Impacto del hallux limitus en la edad escolar

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Tesis doctoral UDC / 2023

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Programa de doctorado en Salud y Motricidad Humana RD/99/2011

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D. Israel Casado Hernández, Profesor Axudante Doutor, pertencente ao Departamento de Enfermaría da Universidad Complutense de Madrid, con docencia na Facultad de Enfermería, Fisioterapia y Podología e **D. Daniel López López,** Profesor Titular de Universidad (acreditado a Catedrático de Universidad), pertencente ao Departamento de Ciencias da Saúde da Universidade da Coruña, con docencia na Facultade de Enfermaría e Podoloxía.

Fan Constar que o presente proxecto de doutoramento de tese por **compendio de publicacións**, titulado "Impacto del hallux limitus en la edad escolar", que presenta a alumna Claudia Cuevas Martínez para optar ao título de Doutor/a con **Mención Internacional**, foi elaborada baixo a nosa dirección no programa de doutoramento Saúde e Motricidade Humana e reúne os requisitos de idoneidade e calidade científica necesarios para obter un informe FAVORABLE.

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Esta tesis se presenta en forma de compendio de artículos de investigación, cumpliendo formalmente los requisitos señalados en el artículo 41 del Reglamento de Estudios de Doctorado de la Universidade da Coruña.

De esta manera, se atienden las orientaciones generales recogidas en el presente documento compuesto por una introducción formada por una justificación razonada de la unidad, coherencia temática y metodología de la tesis en relación con los objetivos que se pretenden lograr, una discusión general que aporta coherencia temática de los distintos estudios realizados, conclusiones generales derivadas de los análisis y estudios realizados y bibliografía de las fuentes consultadas y utilizadas en el desarrollo de la tesis.

A continuación, se presentan las referencias de los tres artículos publicados en revistas indexadas en el *Journal Citations Reports* (JCR), base de datos de reconocido prestigio internacional.

Estudio I: Cuevas-Martínez, C.; Becerro-de-Bengoa-Vallejo, R.; Losa-Iglesias, M.E.; Casado-Hernández, I.; Turné-Cárceles, O.; Pérez-Palma, L.; Martiniano, J.; Gómez-Salgado, J.; López-López, D. Analysis of Static Plantar Pressures in School-Age Children with and without Functional Hallux Limitus: A Case-Control Study. *Bioengineering* 2023,10,628.

https://doi.org/10.3390/bioengineering10060628

[Q2; JCR Factor de impacto de 4.6 (2022)].

Estudio II: Cuevas-Martínez, C.; Becerro-de-Bengoa-Vallejo, R.; Losa-Iglesias, M.E.; Casado-Hernández, I.; Navarro-Flores, E.; Pérez-Palma, L.; Martiniano, J.; Gómez-Salgado, J.; López-López, D. Hallux Limitus Influence on Plantar Pressure Variations during the Gait Cycle: A Case-Control Study. *Bioengineering* 2023,10,772.

https://doi.org/10.3390/bioengineering10070772

[Q2; JCR Factor de impacto de 4.6 (2022)].

Estudio III: Cuevas-Martínez, C.; Becerro-de-Bengoa-Vallejo, R.; Losa-Iglesias, M.E.; Casado-Hernández, I.; Navarro-Flores, E.; Pérez-Palma, L.; Martiniano, J.; López-López, D; Gómez-Salgado, J. Assessment and indicators of hallux limitus related with quality of life and foot health in school children. Front Pediatr. 2023. Artículo Aceptado

[Q2; JCR Factor de impacto de 2.6 (2023)].

A mi madre y a mi marido Oriol,

por apoyarme y haber compartido este periodo.

