad independiente (WHO, 2001). Estos componentes se describen siguiendo el desarrollo ontogénico del control postural humano desde el nacimiento hasta la marcha independiente (Tabla 4). Los EL son capaces de valorar la calidad de la ejecución motora, debido a que cada escalón se asocia de forma análoga pero no idéntica a una edad de desarrollo típico (Vojta, 1987; Schulz et al, 1994).

Tabla 4. Estadios de Locomoción (EL) / Locomotion Stages (LS) (Sanz-Mengíbar et al, 2016)	**Equivalent Ontogenic Pattern**
STAGE 0: **ORIENTATION**. The child´s motor performance is lower than in stage 1. In the supine position the child cannot grasp or turn its head or body in order to establish a contact.	Holokinetic movement
STAGE 1: **REACHING**. The child can turn his head and body towards a stimuli, and at least one hand tries to reach out with palmar flexion and cubital tilt. Grasping is restricted to the finger tips.	Reach out with hands towards toy. 4 month
STAGE 2: **GRASPING**. In prone position	Prone on forearms, weight on one side and able to grasp with the other hand. 4,5 months
STAGE 3: **CREEPING**. Child is able to move forward propping on one or both forearms. Legs may move in association, but are not able to push to create any locomotion.	Creeping or commando crawling. 7 months
STAGE 4: **HOMOLOGOUS CRAWLING**. Bunny hopping. Legs move forward at the same time, while arms can do it in a homologous or alternating way.	No analogy
STAGE 5: **RECIPROCAL CRAWLING**. Crawling on knees and open hands with a cyclic and sinusoidal shift of the centre of gravity around the midline. All extremities step forward alternating in a crossed pattern. This pattern is used by the child independently, without being told and when it moves quickly.	Reciprocal crawling. 9 months.
STAGE 6: **CRUISING**. The child can pull to a stand and walk sideways independently by holding onto furniture with his hands. Pull to stand may already appears at stage 3, but the child cannot step sideways.	Sideways walking/ cruising on the furniture. 12 -13 months
STAGE 7: **INDEPENDENT WALKING**. The child can walk forward and stop without holding on. Walking is the everyday preferred locomotion.	Walking, stop and turn without holding on. 15 months
STAGE 8: **UNILATERAL STANCE ON ONE SIDE**. The child can stand during 3 seconds or more only on one preferred side, left or right foot. The examiner must not demonstrate this test, but give instructions: "lift one knee up towards your belly"	Monopodal stance on right or left foot. 3 years
STAGE 9: **RECIPROCAL UNILATERAL STANCE**. The child is able to stand reciprocally during 3 seconds or more on both sides, right and left. The examiner gives the same instruction as in stage 8.	Monopodal stance on right and left foot. 4 years

LA MEDICIÓN DE LAS CURVAS SAGITALES DE LA COLUMNA VERTEBRAL

BASES ANATÓMICA Y BIOMECÁNICAS

La columna vertebral o raquis, es una estructura ósea compuesta por 33 ó 34 vértebras, alternadas con discos fibrocartilaginosos a los que se unen por fuertes estructuras ligamentosas (Hamill, Knutzen, 1995). Esta estructura provee tres características fundamentales para su funcionalidad: capacidad de soportar cargas axiales, proteger las estructuras del sistema nervioso central y otorgar una adecuada movilidad del tronco (White, Panjabi, 1990)

En el plano frontal la columna vertebral es generalmente simétrica y recta. En el plano sagital existen 4 curvas fisiológicas, 2 convexas anteriormente (lordosis) y 2 convexas posteriormente (cifosis). Por tanto el raquis queda dividido en este plano en: la lordosis cervical, constituida por 7 vértebras (C_1 a C_7); la cifosis torácica o dorsal, constituida por 12 vértebras (T_1 a T_{12}); la lordosis lumbar, constituida por 5 vértebras (L_1 a L_5); la cifosis sacra, constituida por 5 vértebras (S1 a S5), que forman un sólo hueso, el sacro; y la coccígea, formada por 4 ó 5 vértebras que constituyen el cóccix. Las curvas cervical y lumbar son las más móviles (White, Panjabi, 1990).

Los factores mecánicos que justifican la presencia de las curvaturas en el plano sagital son: 1) Su existencia aumenta la resistencia de la columna vertebral a las fuerzas de compresión axial; 2) Proporcionan mayor movilidad al conjunto arquitectural cabeza-pelvis; 3) Aumentan la estabilidad en bipedestación, debido a que la existencia de las curvas agranda el polígono de sustentación corporal delimitado entre los dos pies; 4) Colaboran en el mantenimiento del equilibrio estático de la cabeza y del tronco mancomunadamente con otros factores, como la actividad de la musculatura o la peculiar disposición de la pelvis humana; y 5) Facilitan la absorción de impactos. (Llanos Alcazar, Martin López, 1998; White, Panjabi, 1990).

La articulación intervertebral se controla a través de complejas palancas de fuerza, fulcros (facetas y discos intervertebrales), estructuras pasivas (ligamentos) y fuerzas activas (musculatura). La estabilidad mecánica del raquis se debe mayoritariamente al alto grado de desarrollo del sistema de control neuromuscular (White, Panjabi, 1990).

MEDICIÓN ESTÁTICA DE LA COLUMNA VERTEBRAL.

El método más fiable para cuantificar el grado de cifosis y lordosis, es la radiografía lateral de la columna vertebral (Ashton-Miller, 2004). Existen otros métodos sin irradiaciones ionizantes que nos permiten medir el grado de las curvas sagitales del raquis, como el inclinómetro que aporta una medida no invasiva, reproducible, válida y con buena correlación con la medición radiográfica (Ng et al, 2001; Saur et al, 1996), siendo adecuado para el estudio de la cifosis y de la lordosis.

El concepto del morfotipo raquídeo sagital “integral” fue definido por Santonja (1996) y consiste en añadir a la valoración clásica de las curvas sagitales dorsal y lumbar en bipedestación, el estudio de la disposición sagital de la columna vertebral en flexión máxima del tronco y el estudio en sedentación relajada o asténica lo que mejora e incrementa las posibilidades diagnósticas. Las curvas dorsal y lumbar se cuantifican en bipedestación, en sedentación asténica (Stagnara et al, 1982; Santonja et al, 1996 y 2006; (Sanz-Mengíbar et al, 2017) y sentado en flexión máxima del tronco con miembros inferiores extendidos en posición del test Distancia Dedos-Planta (DD-P) (Santonja et al, 1996 y 2006). Las referencias de normalidad para las mediciones en las posiciones mencionadas se presentan en la tabla 5:

Tabla 5. Clasificación de las curvas dorsal y lumbar en función de las referencias de normalidad (Santonja et al, 1996,2003, 2006 y 2007)

	Morfotipo	Curva Dorsal	Curva Lumbar
Bipedestación	*Normal*	20º- 45º	(-) 20º- 40º
	Hipercifosis/hiperlordosis	> 45º	> (-) 40º
DD-P	*Cifosis Normal*	40º-65º	10º-30º
	Hipercifosisdorsal/Actitud cifótica lumbar	> 65º	≥ 30º
	Distancia dedos-planta	≥ (-2cm)	
	ºL-Hfx	≤100º	
Sedentación Asténica	*Cifosis Normal*	20º- 45º	± 0-15º
	Hipercifosis dorsal/Actitud cifótica lumbar	> 45º	> 15º
	ºL-H SA	80º-100º	

Los valores negativos se refieren a una curva lumbar de concavidad posterior (lordosis), mientras que valores positivos indican concavidad anterior o cifosis (Santonja et al, 2006 y Norkin, White, 1995).

Bipedestación en postura cero

Para la medición de las curvas en bipedestación, el sujeto se sitúa de pie en la postura cero (ACoEM, 1998). Para medir las curvaturas torácica y lumbar, el inclinómetro se coloca al principio de la curva T_1-T_2, hasta el final de la curva torácica (donde se mide la máxima convexidad), se pone a cero y se vuelve a medir hasta donde se obtenga la máxima concavidad que suele ser a la altura de L_5-S_1 (Santonja, 1996 y ACoEM, 1998).

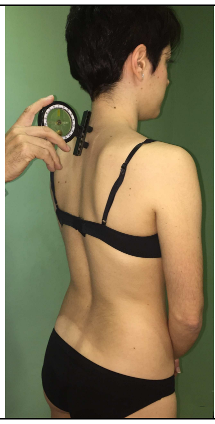


Figura 1. Medición de las curvas sagitales del raquis en posición de bipedestación. Cifosis normal (30^{0}) y lordosis (36^{0}).

<u>En Test Distancia Dedos-planta (DD-P)</u>

La prueba de valoración Distancia Dedos-Planta (DD-P) se realizó siguiendo el procedimiento establecido por el ACSM (ACoEM, 1998). Se utilizó un cajón con una regla milimetrada adherida a su superficie exterior. Las palmas de las manos se deslizan sobre el cajón de medición, hasta alcanzar la máxima distancia posible. El registro se anota en centímetros, considerándose negativos sino alcanzan la planta de los pies y positivos cuando la sobrepasan.

Se insta a mantener la posición durante unos segundos para medir la curva dorsal y lumbar en flexión. Se considera positivos aquellos valores que sobrepasen la planta de los pies (cero de la regla) (Stagnara et al, 1982; Santonja, Martínez 1992; ACoEM, 1998)

En esta postura se midió además el ángulo Lumbo-horizontal en flexión (^{0}L-H fx), al medir con un goniómetro el ángulo de apertura anterior que forma la horizontal con la región lumbosacra (Santonja et al, 1994).

<u>Figura 2</u>. Prueba Distancia Dedos-Planta (DDP) y medición de las curvas sagitales del raquis y el ángulo Lumbo-horizontal en flexión (L-H fx) en esta posición: Adulto y niños.

Sedentación asténica (SA)

Las mediciones en sedentación asténica siguieron el mismo protocolo para las curvas sagitales en flexión del tronco. Con el deportista sentado sobre la camilla en posición relajada, sin apoyar los pies y con los antebrazos apoyados sobre sus muslos (Stagnara et al, 1982 y Santonja, 1996).

Figura 3. Medición de las curvas sagitales del raquis en posición de sedentación asténica (SA).

La cuantificación de las curvas sagitales ha servido para conocer los valores normativos del raquis en sujetos sanos a partir del periodo infantil y para analizar las adaptaciones posturales a determinados factores como en entrenamiento deportivo intensivo (Santonja et al, 2006; Sainz de Baranda, 2010). Se han descrito también adaptaciones por falta de flexibilidad de la columna vertebral en niños con parálisis cerebral frente a niños con desarrollo típico a partir de los 5 años (Abdulwahab, 1966). No existen estudios sobre el desarrollo ontogénico del plano sagital de la columna vertebral en lactantes ni niños en edad preescolar con desarrollo típico. Tampoco se ha investigado la influencia de la maduración funcional del Sistema Nervioso Central sobre dicho morfotipo raquídeo sagital, ni las adaptaciones de la columna vertebral en lactantes y niños en edad preescolar con alteraciones neurológicas.

MEDICIÓN DINÁMICA DE LA COLUMNA VERTEBRAL.

A lo largo de la evolución de las especies, la locomoción bípeda se ha transformado en una tarea habitual y sencilla a simple vista. Sin embargo este patrón se compone de acciones neurológicas, fisiológicas, anatómicas y biomecánicas complejas que se deben ejecutar de forma precisa. En el siglo XIX tuvo lugar la transformación de la biomecánica observacional hacia la cuantificación y el análisis matemático. En el siglo XX se produjo una explosión en el diseño de sofisticados métodos de cuantificación y en las últimas décadas son muchos los estudios destinados a obtener datos sobre el rango de movimiento y las propiedades mecánicas del raquis. Gracias al trabajo de científicos como Wagenaar, Beek, Taylor quedó demostrado que el tronco y el raquis se utiliza para desplazarse y no únicamente para la estabilidad. Por tanto, la locomoción es más que el movimiento de brazos y piernas, es decir que el raquis es el coordinador dinámico entre las fuerzas y movimientos procedentes de los miembros superiores, inferiores y la pelvis (Kummer, 1981; Kumar et al 1995; Gunzburg et al, 1991; Macintosh et al, 1993; Marras, Granata, 1995; Mc Gregor et al, 1995).

Durante la marcha humana a velocidad normal se observan inclinaciones periódicas del tronco, sin embargo los cambios en el plano sagital de la columna vertebral son casi imperceptibles (Zhao et al, 2008). Los cambios en la columna lumbar en niños con desarrollo típico durante el ciclo del paso presentan una alta variabilidad entre sujetos (Zhao et al, 2008 y Whittle, Levine, 1999), lo que no ha permitido hasta ahora hacer generalizaciones sobre el patrón de movimiento. La columna lumbar tiene su propio patrón de movimiento y no refleja simplemente el movimiento de la pelvis (Whittle, Levine, 1999). Cuando se midió el movimiento de la columna lumbar en el espacio en niños con desarrollo típico no se detectaron diferencias significativas al variar la velocidad de la deambulación (Zhao et al, 2008; Crosbie et al, 1997; Wagenaar, Beek, 1992; Murray et al, 1966 y 1970) por lo que se ha sugerido por que la movilidad del tronco debería medirse en relación a otro segmento (Levine et al, 2007; Taylor et al, 1999). En actividades tales como subir y bajar escaleras, o levantarse de una silla, el rango de movimiento de su tronco en relación a la pelvis es mayor que dicha movilidad respecto a las coordenadas espaciales del laboratorio de marcha, a excepción del plano transversal (Krebs et al, 1992). El control del tronco es especialmente importante para los movimientos ántero-posteriores durante la marcha; además, el control del tronco se ha relacionado con los parámetros de marcha relacionados con la dirección del desplazamiento (Winter, 1995; Sæther et al, 2015). En el patrón típico de la marcha madura, la pelvis está rotada hacia la retroversión durante el contacto del talón. A continuación aparece un contragiro durante el primer 10% del ciclo del paso (respuesta a la carga) hasta pasar a una anteversión pélvica (máximo positivo), alcanzado en la fase de apoyo monopodal. Progresivamente el movimiento de la pelvis vuelve a rotar otra vez hasta el nuevo contacto del talón. El segmento torácico inferior está extendido de forma máxima durante dicho contacto de talón, volviendo a una posición neutra hasta la fase de apoyo medio, donde comenzará a extenderse de nuevo a lo largo del apoyo final. Los patrones de movimiento del segmento lumbar se complementan con los de la pelvis. La flexión espinal máxima ocurre con el contacto de talón. A esto sigue una extensión relativamente rápida hasta la posición neutra al comienzo del apoyo monopodal. Posteriormente la flexión se realizará relativamente lenta hasta alcanzar su máximo en el contacto del talón (Crosbie et al, 1997).

El análisis tridimensional de la marcha es uno de los sistemas de medición dinámica más fiables y utilizados en rehabilitación. Permite la medición cinemática y cinética durante la ejecución del patrón de marcha bípeda, característico de la raza humana. Este laboratorio consiste en un pasillo de 9 metros de largo donde los pacientes caminan a su velocidad de preferencia. Un sistema de cámaras infrarrojas capta parámetros tridimensionalmente y un programa informático procesa los datos de movimiento de cada segmento en todos los planos. Los modelos tridimensionales de medición de la columna vertebral son muy complejos y por tanto poco útiles para la práctica clínica, sin embargo es posible interpretar el movimiento de la columna a partir de la angulación entre los segmentos que la delimitan. La pasarela está delimitada por dos cintas a ambos lados para asegurar que los sujetos caminen hacia delante y lo más en línea recta posible en la zona de captura. En la mitad de la pasarela se encuentran en el suelo dos plataformas de fuerza de reacción. El modelo usado se denomina "PlugInGait" (PIG), que consiste en un modelo biomecánico para la implementación transicional convencional a Vicon Nexus. Los criterios de calidad de este modelo son ampliamente aceptados (Kadaba et al, 1990). Las cámaras capturan la luz reflejada desde los marcadores fijados en el sujeto mediante cinta adhesiva, cuya colocación anatómica específica se define en el manual Vicon. El segmento de la parte superior del cuerpo o "tronco" se construye siguiendo la descripción validada del modelo PIG. Los valores sagitales de la columna lumbar o "spine angles" del PIG reflejan el movimiento relativo entre la pelvis y el tronco (Romkes et al, 2007). La Flexión/Extensión se define en el análisis tridimensional por la angulación entre el eje sagital del tórax y el eje sagital de la pelvis sobre el eje transversal fijo de la pelvis. Los valores positivos (Flexión) corresponden a una situación dónde el tórax se encuentra inclinado ventralmente. Valores negativos (Extensión) corresponde a una situación donde el tórax está inclinado hacia atrás.

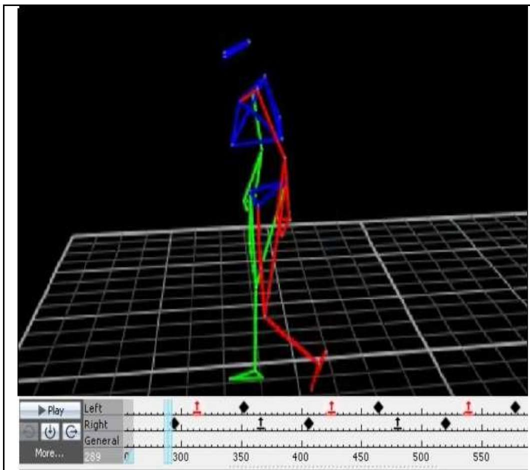


Figura 4. Modelo tridimension durante el análisis de marcha con Vicon.

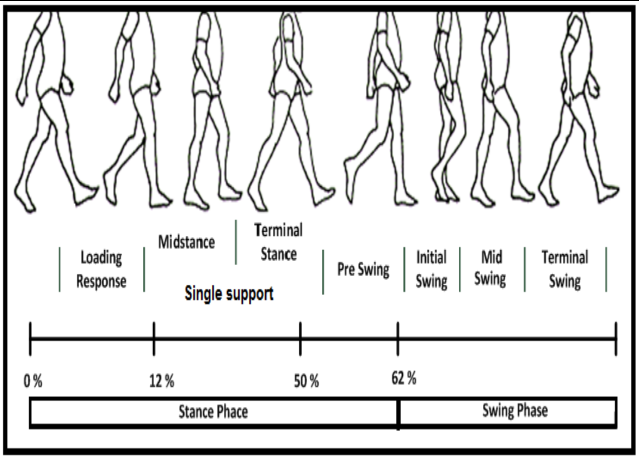


Figura 5. Ciclos de paso valorados durante el análisis de la marcha

2

OBJETIVOS

GOALS

Los objetivos del presente estudio son:

1. Estudiar la validez relativa de criterio y la fiabilidad para la clasificación de la función motora gruesa mediante los "Estadios de Locomoción". Esto nos permitiría comparar la función locomotora de niños con desarrollo típico y niños con parálisis cerebral.

2. Analizar la relación entre la disposición sagital de la columna y el reducido grado de función motora gruesa en personas con parálisis cerebral.

3. Determinar la relación entre la disposición sagital de la columna y el incrementado grado de función motora gruesa en personas con entrenamiento de capacidades locomotoras por encima del desarrollo ontogénico.

The main goals of this research are:

1. To study the criterion-related validity and reliability of the “Locomotor Stages” as classification system of the gross motor function. This would allow us to compare locomotor function of children with typical development and those with cerebral palsy.

2. To assess the relation between the sagittal curves of the spine and the reduced level of gross motor function in subjects with cerebral palsy.

3. To determine the relation between the sagittal curves of the spine and the increased level of gross motor function in subjects training locomotor skills beyond the ontogenic development.

3

CONCLUSIONES

CONCLUSIONS

Esta sección resume las conclusiones principales de las cuatro líneas de investigación incluidas en esta Tesis Doctoral.

<u>LÍNEA DE INVESTIGACIÓN I. Fiabilidad y Valoración comparativa de la funcionalidad en niños con desarrollo típico y niños con parálisis cerebral”</u>:

- Los Estadios de Locomoción es un sistema de clasificación fiable, sensible y específico para la función motora gruesa, que además permite comparar niños con desarrollo típico con niños con parálisis cerebral.

<u>LÍNEA DE INVESTIGACIÓN II. Valoración del plano sagital en el Laboratorio de Análisis de la marcha y su relación con la funcionalidad en niños con parálisis cerebral (funcionalidad reducida):</u>

- Los valores basales y de mantenimiento de la columna lumbar en el plano sagital son específicos para cada nivel de motricidad gruesa en niños con parálisis cerebral, presentando mayor extensión de la columna lumbar aquellos que presentan más altos niveles de función motora gruesa.

- En niños con parálisis cerebral que no pueden deambular de forma independiente, el crecimiento tendrá un efecto atípico opuesto de flexión de la columna normal.

<u>LÍNEA DE INVESTIGACIÓN III. Valoración del plano sagital con el inclinómetro en personas con funcionalidad motora gruesa por encima del desarrollo ontogénico: Gimnastas de Artística con capacidad de marcha con los miembros superiores:</u>

- El entrenamiento funcional de habilidades locomotoras por encima del desarrollo ontogénico, como caminar sobre los miembros inferiores, parece requerir de una adaptación específica, ya que hemos encontrado hipolordosis postural, cifosis torácica funcional y actitud cifótica lumbar durante la sedentación y la flexión del tronco.

This section summarizes the main conclusions of the four research lines integrating this PhD Thesis.

RESEARCH LINE I. "Reliability and comparative classification of the gross motor function in children with typical development and children with cerebral palsy":

- Locomotor Stages is a reliably classification system, sensitive and specific for gross motor function, that also allows plotting typical development children and those with cerebral palsy.

RESEARCH LINE II. "Assessment of the sagittal spinal curves in the gait analysis and its relation with the gross motor function of children cerebral palsy (reduced functionality)":

- Basal and maintenance values of the sagittal lumbar curve are specific to each gross motor level in children with cerebral palsy. Higher classifications of gross motor skills correlate with more extended lumbar spine.

- In Children with cerebral palsy who cannot walk independently, the effect of development is reversed, flexing the lumbar spine.

RESEARCH LINE III. "Assessment of the sagittal spinal curves in the inclinometer in people with increased motor function beyond the ontogenic development: artistic gymnast with walking ability on the upper limbs":

- Functional training of skills beyond the ontogenetic locomotor function, like walking ability on the upper limbs, seems to required specific adaptations in postural hypolordosis, functional thoracic kyphosis and lumbar kyphotic attitude during sitting and trunk flexion.

4

COMPENDIO DE PUBLICACIONES

PUBLISHED ARTICLES

El compendio de trabajos científicos del que forma parte la presente tesis doctoral se presenta a continuación en el formato en que han sido previamente publicados o aceptados. La Comisión General de Doctorado vistos el informe previo del Director del Departamento de Cirugía, Pediatría, Obstetricia y Ginecología de la Universidad de Murcia, y el visto bueno de la Comisión de Ramas de Conocimiento de Ciencias de la Salud, permite la presentación de la presente tesis doctoral como compendio de publicaciones con los siguientes 3 artículos seleccionados y propuestos por el doctorando. Los 3 artículos han sido aceptados por revistas internacionales con impacto y las características de los mismos se presentan en la tabla siguiente.

COMPENDIO DE PUBLICACIONES	
Línea de investigación I: "Fiabilidad y Valoración comparativa de la funcionalidad en niños con desarrollo típico y niños con parálisis cerebral"	
Tipo de estudio Diseño	**Revista**
Medidas repetidas	J Child Neurol
Título	Can Clinical Assessment of Locomotive Body Function Explain Gross Motor Environmental Performance in Cerebral Palsy?
Línea de investigación II: "Valoración del plano sagital en el Laboratorio de Análisis de la marcha y su relación con la funcionalidad en niños sanos y niños con parálisis cerebral (funcionalidad reducida)"	
Tipo de estudio Diseño	**Revista**
Observacional descriptivo	Pediatr Phys Ther
Título	Position between trunk and pelvis during gait depending on the gross motor function classification system
Línea de investigación III: Por último, para la LÍNEA DE INVESTIGACIÓN IV "Valoración del plano sagital con el inclinómetro en personas con funcionalidad motora gruesa por encima del desarrollo ontogénico: Gimnastas de Artística con capacidad de marcha con los miembros superiores"	
Tipo de estudio Diseño	**Revista**
Observacional descriptivo	J Sports Med Phys Fitness
Título	Training intensity and sagittal curvature of the spine in male and female artistic gymnasts

LÍNEA DE INVESTIGACIÓN I

VALORACIÓN COMPARATIVA DE LA FUNCIONALIDAD EN NIÑOS CON DESARROLLO TÍPICO Y NIÑOS CON PARÁLISIS CEREBRAL.

JOSÉ MANUEL SANZ MENGÍBAR

ARTÍCULO 1

Título: Can clinical assessment of locomotive body function explain gross motor environmental performance in cerebral palsy?
Autores: Jose Manuel Sanz Mengibar[1,2], Fernando Santonja[3,4], Paloma Sánchez de Muniain[2], Manuel Canteras Jordana[3] 1 Kiki's Children Clinic, London, United Kingdom 2 Clínica Rehabilitación Infantil, Madrid, Spain 3 Faculty of Medicine, University of Murcia, Murcia, Spain 4 Department of Traumatology, V. de la Arrixaca University Hospital, Murcia, Spain.
Revista: Journal of Child Neurology (ISSN: 0883-0738) (J597) Volumen/páginas/editorial: 31/ 474-480/ SAGE País de publicación:/Año de publicación: USA/2016. Indicios de calidad: Factor de Impacto: 1.434 Base: Web of Science Data; Año: 2015; Área: Neurología clínica (148/193) y Pediatría (66/120)
Aportación del doctorando: - Realización de búsqueda bibliográfica específica en diferentes bases de datos. - Participación en el diseño y localización de la muestra. - Toma de datos y valoración de los deportistas. - Análisis estadístico. - Redacción del artículo.

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Resumen/Abstract: Purpose: Gross Motor Function Classification System (GMFCS) has discriminative purposes but does not assess short term therapy goals. Locomotion Stages (LS) classify postural body functions and independent activity components. To assess the relation between GMFCS and LS will make us understand if clinical assessment can explain and predict motor environmental performance in cerebral palsy (CP). Method: 462 children were assessed with both scales. Results: High reliability and strong negative correlation (-0.908) for GMFCS and LS at any age was found. Sensitivity was 83%, specificity and positive predictive value were 100% within the same age range. Regression analysis showed detailed probabilities for the realization of the GMFCS depending on the LS and the age group. Conclusions: Postural body function measure with LS is reliable, sensitive and specific for gross motor function and able predict environmental performance.

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Can Clinical Assessment of Locomotive Body Function Explain Gross Motor Environmental Performance in Cerebral Palsy?

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Abstract

Gross Motor Function Classification System has discriminative purposes but does not assess short-term therapy goals. Locomotion Stages (LS) classify postural body functions and independent activity components. Assessing the relation between Gross Motor Function Classification System level and Locomotion Stages will make us understand if clinical assessment can explain and predict motor environmental performance in cerebral palsy. A total of 462 children were assessed with both scales. High reliability and strong negative correlation (–0.908) for Gross Motor Function Classification System and Locomotion Stages at any age was found. Sensitivity was 83%, and specificity and positive predictive value were 100% within the same age range. Regression analysis showed detailed probabilities for the realization of the Gross Motor Function Classification System depending on the Locomotion Stages and the age group. Postural body function measure with Locomotion Stages is reliable, sensitive, and specific for gross motor function and able to predict environmental performance.

Keywords

motor development, cerebral palsy, child development, Gross Motor Function Classification System, assessment, disability, development delays

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Traditional classifications of cerebral palsy according to the distributional pattern of affected limbs, degree of motor impairment, or type of movement disorder still have a relevant clinical role but have a limited value as a prognostic tool and indicator of mobility or motor performance.[1-3] Functionality and mobility during daily activities have an important role as a classification and research tool, intending to categorize cerebral palsy into different functional levels.[4,5] Current classification systems of mobility like Gross Motor Function Classification System (GMFCS) do not have "assessing" features, but discriminative purposes,[2,6] limiting its clinical use as it is unable to guide the physical therapy's approach in the short term.[7] Gross Motor Function Classification System is currently one of the most reliable and best known scales in pediatric rehabilitation,[8,9] is widely used in research, in clinical classification, and it is neither time-consuming nor costly.[6] The Gross Motor Function Classification System provides knowledge and heightens interest in activities and participation components and environmental factors[10] regarding mobility for children with cerebral palsy.

The Locomotion Stages (LS)[11,12] had been used for clinical assessment and research to quantify therapeutic outcomes in patients with cerebral palsy.[13-15] These stages of the pathologic locomotion are based on the analytic description of the human postural development, which describes all the motor patterns under the kinematic point of view.[11,13,16] Within the framework of the International Classification of Functioning, Disability and Health (ICF),[10] Locomotion Stages takes body postural function and independent activity components into account. These components are described following the ontogenetic development of human postural control from birth to independent walking (Table 1). Locomotion Stages assesses the performance quality also, this is due to the fact that each defined ontogenetic stage can be associated with a developmental age that is analogous, but not identical, to the normal development.[11,13]

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Table 1. Locomotion Stages.