1. Agradecimientos

Deseo expresar mi más profundo agradecimiento a todas las personas que han dedicado parte de su tiempo y horas de trabajo a la colaboración de esta tesis doctoral:

En primer lugar, mi más sincero agradecimiento al Doctor Daniel López López y al Doctor Israel Casado Hernández, directores de la presente memoria porque, indudablemente, sin su confianza e infinita ayuda no hubiera llegado hasta aquí. Sus enseñanzas sobre el trabajo en equipo han sido inspiradoras y han permitido que alcancemos el éxito de manera conjunta. A lo largo de este camino, me he sentido afortunada de contar con ellos como directores, ya que su dedicación y compromiso han sido ejemplares. Su pasión por la investigación y su capacidad para transmitir conocimiento han dejado una huella en mí que espero saber difundir en el futuro.

A la Doctora Laura Pérez Palma por confiar, desde hace años en mí y mi trabajo, abriéndome puertas que jamás hubiera encontrado sola y acompañándome. Por ser una excelente mentora. Su dedicación y compromiso con mi desarrollo profesional han dejado una huella imborrable en mi vida y en mi carrera.

Al Doctor João Martiniano por aceptarme como Doctoranda en el proyecto de internacionalización de mi tesis, acogerme, ayudarme a valorar los distintos caminos de la investigación y mostrarme una parte ínfima de sus extensos conocimientos.

A los coautores que han formado parte de mis artículos por participar en las distintas fases de revisión y conseguir su publicación.

A todo el equipo y compañeros del Departamento de Podología de la Universidad de Barcelona, por confiar, apoyarme y compartir la felicidad de las metas alcanzadas por cualquier miembro del equipo. A Ariadna por suplirme horas y horas en la consulta para poder dedicar más horas a la consecución de esta Tesis.

En especial, quiero dar mi más profunda gratitud a mi madre por estar siempre a mi lado, animarme a seguir siempre hacia delante para marcarme objetivos cada vez más ambiciosos. A mi marido, por su apoyo incondicional con este proyecto, haciéndoselo suyo también y estando siempre a mi lado. También a mis amigos, por comprender mi ausencia este tiempo y seguir ahí, apoyándome. También a los centros escolares; Col·legi Sant Miquel – Molins de Rei, Barcelona; Escola Vedruna – Malgrat de Mar, Barcelona; CEIP Los Pinos – Bicorp, Valencia y a los tutores legales de los participantes de otras poblaciones; Chella, Valencia; Molins de Rei, Barcelona y también a la dirección del Hospital Podològic Virginia Novel que me permitieron recoger medidas en sus instalaciones. Sin su participación voluntaria esto no hubiera sido posible.

En general, a todos los anteriormente comentados y muchos otros, les agradezco los ánimos, generosidad y apoyo incondicional. Sin duda, habéis contribuido de manera significativa a mi crecimiento tanto académico como personal.

2. Resúmenes

2.1 Resumen

Introducción: el hallux limitus funcional (HLF) es una afectación podológica que procede con una limitación del movimiento de dorsiflexión (DF) de la primera articulación metatarsofalángica (1 MTF) del pie en cadena cinética cerrada. El objetivo de esta tesis por compendio de artículos fue analizar la presión plantar en estática y dinámica de sujetos de edad infantil con y sin presencia de HLF y estudiar la calidad de vida relacionada con esta patología.

Métodos: se realizaron tres estudios de casos y controles. El primero evaluó el análisis estático de las presiones plantares, el segundo el análisis cinemático y el tercer estudio evaluó la calidad de vida mediante el *Foot Health Status Questionnaire* entre ambos grupos.

Resultados: en los tres estudios se observaron diferencias entre ambos grupos y en el tercero, se obtuvieron peores resultados en las dimensiones de la calidad de vida relacionada con la salud del pie en el grupo con presencia de la limitación funcional del hallux.

Conclusiones: los sujetos en edad escolar con presencia de HLF muestran diferencias en las presiones plantares tanto en estática como en dinámica, además de una peor calidad de vida en comparación a los individuos sin afectación funcional del hallux.

2.2 Resumo

Introdución: o Hallux Limitus funcional (HLF) é unha afectación podolóxica que procede cunha limitación do movemento de dorsiflexión (DF) da primeira articulación metatarsofalánxica (1 MTF) do pé nunha cadea cinética pechada. O obxectivo desta tese por compendio de artigos foi analizar a presión plantar estática e dinámica de suxeitos en idade infantil con e sen presenza de HLF e estudar a calidade de vida relacionada con esta patoloxía.

Métodos: realizáronse tres estudos de casos e controles. O primeiro avaliou a análise estática das presións plantares, o segundo a análise cinemático e o terceiro estudo avaliou a calidade de vida mediante o *Foot Health Status Questionnaire* entre ambos os grupos.

Resultados: nos tres estudos observáronse diferenzas entre os dous grupos e no terceiro obtivéronse peores resultados nas dimensións de calidade de vida relacionadas coa saúde dos pés no grupo con presenza de limitación funcional do hallux.

Conclusións: os suxeitos en idade escolar con presenza de HLF mostran diferenzas nas presións plantares tanto estáticas como dinámicas, así como unha peor calidade de vida en comparación cos individuos sen afectación funcional do hallux.

2.3 Abstract

Introduction: functional hallux limitus (FHL) is a podiatric affectation that proceeds with a limitation of the dorsiflexion (DF) movement of the first metatarsophalangeal joint (IMTJ) of the foot in closed kinetic chain. The aim of this thesis was to analyze the static and dynamic plantar pressure in children with and without FHL and to study the quality of life related to this pathology.

Methods: three case-control studies were performed. The first study evaluated the static analysis of pressure platform, the second one the dynamic analysis and the third study evaluated the quality of life by means of the Foot Health Status Questionnaire between both groups.

Results: differences between the two groups were observed in all three studies, and in the third, worse results were obtained in the dimensions of quality of life related to foot health in the group with the presence of functional limitation of the hallux.

Conclusions: school-aged subjects with the presence of FHL show differences in plantar pressures in both static and dynamic, in addition to a worse quality of life compared to individuals without functional hallux involvement.

3. Prólogo

Esta tesis doctoral bajo el título “Impacto del hallux limitus en edad escolar” muestra los resultados de una investigación que gira en torno a la presencia de hallux limitus funcional en población escolar y sus repercusiones baropodométricas y de calidad de vida.

Este trabajo se realizó con una estructura de compendio de artículos publicados en revistas que se encuentran indexadas en el *Journal Citations Reports* y desarrollando distintos aspectos del tema en común, el hallux limitus funcional en edad escolar. Con el fin de conocer cómo afecta esta patología en edad infantil en distintos momentos diarios, se dividió la muestra total de participantes en dos grupos de igual medida; uno con patología y otro sin ella.

En el primer artículo se estudió el análisis estático de las presiones plantares en sujetos con y sin presencia de la patología, centrándonos en las variables obtenidas por la plataforma de presiones T-Plate® con la que se tomaron todas las muestras en estática de un total de 106 sujetos. En el segundo, se realizó un estudio dinámico con la misma plataforma de presiones y se obtuvieron las variables específicas de 100 sujetos para esta medida. El tercero y último, evaluó la calidad de vida entre ambos grupos utilizando el *Foot Health Status Questionnaire* de una muestra total de 116 sujetos.

Cada artículo mostró un primer resultado respecto a los datos sociodemográficos de todos los individuos incluidos en cada estudio, que incluían edad (años), peso (kg), Altura (cm), índice de masa corporal (Kg/cm^2), sexo (niño/niña) y talla de calzado. También se incluyen resultados propios de cada investigación.

En esta obra se encontrará el desarrollo de los estudios de manera ordenada. En primer lugar, una introducción abrirá con el estado actual del tema principal para poner en contexto los elementos esenciales para este trabajo.

Seguidamente se expondrán la hipótesis de la investigación, los objetivos, material y métodos, resultados y las tablas y figuras necesarias para su comprensión donde queda patente la evidencia científica reflejada sobre el tema objeto de estudio.

Finalmente, se expondrá una discusión y conclusión común para los tres artículos.