	Equivalent ontogenic pattern
Stage 0: Orientation. The child's motor performance is lower than in stage 1. In the supine position, the child cannot grasp or turn its head or body in order to establish a contact.	Holokinetic movement
Stage 1: Reaching. The child can turn his head and body toward a stimuli, and at least 1 hand tries to reach out with palmar flexion and cubital tilt. Grasping is restricted to the finger tips.	Reach out with hands towards toy; 4 mo
Stage 2: Grasping. In prone position	Prone on forearms, weight on one side and able to grasp with the other hand; 4-5 mo
Stage 3: Creeping. Child is able to move forward propping on one or both forearms. Legs may move in association, but are not able to push to create any locomotion.	Creeping or commando crawling; 7 mo
Stage 4: Homologous Crawling. Bunny hopping. Legs move forward at the same time, while arms can do it in a homologous or alternating way.	No analogy
Stage 5: Reciprocal Crawling. Crawling on knees and open hands with a cyclic and sinusoidal shift of the center of gravity around the midline. All extremities step forward, alternating in a crossed pattern. This pattern is used by the child independently, without being told and when it moves quickly.	Reciprocal crawling; 9 mo
Stage 6: Cruising. The child can pull to a stand and walk sideways independently by holding onto furniture with his hands. Pull to stand may already appear at stage 3, but the child cannot step sideways.	Sideways walking/cruising on the furniture; 12-13 mo
Stage 7: Independent Walking. The child can walk forward and stop without holding on. Walking is the everyday preferred locomotion.	Walking, stop and turn without holding on; 15 mo
Stage 8: Unilateral Stance on One Side. The child can stand during 3 s or more only on one preferred side, left or right foot. The examiner must not demonstrate this test, but give instructions: "lift one knee up towards your belly"	Monopodal stance on right or left foot; 3 y
Stage 9: Reciprocal Unilateral Stance. The child is able to stand reciprocally during 3 s or more on both sides, right and left. The examiner gives the same instruction as in stage 8.	Monopodal stance on right and left foot; 4 y

Capacity is defined by what a person can do in a standardized context, and performance for the person's current environment.[10] However, environmental performance classified with Gross Motor Function Classification System changes depending on several factors, and for this reason, most of the studies in cerebral palsy have to delimitate the motor function to standardized measures of individuals in clinical settings[9] like Locomotion Stages.

Purpose

This study aims to explore the criterion-related feature of the Locomotion Stages with the "gold standard" Gross Motor Function Classification System in order to understand if clinical assessment of locomotive body function could explain gross motor environmental performance, and could offer a more sensitive and specific prognosis of the development of these skills in children with cerebral palsy.

Method

Seven pediatric physical therapists and 1 rehabilitation consultant with an average of 18.25 (standard deviation = 10.8) years of experience in this field were gathered in a Pediatric Rehabilitation Clinic in Madrid (Spain). The 8 trained experts classified children with cerebral palsy from the same screen at the same time with Gross Motor Function Classification System and Locomotion Stages. Video recordings were made by the same person, including subject's functional abilities and limitations based on their self-initiated movement with particular emphasis on supine, prone, sitting, quad/weight-bearing, kneeling, standing, and wheeled mobility[1,17] and also without any environmental factor, as Locomotion Stages is defined for the highest independent pattern (Table 1). Because of the presumption of the time efficiency of these tests, the time was limited to 2½ hours, in which they could altogether score 31 videos. The children were between 0 and 18 years old and were eligible if they had a diagnosis of cerebral palsy made by a physician. Children were recorded and assigned in a random sequence, and parents agreed with the provided informed consent form. Table 2 shows the sample features.

To determine the intrarater outcomes, a method for functional scales was followed[1,17]: 11 weeks after the first video assessment, 2 of the raters scored the same recordings again independently with both Locomotion Stages and Gross Motor Function Classification System .

Once our reliability was verified, the same therapists recruited children with cerebral palsy in 3 countries: 4 rehabilitation centers, 2 schools, and 4 early intervention centers in 4 different regions in Spain, London, and Rome. Data were collected through direct observation and video recordings from 2008 until November 2013.

Inclusion Criteria

children age 0 to 18 years old with neuromotor findings consistent with cerebral palsy.[18]

Exclusion Criteria

neuromuscular disorders or other conditions that could affect motor performance.

Cerebral palsy was classified in the following subtypes according to the European committees responsible for this condition: spastic

Table 2. Summary of Patient's Characteristics for Reliability Tests, n = 31.

Gender, n (mean age; SD)	
Male	16 (mean age = 74.93 mo, SD = 57)
Female	15 (mean age = 47.26 mo, SD = 48.76)
Mean age, total sample	61.548 mo (SD = 59.87)
GMFCS age ranges (y)	
<2	8 (male = 3, female = 5)
2-4	8 (male = 4, female = 4)
4-6	9 (male = 5, female = 4)
6-12	2 (male = 1, female = 1)
12-18	4 (male 3, female 1)
Diagnosis classification	
Bilateral CP. Spastic tetraplegia	7
Bilateral CP. Spastic diplegia	10
Unilateral CP. Spastic	6 (left, 2; right, 4)
Ataxic	2
Athetoid or dyskinetic	3
Mixed or other syndromes	3

Abbreviations: CP, cerebral palsy; GMFCS, Gross Motor Function Classification System; SD, standard deviation.

Table 3. Summary of Patient's Characteristics for Association Tests, n = 462.

Gender			
Male	288 (mean age = 50.6 mo, SD = 52.51)		
Female	174 (mean age = 54.54 mo, SD = 47.33)		
Mean age, total sample	58.06 mo (SD = 50.64)		
CP subtype classification			
Spastic bilateral	211	Quadriplegia	116
		Triplegia	5
		Diplegia	108
Spastic unilateral	84	Right side	38
		Left side	51
Ataxic	17		
Dyskinetic-athetoid	47		
Mixed	103		
GMFCS level			
I	92		
II	70		
III	62		
IV	104		
V	134		
Age group (y)			
0-2	130		
2-4	121		
4-6	83		
6-12	94		
12-18	34		

Abbreviations: CP, cerebral palsy; GMFCS, Gross Motor Function Classification System; SD, standard deviation.

bilateral, spastic unilateral, dyskinetic, ataxic, and mixed type.[19,20] We also described the distributional pattern of affected limbs as can be observed in Table 3.

A total of 465 children met the inclusion criteria but 3 of them had to be excluded later because of a change in their diagnosis into a degenerative condition (Table 3). Gross Motor Function Classification System age groups were taken into account as a parameter during the data analysis, in order to be able to compare the equivalent levels for both scales. In order to understand if Locomotion Stages was sensitive and specific for motor performance, 21 children from this sample were followed up on for at least 3 occasions chosen at random (these reassessments were not planned, but scheduled at the time of their clinical follow-up). The different periods can be found in the supplementary information, which could show changes in the motor development on both scales, but also in the Gross Motor Function Classification System age group. Only 17 random children could be measured 3 times for the present study. Four samples of this random group could only be measured twice, as researchers lost contact with them for different reasons.

Statistical analyses were performed using the Stata, 12.0, software package for Windows. In addition, *t* tests for paired samples were performed to figure out the intrarater reliability. We examined the strength of the association between Gross Motor Function Classification System and Locomotion Stages using Spearman rank correlation. The association of capability to understand Gross Motor Function Classification System level according to clinical observation of Locomotion Stages was investigated using an ordered logistic regression model, taking into account the ordinal nature of the dependent variable (Gross Motor Function Classification System).

Results

Interrater Reliability

Our results with ANOVA showed that there is a significant relation between the scores for each patient ($P < .05$), but there are no statistically significant differences between the scores of different raters. High values for interrater reliability in Gross Motor Function Classification System (ICC = 0.917 and ICC = 0.952 in the first and second scoring sessions respectively) and Locomotion Stages (ICC = 0.938 and ICC = 0.996).

Intrarater Reliability

Further, *t* test for paired samples found high intrarater reliability using Gross Motor Function Classification System (0.955; P value = .167) and Locomotion Stages (0.987; P value = .568). P values >.05 indicate that there were no statistically significant differences between the scores of the first and second measurements.

Correlation and Regression

Our results showed high negative correlation between both scales (–0.925, P value < .001), also in every age group defined for Gross Motor Function Classification System: 0 to 2 years (–0.936), 2 to 4 years (–0.957), 4 to 6 years (–0.954), 6 to 12 years (–0.960), 12 to 18 years (–0.928). The results from the ordered logistic regression model showed that there is a significant negative association between Locomotion Stages and Gross Motor Function Classification System (β = –2.275, P value < .001). Moreover, the impact of the variable "age group" is positive and significant (β = 1.29, P value < .001). From the estimated regression coefficients, we get detailed probabilities for the realization of the Gross Motor Function

Classification System level depending on the children's Locomotion Stages and the age group (Table 4 and supplementary information).

Most of our children (85.7%) at age 6 to 12 years and Gross Motor Function Classification System level II were scored at level 7 of Locomotion Stages (independent walking). The highest probability for children with Locomotion Stage 7 in the group of age between 6 and 12 years was to perform functionally in the community as described in GFMCS level II. No children with Gross Motor Function Classification System level III under age 4 could walk independently (2 to 5 Locomotion Stage levels). There are no chances to be in a higher Locomotion Stage than 6 (independent cruising), for children with Gross Motor Function Classification System level III under 6 years of age. Even more so, Locomotion Stage 7 or independent walking without any device could only be found in 36% of children with Gross Motor Function Classification System level III when they are more than 12 years old, and never in younger ages. Most older children with Gross Motor Function Classification System level III were scored as Locomotion Stage 6 (cruising), and 21.42% were unable to walk even with assistance (Locomotion Stage 5, reciprocal crawling). Around 50% of children with Locomotion Stages 5 and 6 who will be more likely to be in Gross Motor Function Classification System level III above the 6 years of age, and 95.2% of Gross Motor Function Classification System level IV could not stand independently.

Stability Over Time, Sensibility, and Specificity

Table 5 shows that 36.8% of our sample changed their Gross Motor Function Classification System level when they moved to the next age range and 31.6% changed their Gross Motor Function Classification System level even when they remained in the same age range. This means than an average of 34.2% children changed their Gross Motor Function Classification System level over time. Similar Locomotion Stage stability values were found, with an average of 36.8%.

Sensitivity was 83%, specificity was 100%, and positive predictive value was 100% when the second scoring did not mean a change in the age range of the children. Less stability over time of the Gross Motor Function Classification System level in early ages was shown, and 36.84% of the children changed Gross Motor Function Classification System level when they moved to a different age range. Therefore, lower data were found due to these unexpected cases: sensitivity was 57%, specificity was 58%, and positive predictive value was 40% when children moved to another age range in the reassessment. This represents an overall average sensitivity of 69%, specificity of 80% and positive predictive value of 64%.

Table 4. GMFCS Prediction According to Locomotion Stage and Age.

	GMFCS				
Locomotion Stage	0-2 y	2-4 y	4-6 y	6-12 y	12-18 y
0	V	V	V	V	V
1	V	V	V	V	V
2	IV	IV	V	V	V
3	IV	IV	IV	IV	V
4	III	III	IV	IV	IV
5	II	III	III	III	IV
6	I	II	II	III	III
7	I	I	II	II	II
8	I	I	I	I	II
9	I	I	I	I	I

Abbreviation: GMFCS, Gross Motor Function Classification System.

Table 5. Stability Over Time: Sensitivity and Specificity Data.

When age range did not change 19/38 total	
Sensitivity = 0.83	
False negatives	GMFCS was sensible to a change and not the LS (no/yes/no): 1/19
True positives	Both were sensible to a change (no/yes/yes): 5/19
Specificity = 1	
True negatives	Both stay stable (no/no/no): 13/19
False positives	LS was sensible to a change and not the GMFCS (no/no/yes): 0/19
When age range changed, 19/38 total	
Sensitivity = 0.57	
False negatives	GMFCS was sensible to a change and not the LS (yes/yes/no): 3/19
True positives	Both were sensible to a change (yes/yes/yes): 4/19
Specificity = 0.58	
True negatives	Both stay stable (yes/no/no): 7/19
False positives	LS was sensible to a change and not the GMFCS (yes/no/yes): 5/19
Overall average sensitivity =	0.69
Overall average specificity	0.80
Overall positive predictive value	0.64

Abbreviation: GMFCS, Gross Motor Function Classification System; LS, Locomotion Stage.

Discussion

Functional performance, disability, and health are considered to be delimited by a combination of both contextual and intrinsic factors,[10] but these should be acknowledged individually during the rehabilitation process.

Our results for high intrarater reliability are consistent with previous studies for the use of the Gross Motor Function Classification System in English[1,21] and other languages,[22] with values always greater than 0.91. The number of raters was superior to the average of other studies of reliability found in this field.[1,21,22] Interrater values for Gross Motor Function Classification System levels are also consistent with the latest studies.[1] We found similar results for Locomotion Stage reliability, and both measurements were reliable in order to rate children who have varying degrees of functionality, and also independent raters gave similar scores to the same patient. Slightly higher intrarater and interrater results in our studies for Locomotion Stages versus Gross Motor Function Classification System can be explained by the depth of experience of the raters in scoring with Locomotion Stages. High consistency has been found even when Gross Motor Function Classification System assessment was performed by highly experienced professionals, with nontrained professionals, newly qualified professionals, families,[23-25] or using medical records and videotapes ($k = 0.84$, P value <.0001).[1,21] Further studies should also be done to test if nontrained people show high values in Locomotion Stages also.

Higher levels in Gross Motor Function Classification System and lower levels in Locomotion Stages stand for poor motor performance. In our study, high negative correlation rates, overall and of every age group, mean strong opposite relation between both scoring tests.[1] A high correlation and no statistically significant differences support our hypothesis of considering both scales as equivalent.

The equivalent coefficients represent the speed of reverse growing when plotting 10 levels of Locomotion Stages to 5 Gross Motor Function Classification System levels. All levels of the Gross Motor Function Classification System were found in every age group but all levels of Locomotion Stages were only found from the sixth birthday. Around the first birthday, only 0 to 6 Locomotion Stages can be achieved in healthy neurologic development (Table 1), and the other 3 stages are related with stepping skills and follow the maturation of the gait pattern.[26] This is consistent with our findings: the highest Locomotion Stages found in the group of age 0 to 2 years of our sample was 7 and in the group 2 to 4 years was Locomotion Stage 8. Therefore, 5 levels of Gross Motor Function Classification System plot to 6, 7, or 8 Locomotion Stages in younger ages of cerebral palsy, being confirmed by higher regression coefficients.

Less stability over time of the Gross Motor Function Classification System in early ages was shown because of a change of the different age range, even when motor performance did not change but the activities and participation requirements did. Overall, Locomotion Stage sensitivity and specificity for gross motor performance exceeded minimum standards, and the advantages in making predictions with Locomotion Stages rather than Gross Motor Function Classification System are to avoid "false negative worsening" due to change of age group instead and also "false positives" when children develop new skills but they are described within the same Gross Motor Function Classification System level ("creep on their stomach or crawl on hands and knees"). Every Gross Motor Function Classification System level seems to have 1 or more postural body function or activity components defined for the Locomotion Stages depending on age, as shown for prognostic rates. For these reasons, Locomotion Stages would help to assess overall motor performance and participation from a clinical environment and to be more specific than Gross Motor Function Classification System. On the other hand, Locomotion Stages also assesses the performance quality: each defined ontogenetic stage can be associated and compared from a kinesiological point of view with a developmental age pattern that is analogous, but not identical, to the typically developing children.[11,13]

Research in motor control has to consider environmental, task, and individual capacities,[27] but these last inner body postural components seem to be forgotten in clinical practice. Tasks and environmental factors such as "school," "home," and "outdoors" and facilitators such as "wheeled chair" or "assisted walking" are combined to understand the functional performance of children with cerebral palsy.[9] However, higher levels of independent locomotive aspects could be related with higher overall functional profiles,[15] helping to understand more about our patients' skill at the time of the assessment. Previous research described ordinal distinctions of mobility methods in different environments ("walks, wheeled mobility, assisted mobility and floor mobility" are assumed to reflect important underlying variations in independence) to combine them and make predictions,[9] and our percentage values are in agreement with the findings of these expert authors. High probability of walking was found at age 9 for children with Gross Motor Function Classification System level II[8] or if they were able to sit independently at age 2 years.[2] Gross Motor Function Classification System level III before age 5 had less than 50% probability of walking in all settings using an assistive device, and less than a 60% chance of walking at home or outdoors, respectively.[9] Also, 47% of older children in Gross Motor Function Classification System level III used floor mobility as a preferred method at home[9] and children above 6 years of age in level IV depended on wheeled mobility.[9] Similar prognostic features of the gross motor function seems to be extracted from Locomotion Stages and Gross Motor Function Classification System, even if this study was not designed as a longitudinal follow-up of the same subjects in time, but rather the interpretation from a sample with different ages and functional groups. Because Locomotion Stage does not take age into account and only 1 pattern is included in every stage, unexpected changes in the sensitivity and specificity to measure gross motor skills can be prevented with this classification.

Upper-limb support is a clinically important feature to move around in specific contexts and assisted walking, for example. Other authors tried unsuccessfully to relate gross motor function with hand function in cerebral palsy, plotting 2 scales in a parallel way.[6,8] Locomotion Stage includes the motor skills not only from a creeping, crawling, or gait point of view but also hand function, when these are performed in a longitudinal way. Further studies with children's follow-up over the years could allow us to understand whether better hand function in early ages (Locomotion Stages 1 to 5) could explain assisted walking ability or power chair independency.

The most common method of clinical assessment is the kinesiological comparison of the spontaneous movements of children with brain injury as against typically developing children. An example is the increasing number of gait analysis studies each year. A common feature of this research is that it highlights the importance of the qualitative assessment of motor patterns in pediatric rehabilitation.[26,28,29]

Conclusion

Locomotion Stages is a reliable classification system that is sensitive and specific for gross motor function, with assessing and prognostic properties, and also allows plotting typically developing children and those with cerebral palsy. The clinical implications for therapists, physicians, and researchers would be to understand the overall daily performance and make sensitive prognosis at any age from single motor patterns easily assessed in the therapy room.

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Declaration of Conflicting Interests

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Ethical Approval

All study participants provided written informed consent. The study was approved by the Research Ethics Committee of the University of Murcia; (IRB#r N°R 77/2013).

Supplemental Material

The online [appendices/data supplements/etc] are available at http://jcn.sagepub.com/supplemental.

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LÍNEA DE INVESTIGACIÓN II

VALORACIÓN DEL PLANO SAGITAL EN EL LABORATORIO DE ANÁLISIS DE LA MARCHA Y SU RELACIÓN CON LA FUNCIONALIDAD EN NIÑOS SANOS Y NIÑOS CON PARÁLISIS CEREBRAL (FUNCIONALIDAD REDUCIDA)

JOSÉ MANUEL SANZ MENGÍBAR

ARTÍCULO 2

Título: Position between trunk and pelvis during gait depending on the Gross Motor Function Classification System?

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Aportación del doctorando:

- Realización de búsqueda bibliográfica específica en diferentes bases de datos.
- Participación en el diseño y localización de la muestra.
- Toma de datos y valoración de los deportistas.
- Análisis estadístico.
- Redacción del artículo.

Sanz-Mengibar JM, Altschuck N, Sanchez-de-Muniain P, Bauer C, Santonja-Medina F. **Position between trunk and pelvis during gait depending on the Gross Motor Function Classification System**. Pediatr Phys Ther 2017; 29 (2) 130 - 137.
https://www.ncbi.nlm.nih.gov/pubmed/28319490
Resumen/Abstract: Purpose: To understand if there is a trunk postural control threshold in the sagittal plane during Three-Dimensional Gait Analysis (3DGA) for the transition between the Gross Motor Function Classification System (GMFCS) levels. Method: Kinematics from 97 children with spastic bilateral cerebral palsy (CP) from 3DGA Spine Angles according to Plug In Gate model were plotted relative to their GMFCS level. Results: Only average and minimum values of the lumbar segment correlated with GMFCS. Maximal values at Loading Response correlated independently with age at all functional levels. Significant regressions were found in all average and minimum values when taking age in combination with GMFCS. Conclusion: There is a specific postural control in the average and minimum values for the position between trunk and pelvis in the sagittal plane during gait, for the transition among GMFCS I-III levels. Higher classifications of gross motor skills correlate with more extended Spine Angles.

RESEARCH REPORT

Position Between Trunk and Pelvis During Gait Depending on the Gross Motor Function Classification System

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Purpose: To understand whether there is a trunk postural control threshold in the sagittal plane for the transition between the Gross Motor Function Classification System (GMFCS) levels measured with 3-dimensional gait analysis.
Method: Kinematics from 97 children with spastic bilateral cerebral palsy from spine angles according to Plug-In Gait model (Vicon) were plotted relative to their GMFCS level.
Results: Only average and minimum values of the lumbar spine segment correlated with GMFCS levels. Maximal values at loading response correlated independently with age at all functional levels. Average and minimum values were significant when analyzing age in combination with GMFCS level.
Conclusion: There are specific postural control patterns in the average and minimum values for the position between trunk and pelvis in the sagittal plane during gait, for the transition among GMFCS I-III levels. Higher classifications of gross motor skills correlate with more extended spine angles. (Pediatr Phys Ther 2017;29:130–137)
Key words: cerebral palsy, gait analysis, GMFCS, lumbar vertebrae, trunk control

INTRODUCTION

Poor control of postural trunk muscles is a primary impairment in children with cerebral palsy (CP).[1,2] Accessory muscles compensate to aid in posture, but this reduces their effectiveness as primary movers of the extremities.[1] Underlying trunk control impairment in children with bilateral spastic CP exhibits difficulties with stability between the thorax and pelvis during gait and functional mobility.[3,4] While the importance of trunk control for attaining an upright posture during gait is generally well accepted,[5] research on atypical gait in children with CP, based on 3-dimensional gait analysis (3DGA), focuses on describing the effect of lower limb impairment on gait, while trunk movements are rarely addressed.[3,5] One reason might be that trunk models require greater time to analyze than conventional assessment.[6]

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The trunk is especially important for the control of anterior-posterior movements during gait; moreover, trunk control in sitting is correlated with the gait parameters related to direction of progression.[7] Movement of the trunk is best interpreted in reference to another body segment,[8,9] mainly because primary impairments in the trunk may cause compensatory movements, for example, by allowing the pelvis to flex anteriorly.[10,11] Assessing the ability of the upper trunk to adapt to this anterior pelvic tilt during gait potentially offers information about trunk control in children with CP. Lumbar spine movements are not simply a reflection of pelvic motion[12] and, although periodic trunk flexing motions exist in healthy subjects at different walking speeds, the spinal changes in the sagittal plane during gait are almost negligible,[13] particularly if measured in relation to a global reference frame.[14,15] Children with CP have an increased angle between thorax and pelvis during gait, especially in the sagittal and frontal planes.[16] Trunk range of motion (ROM) relative to the pelvis is also greater than trunk ROM relative to the room coordinates across activities such as stair-climbing and stair-descent,[17] playing an important role for Gross Motor Function Classification System (GMFCS) scoring.

Clinicians recognize that impairments change between GMFCS I-III and that impairment within the higher levels of GMFCS has a wide range.[18,19] Trunk postural control thresholds for the transition among the different Gross Motor Function Measure dimensions have been found and an increase in trunk control could be one of the principal factors separating one GMFCS level from the next.[3] Differences in mean position for the pelvis in the sagittal plane have been found between GMFCS levels,[20] but children with GMFCS I-III had poor correlations between gross motor classification and pelvic tilt ROM, trunk tilt ROM, mean trunk tilt, and trunk obliquity ROM.[20]

Our hypothesis is that there is a trunk postural control threshold for the transition between each walking GMFCS level. Our aim is to investigate this by analyzing relations between the classification system and trunk movement in reference to the pelvis measured during 3DGA in children with bilateral spastic CP.

METHODS

The participants walked at a self-selected speed on a 8-meter walk way in the gait laboratory. The Vicon motion capture system with 6 infrared cameras was used for 3DGA (Vicon, Oxford Metrics, Oxford, the United Kingdom), with a sampling rate of 120 Hz. Vicon Nexus (1.8.2) was used to define gait cycles and to calculate spatiotemporal parameters and sagittal kinematic data. The upper body was modelled according to the Plug-In Gait (PIG) model (see Supplemental Digital Content [SDC] 1, available at: http://links.lww.com/PPT/A130, and SDC 2, available at: http://links.lww.com/PPT/A131). Sagittal spine angles reflect the relative movement between the pelvis and trunk.[16] Spine flexion and extension are defined in 3DGA by the angle between the sagittal thorax axis and the sagittal pelvis axis around the fixed transverse axis of the pelvis. A positive (flexion) angle value corresponds to the situation in which the thorax is tilted forward and a negative (extension) angle value when the thorax is tilted backward relative to the pelvis.

An observational analysis included male and female children aged 2 to 18 years with bilateral spastic CP. Inclusion criteria were ability to ambulate barefoot at least 15 feet in a forward direction, a minimum of 2 representative trials from right and left cycles in their 3DGA, and GMFCS level I, II, or III (with an assistive device when necessary). In addition, participants' parents or guardians gave informed consent. Exclusion criteria were diagnosis of spastic unilateral or nonspastic CP, secondary orthopedic, neuromuscular, or cardiovascular conditions, incomplete files or fewer than 2 trials, no trunk markers or no available PIG model, and video-recordings or clinical records limiting the available information during 3DGA and functional classification. Data from 97 of 107 children with bilateral spastic CP met the inclusion criteria. Age groups according to the GMFCS were taken into account for data analysis (Table 1). The study was approved by the Research Ethics Committee of the University of Murcia.

Statistical Analysis

Two representative trials from right and left cycles were used for further data processing with MATLAB routines (Mathworks R2009a). Average, minimum, and maximum degrees of the spine angles were extracted at different gait events of the trials. The following data from the sagittal plane at the following left (le) and right (ri) leg events were plotted against GMFCS level and age: loading response (LoadiResp), preswing (Preswing), mean of single support (SpineSS), mean of swing phase (SpineSwing), mean of stance phase (SpineStance), and mean of gait cycle (SpineGC) (See SDC 3, available at: http://links.lww.com/PPT/A132). Spearman correlation coefficients were calculated, and the association between GMFCS level and spinal curves was investigated using Ordinary Least Squares, taking into account the ordinal nature of the dependent variables. Alpha value was 0.05. Statistical analyses were performed using STATA 12.0 software package for Windows.

RESULTS

There were no significant correlations between ages and GMFCS levels. All average and minimum values of the sagittal plane of the spine angles during the investigated gait events showed a significant fair to moderate correlation with the GMFCS level, with a slight increase in correlation values if the function variable also incorporated the age group.[21] Maximal spine values had no significant differences by GMFCS level. Significant values or the correlation between GMFCS-age and spine angles and correlation values between GMFCS and spine angles without taking age group into account are in Table 2 and SDC 4 (available at: http://links.lww.com/PPT/A133). The values of the regression of the independent effect of GMFCS on the spine are in Table 3.

Age group correlated only with maximal values of spine angles during loading response at functional levels (right side $R = 0.386$, $P < 0.001$ and left side $R = 0.403$, $P < 0.001$), and poorly with maximum stance value (left $R = 0.214$, $P < 0.01$, and right $R = 0.207$, $P < 0.01$) and with maximum value during swing phase (left $R = 0.220$, $P < 0.01$, and right $R = 0.238$, $P < 0.001$) (SDC 5, available at http://links.lww.com/PPT/A134).

Significant regressions were found in all the average and minimum values, when studying the age in combination with GMFCS as observed in Table 4, while all the maximum values

TABLE 1

Sample Distribution (n = 97)

Age Group According to GMFCS	Age, y	GMFCS I (n)	GMFCS II (n)	GMFCS III (n)
2	2-4	1	2	1
3	4-6	0	6	2
4	6-12	10	22	19
5	12-18	10	17	7
n		21	47	29

Abbreviation: GMFCS, Gross Motor Function Classification System.

TABLE 2
Correlation of Spine Angles and GMFCS-Age

Average SpineGCle	Average SpineGCri	Minimum SpineGCle	Minimum SpineGCri
0.478[a]	0.481[a]	0.451[a]	0.454[a]
Average SpineStancele	Average SpineStanceri	Minimum SpineStancele	Minimum SpineStanceri
0.474[a]	0.493[a]	0.438[a]	0.444[a]
Average SpineSwingle	Average SpineSwingri	Minimum SpineSwingle	Minimum SpineSwingri
0.488[a]	0.457[a]	0.464[a]	0.432[a]
Average SpineSSle	Average SpineSSri	Minimum SpineSSle	Minimum SpineSSri
0.463[a]	0.501[a]	0.437[a]	0.479[a]
Average Spine LoadiResponsele	Average Spine LoadiResponseri	Minimum Spine LoadiResponsele	Minimum Spine LoadiResponseri
0.500[a]	0.475[a]	0.466[a]	0.421[a]
AverageSpine Preswingle	AverageSpine Preswingri	Minimum SpinePreswingle	Minimum SpinePreswingri
0.463[a]	0.501[a]	0.466[a]	0.479[a]

Abbreviations: Average Spine, mean Spine Angles Value; Le, Left; LoadiResp, Loading response; Minimum Spine, minimum Spine Angle value; Preswing, Preswing; SpineGC, Mean of Gait Cycle; SpineSS, Mean of Single Support; SpineSwing, Mean of Swing Phase; SpineStance, Mean of Stance Phase; Ri, Right.
[a]$P < 0.001$.

that correlated independently with age were not significant anymore. The development of most relevant sagittal spine angles through the gait cycle of every GMFCS level is plotted in Fig. 1. Descriptive minimum, maximum, and average values of every GMFCS level are in SDC 6 (available at: http://links.lww.com/PPT/A135).