4. Índice

5. Introducción

El hallux limitus funcional (HLF) se describe como la restricción de movimiento de dorsiflexión (DF) de la falange proximal del hallux respecto al primer metatarsiano, esto ocurre únicamente en cadena cinética cerrada y el rango de movimiento fisiológico se mantiene en cadena cinética abierta (1,2). El HLF se diagnostica clínicamente mediante el test validado para HLF descrito por Dananberg (3–5). El correcto movimiento de DF de la primera articulación metatarsofalángica (MTF) es necesario durante el ciclo de la marcha, en la fase de propulsión (4–7) por la acción del tercer *rocker* (8–10) con el fin de estabilizar el pie durante fase final de la marcha y para que la propulsión sea eficaz (11,12). La 1ª MTF soporta entre el 40% y 50% del peso corporal durante la fase final de la marcha, cuando la DF es fisiológica oscila entre los 50 y 90 grados (13–16). Cuando la DF se ve limitada, independientemente que la articulación se encuentre con o sin carga de peso, la patología se conoce como hallux limitus (HL) (11,12). Esta es la segunda causa de patología artrítica más frecuente en población adulta y su incidencia aumenta en función a la edad (13). En edad adulta, 1 de cada 40 personas mayores de 50 años presentan signos artríticos prematuros en el pie secundarias a esta limitación (13,17,18) pero también está presente en un 10% de la población con edades comprendidas entre 20 y 34 años (19). Cuando la limitación se agrava y el rango de movimiento está bloqueado, se afecta el plano sagital y es habitual que la patología degenere en un hallux rigidus (HR) o hallux valgus (HV) (9,19–21).

Las teorías del plano sagital fueron descritas por Dananberg, en ellas se describió que un bloqueo en cualquier articulación móvil genera compensaciones y, por lo tanto, patologías secundarias que pueden ser proximales o distales a la articulación bloqueada (22–24).

La limitación de la 1ª MTF es la más frecuente del plano sagital, como consecuencia de este bloqueo, se modifica la orientación del eje del primer radio (1R) y se provoca una alteración del movimiento causando mecanismos compensatorios. Además, se producirá un mayor gasto energético debido al mayor requerimiento muscular para mantener la estabilidad y avanzar el centro de masas (CDM) durante la marcha. En ocasiones se puede dañar el complejo músculo-ligamentoso por un incorrecto equilibrio de fuerzas (3,5,25,26).

Estas compensaciones secundarias pueden provocar sintomatología local como metatarsalgia y sesamoiditis, pero también sintomatología en distintos puntos corpóreos como por ejemplo el flexor largo del hallux en su recorrido retro maleolar, gonalgias o lumbalgias (27,28). Al modificar la posición del cuerpo y del CDM, las presiones plantares obtenidas por baropodometría también se ven alteradas respecto a los parámetros fisiológicos, aumentando o disminuyendo la presión plantar (10,27,29).

Las plataformas portátiles de presiones son dispositivos utilizados para evaluar la presión plantar durante la fase de apoyo de la marcha y puede realizarse en estática o dinámica. Estas plataformas se componen de sensores colocados en la superficie sobre la que se coloca el individuo, lo que permite medir las fuerzas de presión ejercidas por los pies (30).

Una alteración biomecánica resulta por una descompensación de las fuerzas reactivas del suelo (FRS). En el HL las fuerzas verticales de flexión plantar que actúan sobre la primera cabeza metatarsal (CMT) están desequilibradas con las fuerzas opuestas de DF, provocando una restricción del movimiento (5).

Durante la dinámica, en la población adulta se pueden observar distintas compensaciones secundarias a este bloqueo principal que afecta a la 1ª MTF. Se puede generar un adelanto del tronco para favorecer el avance del centro de gravedad (CDG) y reducir las FRS sobre la articulación afectada con el fin de agilizar el momento de propulsión disminuyendo los vectores de fuerza que actúan sobre ella, compensándolo con una hiperlordosis para mantener el CDM vertical. Además, una disminución del movimiento de extensión de la cadera genera una falta de contracción del músculo bíceps femoral, produciendo un bloqueo de la articulación sacroilíaca e hiperlordosis secundario a una activación muscular prolongada de los músculos psoas iliaco y cuadrado lumbar al no poder contrarrestar la acción de los músculos extensores de la cadera, provocando finalmente una elevación precoz del talón. También, durante el contacto inicial de la pierna en apoyo en la fase de marcha, la pierna estará en flexión para equilibrar la falta de extensión de la cadera (31,32). La disfunción del pie puede deteriorar la calidad de vida de las personas (20), siendo más frecuente la patología en antepié (33) y estando presente en un 70 - 80% de la población adulta y en un 30% en población pediátrica (34).