DISCUSSION

Lower limb kinematics do not provide data for GMFCS levels to be defined by a specific gait pattern due to variability and overlap.[18] However, our research provides data as to how these clinical differences form groups according to their effect on trunk control. Minimum spine angle values show the basal position between trunk and pelvis (usually negative or lordotic), while maximum values reflect the highest flexed position during active effort. Our results suggest specific sagittal basal and average positions at the lumbar level for GMFCS levels. Children with lower functional levels tend to flex the trunk in reference to the pelvis, while children with higher functional levels show a more extended posture of spine angles during gait. This is reflected by the weak but positive correlations between GMFCS and spine angles.

The stability over time that characterizes the GMFCS[22] maintains the same gross functional score during development from the age of 3 years (4-6 years); therefore, the effect on the basal position of spine angles depends on the activity and participation components of the functional level that a child could reach within a specific GMFCS level according to age group.[21,23] GMFCS stability is supported in this study by the similarity in the correlations between the position of the lumbar spine when we interpret either the interaction of age and GMFCS measured together (Table 2), or the GMFCS independently of the child's age (SDC 7, available at: http://links.lww.com/PPT/A136). Graphs also depict spine angles similarity for the 3 functional levels when reaching gross motor stability around age 6,[22] though the spine angles drift apart from this point, which seems to depend on the locomotion possibilities. Linear regression supports the prediction until 18 years of age.

When external factors such as inclination of the surface limit forward locomotion, the lumbar spine flexes to decrease the moment of gravity.[8] This is observed in our participants with motor impairment who have factors limiting forward locomotion. Children with GMFCS III ambulate with an assistive device at all times, including during 3DGA.[22] As evident in the graphics, only during independent walking and unsupported stair-climbing (GMFCS I) is there an extensor tendency of the basal values of spine angles during gait at any given age. As children with GMFCS levels II and III age, their basal position shifts toward flexion, eventually reaching positive values. Children with GMFCS level II walked unassisted during 3DGA but used a walker outdoors, while children with GMFCS level III required assistance from the upper limbs during the assessment and all daily performance. The degree of progression of flexion seems to respond to the degree of assistance from the upper limbs during movement in the environment. Many differences have been observed between the assisted gait patterns of children who walk independently and those who cannot.[24] This lumbar pattern may relate to the upper limbs' compensation for the inability to walk independently, which requires an upright trunk. When children are able to walk with a hand-held assistive device that does not restrict movement of the trunk or pelvis,[1] increased trunk flexion between GMFCS II and III is observed.[18]

Our reported angle values between trunk and pelvis should be compared with other studies, because of differences in age ranges, conditions, measurement techniques, and anterior or posterior aids. The anterior pelvic tilt and flexion of the trunk are significantly lower throughout the gait cycle when using a posterior walker[25] in comparison with an anterior walker. It has been observed that trunk flexion can increase by 12° using an anterior walker rather than a posterior walker; likewise pelvic tilting about 7°, and the relation between trunk and pelvis in the sagittal plane about 20° if average data of children 2 to 12 years old were combined.[25,26] Our spine angle results are not affected by the type of walking aid. Only 1 child with GMFCS III was assisted by the hands. Children with GMFCS III used posterior walkers (n = 2). In the group aged between 6 and 12 years, 15 children performed with a posterior walker, 3 used crutches,

TABLE 3

Independent Regressions of "GMFCS" and "Age" in Relation With Sagittal Spine Angles

Variables	Maximum Spine Swingri	Maximum Spine Swingle	Minimum Spine Swingri	Minimum Spine Swingle	Average Spine Swingri	Average Spine Swingle	Maximum Spine Stanceri	Maximum Spine Stancele	Minimum Spine Stanceri	Minimum Spine Stancele	Average Spine Stanceri	Average Spine Stancele	Maximum Spine GCri	Maximum Spine GCle	Minimum Spine GCri	Minimum Spine GCle	Average Spine GCri	Average Spine GCle
GMFCS	−0.810	−0.597	9.357^{a}	9.856^{a}	9.192^{a}	9.541^{a}	−0.336	0.0370	9.162^{a}	9.211^{a}	9.503^{a}	9.143^{a}	−0.957	−0.185	9.692^{a}	9.511^{a}	9.369^{a}	9.246^{a}
	(0.676)	(0.668)	−2.018	−2.015	−1.898	−1.884	(0.611)	(0.618)	−1.960	−1.998	−1.834	−1.863	(0.657)	(0.619)	−1.987	−2.017	−1.849	−1.865
Age	1.714^{b}	1.558^{b}	2.244	3.555^{c}	2.735	4.026^{b}	1.339^{b}	1.424^{b}	2.869	2.928	3.585^{c}	3.602^{c}	1.413^{b}	0.939	2.714	3.471^{c}	3.278^{c}	3.728^{c}
	(0.689)	(0.681)	−2.058	−2.055	−1.936	−1.922	(0.623)	(0.630)	−1.999	−2.037	−1.871	−1.899	(0.670)	(0.631)	−2.026	−2.057	−1.886	−1.902
Constant	3.682	3.642	−42.40^{a}	−48.76^{a}	−40.09^{a}	−46.30^{a}	5.791^{c}	4.901	−44.81^{a}	−45.62^{a}	−43.80^{a}	−43.14^{a}	8.961^{a}	9.005^{a}	−46.79^{a}	−49.55^{a}	−42.41^{a}	−44.10^{a}
	−3.251	−3.211	−9.708	−9.690	−9.129	−9.062	−2.940	−2.970	−9.427	−9.608	−8.822	−8.958	−3.159	−2.976	−9.556	−9.702	−8.894	−8.968
Observations	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109
R^2	0.069	0.056	0.174	0.198	0.190	0.215	0.045	0.046	0.180	0.177	0.219	0.202	0.061	0.022	0.191	0.187	0.209	0.207
	Maximum Spine Preswingri	**Maximum Spine Preswingle**	**Minimum Spine Preswingri**	**Minimum Spine Preswingle**	**Average Spine Preswingri**	**Average Spine Preswingle**	**Maximum lSpine Loading Responseri**	**Maximum lSpine Loading Responsele**	**Minimum Spine Loading Responseri**	**Minimum Spine Loading Responsele**	**Average Spine Loading Responseri**	**Average Spine Loading Responsele**	**Maximum Spine SSri**	**Maximum Spine SSle**	**Minimum Spine SSri**	**Minimum Spine SSle**	**Average Spine SSri**	**Average Spine SSle**
GMFCS	−0.795	−0.408	10.18^{a}	9.159^{a}	9.880^{a}	9.168^{a}	0.421	0.661^{c}	8.920^{a}	9.246^{a}	8.825^{a}	9.498^{a}	−0.795	−0.408	10.18^{a}	9.327^{a}	9.880^{a}	9.168^{a}
	(0.609)	(0.659)	−1.971	−1.873	−1.851	−1.887	(0.377)	(0.393)	−2.038	−1.890	−1.843	−1.832	(0.609)	(0.659)	−1.971	−2.023	−1.851	−1.887
Age	1.096^{c}	1.013	3.173	2.962	3.632^{c}	3.242^{c}	1.683^{a}	1.867^{a}	2.856	3.388^{c}	3.757^{b}	4.352^{b}	1.096^{c}	1.013	3.173	2.907	3.632^{c}	3.242^{c}
	(0.621)	(0.672)	−2.010	−1.911	−1.888	−1.925	(0.384)	(0.401)	−2.079	−1.928	−1.879	−1.868	(0.621)	(0.672)	−2.010	−2.063	−1.888	−1.925
Constant	5.334^{c}	5.567^{c}	−47.52^{a}	−42.22^{a}	−45.00^{a}	−42.02^{a}	−3.174^{c}	−4.554^{b}	−43.62^{a}	−44.26^{a}	−42.28^{a}	−46.57^{a}	5.334^{c}	5.567^{c}	−47.52^{a}	−44.90^{a}	−45.00^{a}	−42.02^{a}
	−2.928	−3.168	−9.481	−9.010	−8.902	−9.078	−1.812	−1.889	−9.804	−9.092	−8.863	−8.810	−2.928	−3.168	−9.481	−9.728	−8.902	−9.078
Observations	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109
R^2	0.045	0.025	0.212	0.195	0.228	0.195	0.159	0.184	0.162	0.199	0.198	0.228	0.045	0.025	0.212	0.176	0.228	0.195

Abbreviations: Average Spine, mean Spine Angles Value; GC, mean gait cycle; Le, Left; LoadiResp, Loading response; Minimum Spine, minimum Spine Angle value; Preswing, Preswing; Ri, Right; SpineGC, Mean of Gait Cycle; SpineSS, Mean of Single Support; SpineStance, Mean of Stance Phase; SpineSwing, Mean of Swing Phase.

$^{a}P < 0.0001$. $^{b}P < 0.001$. $^{c}P < 0.01$.

TABLE 4

Regression of "GMFCS-Age" Combined in Relation With Sagittal Spine Angles

Variables	Maximum Spine Swingri	Maximum Spine Swingle	Minimum Spine Swingri	Minimum Spine Swingle	Average Spine Swingri	Average Spine Swingle	Maximum Spine Stanceri	Maximum Spine Stancele	Minimum Spine Stanceri	Minimum Spine Stancele	Average Spine Stanceri	Average Spine Stancele	Maximum Spine GCri	Maximum Spine GCle	Minimum Spine GCri	Minimum Spine GCle	Average Spine GCri	Average Spine GCle
gmfcsage	−0.346	0.0449	6.608[a]	6.136[a]	6.753[a]	6.462[a]	1.883[a]	1.221	6.394[a]	5.858[a]	6.835[a]	6.405[a]	1.067	1.232	6.350[a]	5.845[a]	6.914[a]	6.409[a]
	−1.001	(0.990)	−2.921	−2.925	−2.735	−2.720	(0.887)	(0.908)	−2.837	−2.905	−2.635	−2.689	(0.968)	(0.909)	−2.879	−2.934	−2.656	−2.692
Constant	0.857	4.008	11.54	1.338	15.05	6.458	21.16[b]	14.87[c]	7.387	2.206	12.00	9.160	17.67[a]	19.06[a]	5.052	−1.830	14.04	8.225
	−8.802	−8.699	(25.68)	(25.72)	(24.04)	(23.92)	−7.798	−7.978	(24.94)	(25.54)	(23.17)	(23.64)	−8.508	−7.993	(25.31)	(25.80)	(23.35)	(23.66)
Observations	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109
R^2	0.071	0.056	0.212	0.230	0.234	0.255	0.085	0.062	0.218	0.207	0.266	0.243	0.072	0.038	0.227	0.217	0.257	0.247

	Maximum Spine Preswingri	Maximum Spine Preswingle	Minimum Spine Preswingri	Minimum Spine Preswingle	Average Spine Preswingri	Average Spine Preswingle	Maximum lSpine Loading Responseri	Maximum lSpine Loading Responsele	Minimum Spine Loading Responseri	Minimum Spine Loading Responsele	Average Spine Loading Responseri	Average Spine Loading Responsele	Maximum Spine SSri	Maximum Spine SSle	Minimum Spine SSri	Minimum Spine SSle	Average Spine SSri	Average Spine SSle
gmfcsage	0.689	0.754	6.546[a]	7.071[b]	6.675[a]	6.148[a]	0.787	0.150	6.089[a]	5.898[a]	7.538[b]	5.959[a]	0.689	0.754	6.546[a]	6.017[a]	6.675[a]	6.148[a]
	(0.900)	(0.973)	−2.851	−2.689	−2.665	−2.732	(0.553)	(0.582)	−2.962	−2.742	−2.630	−2.652	(0.900)	(0.973)	−2.851	−2.939	−2.665	−2.732
Constant	10.96	11.72	5.926	15.51	9.497	8.173	3.249	−3.325	6.092	3.892	19.26	2.084	10.96	11.72	5.926	4.224	9.497	8.173
	−7.910	−8.558	(25.06)	(23.64)	(23.42)	(24.02)	−4.862	−5.115	(26.04)	(24.11)	(23.12)	(23.31)	−7.910	−8.558	(25.06)	(25.84)	(23.42)	(24.02)
Observations	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109
R^2	0.051	0.031	0.249	0.245	0.272	0.232	0.175	0.184	0.195	0.232	0.256	0.263	0.051	0.031	0.249	0.208	0.272	0.232

Abbreviations: Average Spine, mean Spine Angles Value; GC, mean gait cycle; Le, Left; LoadiResp, Loading response; Minimum Spine, minimum Spine Angle value; Preswing, Preswing; Ri, Right; SpineGC, Mean of Gait Cycle; SpineSS, Mean of Single Support; SpineStance, Mean of Stance Phase; SpineSwing, Mean of Swing Phase.

[a]$P < 0.001$. [b]$P < 0.0001$. [c]$P < 0.01$.

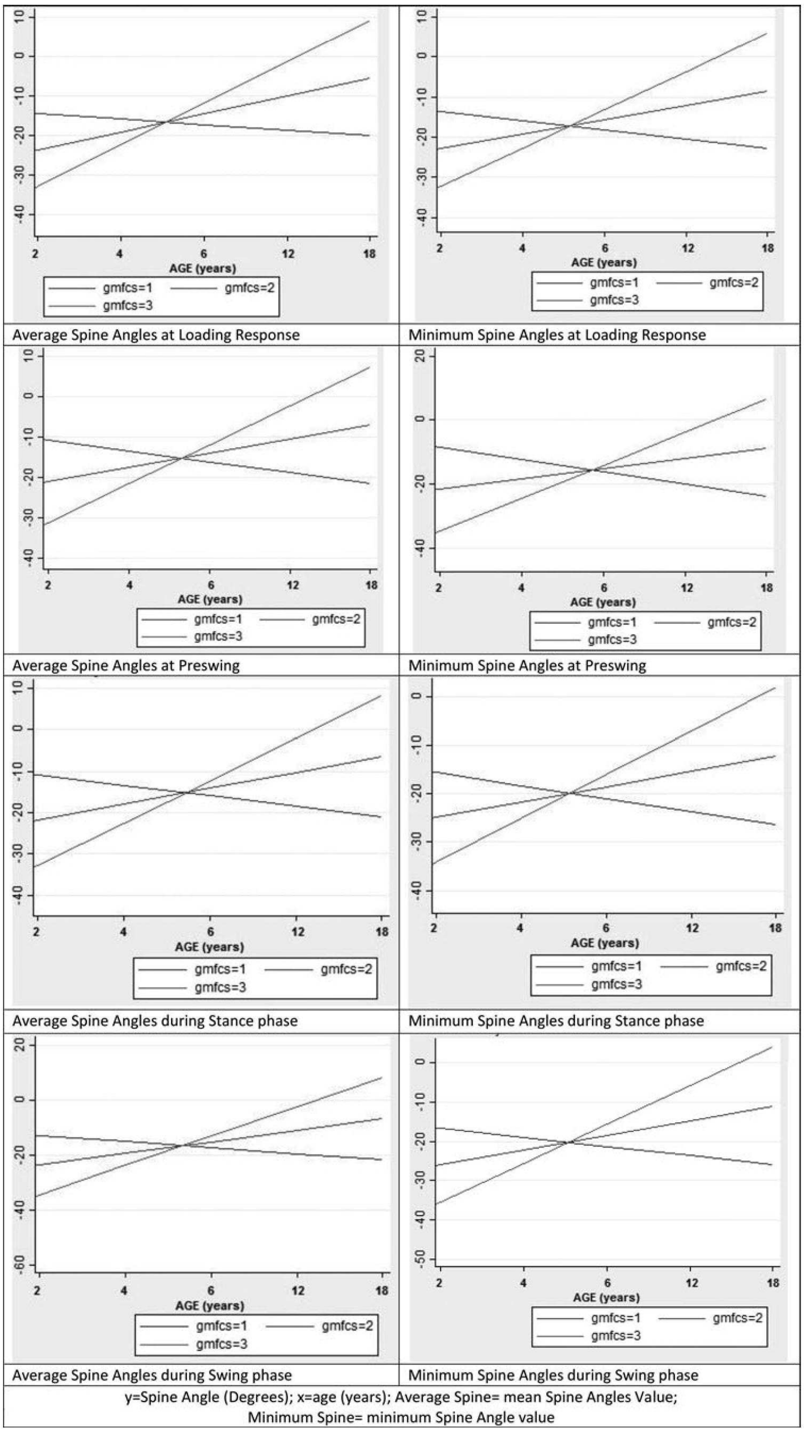

Fig. 1. Predictive evolution of children with cerebral palsy according to Gross Motor Function Classification System.

and only 1 was assessed with an anterior walker, and none of these children showed a flexed spine position. Four children older than 12 years used crutches, 1 performed with posterior walker, and 2 were assisted by hand by an adult. Children older than 12 years showed on average a higher flexed position in comparison to the younger children with GMFCS III and in relation to the other GMFCS levels in the same age group. Furthermore, higher trunk flexion was observed in children with GMFCS III as compared with those with GMFCS II, even though the use of an assistive device was considered that did not limit the trunk or pelvis movements.[1,27,28]

Increased thorax and spine motion toward extension might be interpreted as a dynamic compensation counterbalancing pelvic movement toward anterior tilt.[4,20] The pelvic segment in this study was anteriorly tilted in reference to the lab coordinates in all children with bilateral spastic CP. The spine angles in children with CP show the ability of the trunk to remain upright on the uneven pelvic segment through adaptations of the lumbar spine.[29] Range of motion differed significantly between GMFCS levels only for pelvic anterior/posterior tilt, with children in GMFCS II showing significantly higher ROM during gait than those in GMFCS I (difference 3°-5°)[20] and was even higher in those with GMFCS III (difference 7° with GMFCS II).[18] Range of motion for thoracic kyphosis was significantly higher in children with GMFCS II (8.8°) compared with GMFCS I (5.1°).[20] Higher trunk flexion was observed in children with GMFCS III as compared with those with GMFCS II.[1] Range of motion for lumbar lordosis did not differ significantly between groups.[20] The increased absolute ROM of pelvis, thorax, and angle of thoracic kyphosis in the sagittal plane in children with GMFCS III compared with those with GMFCS II, and even more with GMFCS I, points to reduced anterior/posterior stability in children with more severe motor involvement.[1,20]

The specific role of the trunk in controlling gait may be determined by the relation between upper and lower trunk segments. Spine angles are not a direct measure of the lumbar spine, but a relative position of the sagittal axis of the trunk and pelvic segments. However, similar values have been found in the literature when taking direct values from lumbar lordosis during gait in children in age groups 4 and 5 with GMFCS I and II (−14.5°, SD = 5.6 vs our average data −11.65°, SD = 14.53).[20] Our data during loading response (−5.00°, SD = 21.20) and toe off (−6.52°, SD = 21.23) can be compared with previous research that investigated lumbar spine in children with CP during double limb support phase (−3.7°, SD = 11.0; −6.4°, SD = 10.8, respectively).[9] The PIG model has been described and validated although there are more specific models for the assessment of spine movement during gait.[9] Increased complexity and the greater time needed for data collection, however, make full-body 3DGA with detailed spinal analysis less clinically applicable.[30] The regression model value of approximately 20% (R^2) suggests that there are additional factors, contributing to spine angles, besides GMFCS and age. These could include injury type, postural habits, child's visual ability, cognitive capacity, motivation, parental encouragement, and the contribution of therapies,[22] for instance. Our results had greater variability than previous studies possibly because of a wider age range of participants. Because of this and the low R^2 value, the absolute angles from the spine angles are not considered as precise clinical values, but they predict the tendency toward flexion or extension of the lumbar spine related to age and GMFCS.

Improving this segment of the trunk where control is weak might produce clinical improvements in gross motor function and mobility.[3] The use of orthotics to improve gait should consider the effect in the minimum and average values of the sagittal plane of the lumbar spine.

This research may support therapeutic interventions targeting impaired trunk control to improve gait in children with spastic diplegia.[3] The research supports assessing their effect on the minimum and average values of the sagittal plane of the lumbar spine. An integrative study of the motion of the spinal column combined with limb kinematics, and larger samples, could be valuable for further exploring the locomotive function of human spine.[13]

CONCLUSIONS

There are specific postural control patterns in the average and minimum values for the position between trunk and pelvis in the sagittal plane during gait, for the transition among GMFCS I-III levels. Higher classifications of gross motor skills correlate with more extended spine angles and in children with CP who cannot walk independently, the effect of development is reversed, flexing the trunk in relation to the pelvis.

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CLINICAL BOTTOM LINE

Commentary on "Position Between Trunk and Pelvis During Gait Depending on the Gross Motor Function Classification System"

"How should I use this information?"

This descriptive study uses 3-dimensional gait analysis to measure sagittal plane trunk position in individuals with cerebral palsy (CP) at Gross Motor Function Classification System (GMFCS) Levels I to III across age groups. The authors conclude that orientation of the thorax compared with the pelvis is more extended in children with CP at GMFCS Level I and that the angle gradually becomes more flexed as severity of CP and age increase in children at GMFCS Levels II and III.

Prediction of trunk position by GMFCS level and age using regression analysis reveals that only 20% of sagittal trunk position variance is related to these factors. The authors suggest that direct intervention to trunk position may impact functional independence in people with CP. They also present multiple theories proposing that trunk position may be a consequence of other factors (ie, assistive devices, postural control, and vision). The results of this investigation suggest that clinicians should be mindful of trunk position in movement observation and consider all reasons that trunk position may be altered.

"What should I be mindful about?"

There are a number of factors that make this information difficult to translate into the clinic. First, the complexity of the mathematical modeling makes application and generalizability of the results challenging. Second, the results of the study are statistically significant but may not be clinically significant. Third, poor description of assistive devices, orthotics, and shoe wear limits the strength of the authors' conclusions and generalizability of the results. Finally, clinical application of the findings may be difficult because of the challenges in observing subtle differences of thoracic position across the gait cycle. Further research should consider factors that contribute to spine angles in addition to GMFCS level and age and use of this information to inform intervention for individuals with CP.

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LÍNEA DE INVESTIGACIÓN III

Línea de investigación III: "Valoración del plano sagital con el inclinómetro en personas con funcionalidad motora gruesa por encima del desarrollo ontogénico: Gimnastas de Artística con capacidad de marcha con los miembros superiores"

JOSÉ MANUEL SANZ MENGÍBAR

ARTÍCULO 3

Título: Training intensity and sagittal curvature of the spine in male and female artistic gymnasts
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Aportación del doctorando: - Realización de búsqueda bibliográfica específica en diferentes bases de datos. - Participación en el diseño y localización de la muestra. - Toma de datos y valoración de los deportistas. - Análisis estadístico. - Redacción del artículo.

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Resumen/Abstract:

BACKGROUND: Specific adaptations of the spine in the sagittal plane have been described according to different sports disciplines. The goal of this study was to describe the integrative diagnosis of the sagittal morphotype of the spine in male and female artistic gymnasts. METHODS: 48 gymnasts were measured with an inclinometer. Thoracic and Lumbar curves were quantified in standing position, in Sit and Reach and Slump Sitting in order to assess the sagittal spine posture and analyze if adaptations were related to training intensity. RESULTS: Correlation values of the sagittal plane spine measurements showed significantly increased thoracic kyphosis in men (-0.445, p<0.001). No significant correlations have been found between training hours per year or training volume and any measurements of the spine on the sagittal plane. When data from the two sitting tests were integrated, 62.5% of gymnasts had a functional thoracic kyphosis and 39.6% had lumbar kyphotic attitude. CONCLUSIONS: Our hypothesis has only been partially confirmed, because training intensity did not influence the sagittal curvatures in artistic gymnastics; however, this sport seems to cause specific adaptations in postural hypolordosis, functional thoracic kyphosis and lumbar kyphotic attitude during sitting and trunk flexion. The implications of the functional adaptations observed in our results may require a preventive intervention in male and female artistic gymnasts can be assessed with the integrative diagnosis of the sagittal morphotype of the spine.

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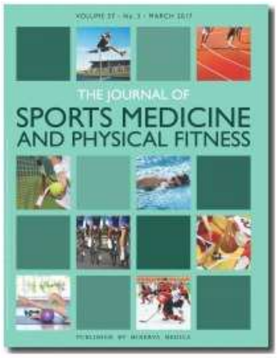

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Training intensity and sagittal curvature of the spine in male and female artistic gymnasts

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Training intensity and sagittal curvature of the spine in male and female artistic gymnasts

Introduction

The spine is designed to bear loads within normative ranges of motion and therefore its sagittal curvatures in athletes has to be assessed (Sainz de Baranda et al, 2010). Kyphotic posture is often adopted and loss of lumbar lordosis during trunk flexion causes wedging of vertebral bodies in an immature spine due to excessive compression on the vertebral growth plates (Wojtys et al, 2000). The degrees of thoracic and lumbar curvatures influence the loads affecting the vertebral bodies and the stresses on the intervertebral discs. Sagittal misalignments of the spine have been related to different back problems in adults, such as back pain or vertebral disc degeneration (Callaghan et al, 2001). These negative impacts justify the research on the relation between the systematic sports training and the alignment of the sagittal curvatures of the spine (Santonja, Morales, 2008).

Intense programs with high-volume training increase the probabilities of sagittal spine curvature modifications (López-Miñarro et al, 2009). Thoracic and lumbar spine curvatures have been correlated to training time (Wojtys et al, 2000) and also specific spine morphotypes in different sports have been observed (Förster et al, 2009). Previous research assessed the sagittal plane of the spine in different athletes such as swimmers (Pastor et al, 2002), rhythmic gymnasts (Ohlen et al, 1989 and Martínez Gallego et al, 2006), climbers (Förster et al, 2009), bodybuilders (López-Miñarro et al, 2009), dancers (Gómez Lozano et al, 2013) and wrestlers (Rajabi et al, 2008). Other studies included different disciplines such as weightlifting, tennis, hockey, football, rowing, water polo and volleyball (Dalichau et al, 2001; Boldor et al, 1999 and Uetake et al, 1998). Postural adaptations in the sagittal plane of the thoracic and lumbar spine were found in most of these studies (Santonja, 1996). Research on the relationship between men's or women's artistic gymnastics training intensity and sagittal spine curvatures has not been found. These athletes are exposed to risk factors such as wide repetitive trunk movements in flexion and sustained postures outside the normal range (Ohlen et al, 1989 and Harringe et al, 2007) with an emphasis on spine engagement during propping and suspension of the body weight by the upper limbs.

The most reliable technique to quantify kyphosis and lordosis is the spine conventional X-ray (Ashton-Miller et al, 2004). There are other methods free of ionizing radiation that assess the curvatures of the spine in the sagittal plane, for instance, the inclinometer provides a noninvasive evaluation with good reproducibility, reliability and correlation with the radiographic measurement (Ng et al, 2001 and Saur et al, 1996). The "integrative diagnosis of the sagittal morphotype of the spine" was defined by Santonja (Santonja, 1996) and adds the assessment of the sagittal curvatures with the inclinometer during maximal trunk flexion and slump sitting (Santonja, 1996 and Sainz de Baranda et al, 2009) to the classical quantification of the thoracic and lumbar spine in standing position in order to increase the diagnostic power. Normal kyphosis is considered when curvature measurements are within normative values in standing position, Sit and Reach (SR) and Slump Sitting (SS) tests (Sainz de Baranda et al, 2010) (Table I). Functional thoracic kyphosis is defined for normative values in standing, but hyperkyphosis in SR and/or in SS. Normal lumbar lordosis is considered when curvature measurements are within normative values in standing and gently flex (10^0-30^0) in SR. Lumbar kyphotic attitude is defined for normative values in standing, but lumbar curvature is $> 30^0$ in SR or $> 15^0$ in SS.

Table I. Classification of the sagittal thoracic and spine curvatures according to the normative data

	Morphotype	Thoracic Curvature	Lumbar Curvature
Standing	*Normal range*	20^{0}- 45^{0}	(-) 20^{0}- 40^{0}
	Hyperkyphosis/hyperlordosis	> 45^{0}	> (-) 40^{0}
Sit and Reach	*Normal range Kyphosis*	40^{0}-65^{0}	10^{0}-30^{0}
	Thoracic Hyperkyphosis / Lumbar Kyphotic attitude	> 65^{0}	≥ 30^{0}
	Distance fingers-toes	≥ (-2cm)	
	Lumbo-horizontal angle in Sit and Reach	≤100^{0}	
Slump sitting	*Normal range Kyphosis*	20^{0}- 45^{0}	± 0-15^{0}
	Thoracic Hyperkyphosis / Lumbar Kyphotic attitude	> 45^{0}	> 15^{0}
	Lumbo-horizontal angle in Slump Sitting	80^{0}-100^{0}	

The goal of this study is to describe the integrative sagittal morphotype of the spine in men and women's artistic gymnastics according to training volume and intensity. Our hypothesis is that there is a specific adaptation of the spine to the specific requirements of Men's and Women's artistic gymnastics and to training intensity.

Methods

In order to confirm or rule out our hypothesis, an observational analysis was developed to describe and relate the spine measurements with the training intensity variables of male and female artistic gymnasts. The study was approved by the Research Ethics Committee of the University of Murcia.

Participants were recruited from 10 different clubs belonging to gymnastics federations in four different countries participated. Gymnasts, parents and coaches were informed of the study procedures before the assessment and all study participants provided written informed consent. Inclusion criteria were: belonging to a male or female artistic gymnastics club with membership in a gymnastics federation, participating in national or international competitions, and having trained 18 hours per week or more during the last 12 months (Sainz de Baranda et al, 2010). Exclusion criteria were having scoliosis or having received a treatment such as a back brace or specific exercises for any other spine condition (Sainz de Baranda et al, 2010 and Wojtys, 2000). The final sample included 48 artistic gymnasts, 35 were Spanish, 11 were English, a Ukrainian and an American. The sample included 24 women and 24 men, including 10 members of Spanish men's national team. Because of the hypothesis generating character of the study, randomization, a sample size and power calculation were not needed.

Quantification of the sagittal curvatures of the spine was carried out with a Unilevel inclinometer (ISOMED, Inc., Portland, OR), according to Santonja's methodology (Santonja, 1996). Measurements were performed by an expert physiotherapist and the gymnasts were assessed barefoot and in their underwear. Data from every gymnast were obtained during the same session (Sainz de Baranda et al, 2009). Thoracic and lumbar spine curvatures in the sagittal plane were measured in standing position, in slump sitting (SS) (Stagnara et al, 1982; Santonja et al, 1996 and 2006) and during the Sit and Reach (SR) test on maximal trunk flexion with legs fully extended (Santonja et al, 1996 and 2006). The inclinometer was placed at the beginning of the curve at T_1-T_2, T_{12}-L_1 and L_5-S_1 (Santonja, 1996) in order to quantify the thoracic and lumbar curves. Negative values stand for degrees of posterior concavity (lordosis), and positive values stand for anterior concavity or kyphosis (Santonja, 2006 and Norkin, White, 1995). Inclinometer normative data for the curvatures in these positions was obtain from table I. Gymnasts stood in neutral posture (ACoEM, 1998) and the SR test was performed afterwards according to ACSM procedure (ACoEM, 1998). The hands of the gymnast were placed at the greatest reach on the box with the ruler. Positive values in centimeters were considered beyond the toes, and negative values when the fingertips did not reach them (Stagnara et al, 1982; Santonja, Martínez 1992 and Ayala et al, 2013). After thoracic and lumbar curves measurements, lumbo-horizontal angle in flexion (L-H fx) during SR was also quantified with a goniometer (Santonja et al, 1994). The branches of the goniometer were aligned with the horizontal line and the spinous processes of L_5 to S_2 in order to record the anterior angle between the two references. The assessment in SS included the same procedures as in SR. The gymnasts were sitting on the plinth in a relaxed and asthenic posture. Feet were off the ground without any support and the forearms were resting on their thighs (Santonja, 1996 and Stagnara et al, 1982).

Wojtys et al (Wojtys et al, 2000) and Sainz de Baranda (Sainz de Baranda et al, 2010) criteria were used to calculate the intensity variables "training hours per year", the "training volume" of each gymnast, as well as the group division according to these parameters. "Training hours per year" equals the training hours per day x weekly training days x 4 weeks per month x months per year. "Training volume" equals the number of years training x training hours per year. Two groups were established according to which had trained more than or less than 400 hours per year. The gymnasts were also divided according to whether they accumulate more or less than 2000 hours of training volume (Sainz de Baranda et al, 2010).

Statistical analyses were performed using the SPSS 15.0 software package for Windows. Sagittal plane spine measurements were plotted against age, gender, height, training volume, years of training, and training hours per day, week and year. The strength of the association between these variables was calculated using Spearman's rank correlation. Descriptive data were obtained with Microsoft Excel 2003, in order to understand average curvature values according to age and gender. The percentages of gymnasts with spine curvatures outside the normative values were also calculated.

Results

Sample features including age, height and training intensity can be observed in table II.

Table II. Summary of Gymnast's Characteristics						
	Overall average n=47	SD	Men n=23	SD	Women n=24	SD
Age (months)	180.32	61.02	220.61	61.73	141.71	24.95
Years of training	8.28	4.92	11.43	5.05	5.25	2.13
Training hours per day	3.66	1.21	4.22	1.53	3.13	0.26
Training hours per week	18.55	6.20	21.09	7.57	16.13	3.11
Training volume	6989.83	6302.75	10636.57	7242.90	3495.04	1796.49
Training hours per year	742.13	248.37	843.48	302.93	645.00	124.44
Height (centimeters)	151.81	17.100	161,41	13.49	142.60	15.164

Significant differences between our male and female groups were found. Men were older (-0.653, p<0.001. Average in years 18.3±5.1 versus 11.8±2), taller (-0.556, p<0.001), trained more hours per year (-0.404, p<0.001) and had superior training volume (-0.573, p<0.001) in our sample.

Correlation values of the sagittal plane spine measurements showed significantly increased thoracic kyphosis in men (-0.445, p<0.001). With an average 39.6^0 versus 31.8^0 in women, 12.5% of male gymnasts showed thoracic hyperkyphosis in standing position, while 4.1% of women showed hyperkyphosis and 2.1% hypokyphosis. Thoracic spine curvature in Slump Sitting test showed poor correlation with gender (-0.307, p<0.01).

No significant correlations have been found between training hours per year or training volume and any measurements of the spine on the sagittal plane. Training volume was correlated with age as expected (0.896, p<0.001) but training hours per year was not related to age. Table III summarizes other correlation values between the studied variables.

Table III. Correlations between the sagittal spine curvatures values and potential risk factors						
		Gender	Age	Training hours per year	Training volume	Height
Gender			-0.653(**)	-0.404(**)	-0.573(**)	-0.556(**)
Years of training		-0.635(**)	0.934(**)	0.264	0.945(**)	0.666(**)
Height		-0.556(**)	0.716(**)	0.466(**)	0.562(**)	
Standing position	Thoracic Kyphosis	-0.455(**)	0.332(*)	0.145	0.192	0.531(**)
	Lumbar Lordosis	0.128	0.028	0.230	-0.054	0.036
Sit and Reach	Thoracic spine	-0.068	0.160	-0.011	0.256	0.049
	Lumbar spine	0.093	-0.192	-0.187	-0.236	0.134
	L-H fx	0.054	-0.194	-0.020	-0.232	0.082
Sit and Reach		0.036	0.315(*)	0.260	0.331(*)	0.104
Slump Sitting	Thoracic spine	-0.307(*)	0.234	0.060	0.111	0.102
	Lumbar spine	0.015	-0.180	0.026	-0.106	0.071
	L-H SS	-0.237	0.011	0.032	0.106	-0.005

***** Significant correlation p<0.05.
****** Significant correlation p<0.01
L-H Fx= Lumbo-horizontal angle in flexion during Sit and Reach test
L-H SS= Lumbo-horizontal angle in flexion during Slump Sitting test

Table IV describes the average descriptive values of the sagittal curves, as well as the percentage of gymnasts whose measurements were outside the normative range. The number of cases according to the classical diagnosis in standing position of the thoracic spine (1 flat back, 39 normal range kyphosis and 8 thoracic hyperkyphosis) and lumbar spine (8 Hypolordosis, 34 normal range lordosis and 6 hyperlordosis) is reported in detail in table V. The sagittal morphotype of the spine integrating the three tests can be observed in the last row of this table. 30 of the 39 gymnasts with normal range kyphosis in standing position adopted a hyperkyphotic attitude during SR and they were diagnosed with “functional kyphosis”. 19 of the 34 gymnasts with normal range lumbar lordosis in standing position adopted a kyphotic posture during the SR and SS tests, and they were diagnosed with “Kyphotic lumbar attitude”.

Table IV. Average values and percentages of male and female artistic gymnasts with sagittal spine curvatures outside the normative values

		Overall		Male			Female		
		Average n=47	SD	Average n=23	SD	**% outside normative values**	Media n=24	SD	**% outside normative values**
Standing	**Thoracic Kyphosis**	35.68º	8.63	39.65º	6.69	**12.5**	31.88º	8.67	**6.24**
	Lumbar Lordosis	- 29.16º	10.85	- 27.76º	10.65	**14.6**	- 30.50º	11.09	**14.6**
Sit and Reach	**Thoracic spine**	62.17º	10.78	62.91º	8.44	**16.6**	61.46º	12.77	**20.8**
	Lumbar spine	26.90º	8.97	26.07º	8.43	**18.74**	27.71º	9.56	**22.9**
	L-H fx	85.68º	21.38	84.52º	22.49	**37.5**	86.79º	20.69	**33.3**
Sit and Reach		16.88	14.02	16.37	19.14	**6.2**	17.38	6.49	**4.2**
Slump Sitting	**Thoracic spine**	52.36º	10.17	55.52º	7.83	**43.75**	49.33º	11.35	**37.5**
	Lumbar spine	15.62º	6.41	15.52º	6.92	**20.9**	15.71º	6.02	**18.75**
	L-H SS	108.85º	7.50	110.65º	7.13	**45.8**	107.13º	7.58	**39.6**

L-H Fx= Lumbo-horizontal angle in Sit and Reach test
L-H SS= Lumbo-horizontal angle in Slump Sitting test

Table V. Distribution according to the classical thoracic and lumbar morphotypes in standing position and according to the integrative diagnosis of the sagittal morphotype of the spine"

	Thoracic spine			Lumbar spine		
	Decreased	**NORMAL RANGE**	**Increased**	**Decreased**	**NORMAL RANGE**	**Increased**
Standing position	*1*	*39*	*8*	*8*	*34*	*6*
	2.08%	*81.2%*	*16.6%*	*16.6%*	*70.2%*	*12.5%*
	1 Flat Back	*39 Normal Range*	*8 Hyperkyphosis*	8 Hypolordosis	*34 Normal Range*	*6 Hyperlordosis*
Sit and Reach	*0*	*30*	*18*	*1*	28	*19*
	0%	*62.5%*	*37.%*	*2.1%*	58.3%	*39.6%*
Slump Sitting	*1*	*9*	*38*	*0*	*29*	*19*
	2.1%	*18.75%*	*79.1%*	*0%*	*60.4%*	*39.5%*
SAGITTAL INTEGRATIVE MORPHOTYPE	*1 Postural Flat Back*	*9 Normal Range*	*8 Hyperkyphosis*	*1 Hypolordosis*	*28 Normal Range*	*6 Hyperlordosis*
		30 Functional Kyphosis (62.5%)		*7 Postural Hypolordosis (14.6%)*	*19 Lumbar Kyphotic attitude (39.6%)*	

Table V compares the gymnast sample according to the classical thoracic and lumbar spine morphotypes in standing only and the integrative sagittal morphotype of the spine. This last diagnosis integrates three postures (standing, SR and SA).

Discussion

Our assessment confirms that sagittal curvatures of the spine can be modified with intensive artistic gymnastics training as previously described in other sports (Uetake et al, 1998 and Sainz de Baranda et al, 2009). Nevertheless, relation between the alignment of the spine in the sagittal plane with the training intensity (neither training hours per year, nor with the training volume) has not been found, so the second part of our hypothesis can not been confirmed. Only a poor correlation between the training volume and the Sit and Reach test has been observed but this may be related to similar correlation strength with age. In contrast with our results, Martínez Gallego and Rodríguez (Martínez Gallego et al, 2006) found significant differences when training intensity of rhythmic gymnastic was taken into account between 10 and 14 years of age. Reduced thoracic kyphosis in standing and during trunk flexion, as well as reduced lumbar lordosis in standing was observed in high-competition rhythmic gymnasts in contrast to lower intensity training (Martínez Gallego et al, 2006).

There are differences between the apparatus, skills and physical features in men's and women's artistic gymnastics. Despite many common sports movements, international regulation supports these distinctions. Our male and female groups had also significant differences according to age, height, training hours per year and training volume. Nevertheless, when the impact of gender on the sagittal spine curves was taken into account, only increased men's thoracic kyphosis in standing was found. Our results are consistent with those found in trampoline gymnasts: men showed greater thoracic kyphosis in standing, but also in trunk flexion (Sainz de Baranda et al, 2009). This last finding differs from our results, as male artistic gymnasts showed only a poor correlation with thoracic kyphosis in SS. Also, the percentage of thoracic hyperkyphosis during SR is slightly higher in female artistic gymnasts than in female trampoline gymnasts (Sainz de Baranda et al, 2009). The male and female samples size and distribution is a study limitation (only five women trained less than 2000 hours, for instance). Future studies including larger samples would reduce the differences between groups and would further evaluate the association between the sagittal curvatures of the spine and Artistic Gymnastic training.

Most of the artistic gymnasts with curvature values outside the normative data in SS showed thoracic hyperkyphosis and lumbar kyphotic attitude, and only one subject had flatback (Santonja, Pastor, 2003). It is important to note the high percentages of gymnast with curvature values outside the normative data. The percentage of artistic gymnasts with abnormal lumbar lordosis in standing is greater than those found in swimmers (Pastor et al, 2002) (4.8% of reduced lumbar lordosis versus 16.6% and 7.1% of lumbar hyperlordosis versus 12.5%). Lumbar hyperlordosis has been observed in high competition rowers, swimmers and gymnasts (Pastor et al, 2002; Dalichau et al, 2001 and Sainz de Baranda et al, 2010). 16,6% of our sample had thoracic hyperkyphosis in standing and this finding was similar to other sports such as climbing (Förster et al, 2009 and Morrison, Schoffl, 2007), rowing (Boldor et al, 1999 and Uetake et al, 1998) and swimming (Pastor et al, 2002 and Wilsonv, 1982). We would also like to emphasize that only 9 of 39 subjects with a normal range of thoracic kyphosis while standing actually remain within normative values during the three tests. The remaining 30 gymnasts with a normal range of thoracic kyphosis in standing had function kyphosis because they showed an increased curvature in trunk flexion (SR) or in SS.

Lumbar kyphosis was observed in most of the artistic gymnasts in sitting (87.2% had L-H during SS>100^0) probably as a result of poor postural hygiene despite the strong trunk, pelvis and hip muscle development in this sport. Greater values than normal range in SR test can be observed in our subjects (+16.88±14.02). It should be highlighted that 39.6% of our sample had hamstring shortness (lumbar kyphotic attitude) even though this sport requires wide trunk mobility. Therefore, SR is not a valid test to assess hamstrings extensibility (Norkin, White, 1995) in artistic gymnastics because the increased spine flexion that can be observed is due not to this feature, but sport functional requirements.

Repetitive and intense hip and trunk flexion gestures, as well as full body weight bearing on the upper limbs can be observed in artistic gymnastics. Thoracic hyperkyphosis related to sports training of spine flexion and the ability to shift the body using the upper limbs has been previously described (Wilson, 1982; Morrison, Schoffl, 2007 and Förster et al, 2009). These functional adaptations of the spine morphology are aimed at satisfying the biomechanical stresses (Morrison, Schoffl, 2007) specific to every sport (Dalichau et al, 2001 and Förster et al, 2009) and the integrative diagnosis of the sagittal morphotype of the spine is required for their assessment (Santonja, 1996). The implications of this study include that the functional adaptations observed in our results may require a preventive intervention in male and female artistic gymnasts.

Conclusion

Our hypothesis has only been partially confirmed, because training intensity did not influence the sagittal curvatures in artistic gymnastics; however, this sport seems to cause specific adaptations in postural hypolordosis, functional thoracic kyphosis and lumbar kyphotic attitude during sitting and trunk flexion. Larger male and female samples will be very valuable for further exploring the association between the sagittal curvatures of the spine and Artistic Gymnastic training. Future studies may also describe the effect of preventive intervention for the functional adaptations described.

Figure 1. Measurement of the sagittal curvature of the spine in standing position. Normal Kyphosis (30^{0}) and Lordosis (36^{0}).

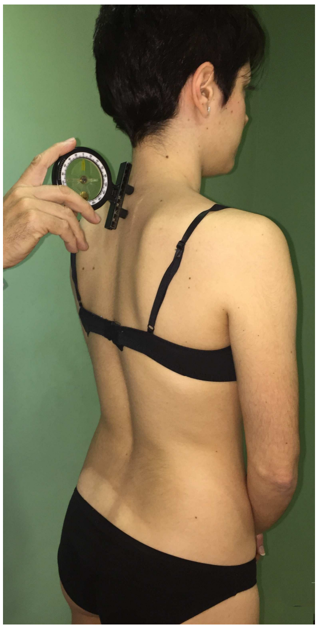

Figure 2. Sit and Reach test (SR) and measurement of the sagittal spinal curves and Lumbo-horizontal angle in flexion (L-H fx) in this position. Gymnast with Functional Thoracic Kyphosis. (hyperkyphosis in SR 72^{0}).

Figure 3. Measurement of the sagittal curvature of the spine in Slump Sitting (SS). Gymnast with Functional Thoracic Kyphosis (hyperkyphosis in SS of 64º).

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ANEXO:

RESUMEN EN INGLÉS

ENGLISH ABSTRACT

ENGLISH ABSTRACT

INTRODUCTION

Gross Motor Function Classification System (GMFCS) is the gold standard for gross motor classification in children with cerebral palsy; however it does not describe equivalent levels in children with typical development. The Locomotor Stages could be a reliable classification system, equivalent to GMFCS, and would also allow plotting typical development children and those with cerebral palsy. Locomotor Stages had been used for clinical assessment and research to quantify therapeutic outcomes in patients with cerebral palsy. Within the framework of the International Classification of Functioning, Disability and Health (ICF), Locomotor Stages takes body postural function and independent activity components into account. Studies on the measurement of the ontogenic development of the spine in the sagittal plane of babies and toddlers with typical development are limited. Prenatal and neonatal measurements of the spinal curves are subject to variability due to the body positioning. Supine position offers limited access to the spine, while resting head and limb position is difficult to obtained in prone. On the other hand, sagittal spinal curve vary dynamically within a range during the execution of a selective motor patter and would require being accessible at any age or developmental stage. In order to be able to compare within groups, also static measurements should be standardized to be easily accessible. On top of that, measurements should be sensible to curves changes and maybe specific to different variables like age or gross motor level.

The relationship between spinal curves on the sagittal plane during gait and gross motor function in children with cerebral palsy has been suggested but not deeply studied. Research on the relationship between other functional maturation stages of the Central Nervous System and spinal curves has not been found. It is widely accepted that gross motor and locomotor function are limited to a combination of compensatory movements coming from lower limb alterations and postural control deficits. Measuring the impact of distal patterns of movement on proximal segments including the spine is technically complex during dynamic activities other than walking and therefore there is limited data on the sagittal spinal curves in children with lower gross motor function levels. The quantification of sagittal curves is useful to understand the normative values of a healthy spine in teenagers and adults, and has helped to report postural adaptation to different factors like intense sport training.

Beside static spine measurements, the lumbar spine is essential for the postural control during gait, and but its impact in the gross motor function has not been previously reported. Three-dimensional gait analysis provides a validated quantification of the spine kinematics during a dynamic pattern.

HYPOTHESIS AND GOAL

Our starting point is the following hypothesis: "There is a relation between the human gross motor function and the sagittal curves of the spine. This relation is valid in subjects with cerebral palsy and it responds to typical ontogenic development and also as adaptative effect to training". The main goals of this PhD Thesis are: A) to study the criterion-related validity and reliability of the "Locomotor Stages" as classification system of the gross motor function. This would allow us to compare locomotor function of children with typical development and those with cerebral palsy and to confirm its simultaneous development. B) To study the relation between the sagittal curves of the spine and the reduced level of gross motor function in subjects with cerebral palsy. C) To study the relation between the sagittal curves of the spine and the increased level of gross motor function in subjects training locomotor skills beyond the ontogenic development.

METHOD

Our first study was design to be able to validate the Locomotor Stages. We would need this classification system in order to compare gross motor function between children with cerebral palsy and those with typical development during the rest of the Thesis. Once our reliability was verified, we recruited children with cerebral palsy in three countries. Data were collected through direct observation and video recording. A total of 465 children met the inclusion criteria but three of them had to be excluded later due to a change in their diagnosis into a degenerative condition. GMFCS age groups were taken into account as a parameter during the data analysis, in order to be able to compare the equivalent levels for both scales. In order to understand if Locomotor Stages was sensitive and specific for motor performance, 21 children from this sample were followed up on for at least three occasions chosen at random (these reassessments were not planned, but scheduled at the time of their clinical follow up).

The following study was designed to measure sagittal curves of the spine during a dynamic movement such as walking. Sagittal trunk-pelvis kinematics from 97 children with cerebral palsy from Three-Dimensional Gait Analysis (3DGA) were plotted relative to their Locomotor Stage. The children walked at a self-selected speed on a nine meter walk way in the gait laboratory. The Vicon motion capture system with six infrared cameras was used for 3DGA (Vicon, Oxford Metrics, Oxford UK), with a sampling rate of 120 Hz. Vicon Nexus (1.8.2) was used to define gait cycles and to calculate spatio-temporal parameters, sagittal kinematics data. Upper body was modeled according to the Plug In Gait model. Sagittal Spine Angles reflects the relative movement between the pelvis and trunk Spine Flexion/Extension is defined in 3DGA by the angle between the sagittal thorax axis and the sagittal pelvis axis around the fixed transverse axis of the pelvis. A positive (Flexion) angle value corresponds to the situation in which the thorax is tilted forward and a negative (Extension) angle value when the thorax is tilted backwards relative to the pelvis. Two representative trials from right and left cycles were used for further data processing with custom-made Matlab routines (Mathworks R2009a). Average, minimum and maximum degrees of the Spine Angles were extracted at different gait events of the trials. The following data from the sagittal plane at the following left (le) and right (ri) leg events were plotted against GMFCS and age: Loading response (LoadiResp), Preswing (Preswing), mean of Single Support (SpineSS), mean of Swing Phase (SpineSwing), mean of Stance Phase (SpineStance), and mean of Gait Cycle (SpineGC) (See supplemental digital content C). Spearman correlation coefficients were calculated, and the association to understand GMFCS level according to the spinal curves was investigated using Ordinary Least Squares (OLS), taking into account the ordinal nature of the dependent variables for the use of this regression model. Level of significance was set to alpha = 0.05. Statistical analyses were performed using STATA 12.0 software package for Windows.

Participants with increased gross motor function were recruited from 10 different clubs belonging to gymnastics federations in four different countries participated. The final sample included 48 artistic gymnasts, 35 were Spanish, 11 were English, a Ukrainian and an American. The sample included 24 women and 24 men, including 10 members of Spanish men's national team. Quantification of the sagittal curvatures of the spine was carried out with a Unilevel inclinometer (ISOMED, Inc., Portland, OR), according to Santonja's methodology (Santonja, 1996). Measurements were performed by an expert physiotherapist and the gymnasts were assessed barefoot and in their underwear. Data from every gymnast were obtained during the same session. Thoracic and lumbar spine curvatures in the sagittal plane were measured in standing position, in slump sitting (SS), and during the Sit and Reach (SR) test on maximal trunk flexion with legs fully extended. The inclinometer was placed at the beginning of the curve at T_1-T_2, T_{12}-L_1 and L_5-S_1 in order to quantify the thoracic and lumbar curves. Negative values stand for degrees of posterior concavity (lordosis), and positive values stand for anterior concavity or kyphosis. Gymnasts stood in neutral posture and the SR test was performed afterwards according to ACSM procedure. The hands of the gymnast were placed at the greatest reach on the box with the ruler. Positive values in centimeters were considered beyond the toes, and negative values when the fingertips did not reach them. After thoracic and lumbar curves measurements, lumbo-horizontal angle in flexion (L-H fx) during SR was also quantified with a goniometer. The branches of the goniometer were aligned with the horizontal line and the spinous processes of L_5 to S_2 in order to record the anterior angle between the two references. The assessment in SS included the same procedures as in SR. The gymnasts were sitting on the plinth in a relaxed and asthenic posture. Feet were off the ground without any support and the forearms were resting on their thighs.

RESULTS

When plotting gross motor classification systems, high reliability and strong negative correlation (-0.908) for GMFCS and Locomotor Stages at any age was found. Sensitivity was 83%; specificity and positive predictive value were 100% within the same age range. Regression analysis showed detailed probabilities for the realization of the GMFCS depending on the Locomotor Stages and the age group.

During the assessment of the sagittal curves of the spine during three dimensional movement analyses in ambulatory children with cerebral palsy, we obtained the following results: only average and minimum values of the lumbar segment correlated with GMFCS. Maximal values at Loading Response correlated independently with age at all functional levels. Significant regressions were found in all average and minimum values when taking age in combination with GMFCS. All average and minimum values of the sagittal plane of the lumbar spine during the investigated gait events showed a significant fair-to-moderate correlation with the GMFCS level, with a slight increase in correlation values if the function variable also incorporated the age group.

Maximal spine values had no significant differences by GMFCS level. The values of the regression of the independent effect of GMFCS on the spine have been also stated in this research. Age group correlated only with maximal values of lumbar spine during loading response at functional levels (right side R=0.386, p<0.001 and left side R=0.403, p<0.001), and poorly with maximum stance value (left R=0.214, p<0.01 and right R=0.207, p<0.01) and with maximum value during swing phase (left R=0.220, p<0.01 and right R=0.238, p<0.001). Significant regressions were found in all the average and minimum values, when studying the age in combination with GMFCS, while all the maximum values which correlated independently with age were not significant anymore. The development of most relevant sagittal lumbar spine through the gait cycle of every GMFCS level can be observed in the graphs developed in this study. Descriptive minimum, maximum and average values of every GMFCS level have been also stated. All average and minimum of the sagittal plane of the lumbar spine during the investigated gait events showed a positive moderate correlation with age, and showed positive poor correlation with the Locomotor Stages in children with typical development. Significant correlations were found between all average and minimum values of the lumbar spine and Locomotor Stages in children with cerebral palsy.

Finally, the results of the spine adaptation in subjects with gross motor skills developed above the ontogenic level are: Correlation values of the sagittal plane spine measurements showed significantly increased thoracic kyphosis in men (-0.445, p<0.001). With an average 39.6^0 versus 31.8^0 in women, 12.5% of male gymnasts showed thoracic hyperkyphosis in standing position, while 4.1% of women showed hyperkyphosis and 2.1% hypokyphosis. Thoracic spine curvature in Slump Sitting test showed poor correlation with gender (-0.307, p<0.01). No significant correlations have been found between training hours per year or training volume and any measurements of the spine on the sagittal plane. Training volume was correlated with age as expected (0.896, p<0.001) but training hours per year was not related to age. We have now described the average descriptive values of the sagittal curves, as well as the percentage of gymnasts whose measurements were outside the normative range. The number of cases according to the classical diagnosis in standing position of the thoracic spine are: 1 flat back, 39 normal range kyphosis and 8 thoracic hyperkyphosis. And for lumbar spine: 8 Hypolordosis, 34 normal range lordosis and 6 hyperlordosis. 30 of the 39 gymnasts with normal range kyphosis in standing position adopted a hyperkyphotic attitude during Sit and Reach and they were diagnosed with "functional kyphosis". 19 of the 34 gymnasts with normal range lumbar lordosis in standing position adopted a kyphotic posture during the Sit and Reach and SS tests, and they were diagnosed with "Kyphotic lumbar attitude".

CONCLUSIONS

Postural body function measure with Locomotor Stages is reliable, sensitive and specific for gross motor function and able predict environmental performance. The clinical implications for therapists, physicians and researchers would be to understand the overall daily performance and make sensitive prognosis at any age from single motor patterns easily assessed in the therapy room. For research, Locomotor Stages is a reliably classification system, sensitive and specific for gross motor function, with assessing and prognostic properties, that also allow plotting typical development children and those with cerebral palsy.

Our hypothesis has been confirmed, since there are specific adaptations of the sagittal curves of the spine according to the gross motor function level. We found that basal and maintenance values of the sagittal lumbar spine are specific to every gross motor level in children with cerebral palsy. There is a specific postural control in the average and minimum values for the position between trunk and pelvis in the sagittal plane during gait, for the transition among GMFCS I-III levels. Higher classifications of gross motor skills correlate with more extended lumbar spine. In Children with cerebral palsy who cannot walk independently, the effect of development is reversed, flexing the trunk in relation to the pelvis.

Functional training of skills beyond the ontogenetic locomotor function, like walking ability on the upper limbs, seems to require also adaptations of the sagittal spinal curves. Artistic gymnastics seems to cause specific adaptations in postural hypolordosis, functional thoracic kyphosis and lumbar kyphotic attitude during sitting and trunk flexion. Training intensity did not influence the sagittal curvatures in artistic gymnastics; however, this sport seems to cause specific adaptations in postural hypolordosis, functional thoracic kyphosis and lumbar kyphotic attitude during sitting and trunk.

We can state that there is a relation between the human gross motor function and the sagittal curves of the spine, and this is valid for reduced development or increased locomotor skills.