Estudios previos han concluido que, en población adulta, las presiones plantares entre sujetos con HL, HV y sanos, aquellos que presentaron restricción de movimiento de DF en la 1ª MTF mostraron un aumento de pico de presión debajo del hallux, dedos menores y 3ª - 4ª CMT (35); otros han relacionado el HL con una mayor tensión en la fascia plantar (12) y diversos estudios también con pies pronados o muy pronados debido a un desajuste biomecánico y estructural (7,36,37).

La calidad de vida del pie puede verse afectada por múltiples factores, incluida la presencia de patologías o características específicas. Para determinar la calidad de vida en la población general se desarrolló el *Foot Health Status Questionnaire* (FHSQ), un test que está validado y se utiliza para para evaluar la calidad de vida relacionada con la salud del pie (19,38), determinar el impacto que provoca en la salud una patología y comprobar su tratamiento, si se desea (39).

Existen varios estudios que utilizan el FHSQ para estudiar la calidad de vida en relación con determinadas patologías tanto del pie como otras enfermedades sistémicas en distintas edades (33,34,40,41).

6. Justificación

El HL es una patología que afecta al movimiento de la 1ª MTF, generando alteraciones biomecánicas a quien lo padece. Es habitual encontrarlo en población adulta, pero también tiene una relevancia significativa en población más joven, incluso en población infantil.

Su estudio y diagnóstico en edades tempranas es crucial para prevenir o minimizar las compensaciones secundarias y patologías posteriores más graves frecuentes en edad adulta como por ejemplo el HR o HV, patologías que afectan tanto a la biomecánica como a la calidad de vida de las personas.

Es una patología funcional que puede pasar desapercibida en edad infantil, no obstante, hay que tenerlo en cuenta en las exploraciones biomecánicas y tratarla para disminuir las implicaciones a largo plazo en la salud y función del pie.

La detección de HLF en edades tempranas puede permitir la continuidad de los estudios para determinar los tratamientos o cambios en el estilo de vida que puedan afectar favorablemente a esta patología. Es importante llevar a cabo exploraciones podológicas en edades tempranas aprovechando los colegios y visitas médicas pediátricas para establecer campañas de detección precoz de problemas biomecánicos que pueden suponer un empeoramiento temprano de la calidad de vida en los escolares que lo presentan.

El estudio del impacto de esta patología en edad escolar es novedoso y necesario, para comprender sus consecuencias, mejorar la atención médica a los pacientes y reducir las consecuencias de complicaciones médicas futuras.

El diagnóstico mediante una simple prueba clínica facilita mucho el diagnóstico temprano de esta patología disminuyendo actuaciones terapéuticas futuras invasivas y traumáticas. De manera que la actuación terapéutica temprana o el seguimiento y evolución de la patología se ve facilitada y al alcance de todos los podólogos y sanitarios.

Por ese motivo, se investigará sobre la limitación funcional del movimiento de DF de la 1ª MTF en sujetos en edad escolar.

Por todo lo mencionado hasta el momento, se planteó la siguiente pregunta de investigación: ¿Existe diferencia entre las presiones plantares en estática y dinámica entre sujetos con HLF en edad escolar?, ¿Afecta negativamente la presencia de HLF en la calidad de vida de sujetos en edad escolar?

7. Hipótesis

Esta es una tesis por compendio de artículos, de manera que se presentaron tres hipótesis principales:

La primera hipótesis (estudio I) que se presentó en esta investigación fue que los sujetos en edad escolar con HL tendrían un incremento de presiones plantares en estática.

La segunda hipótesis (estudio II) fue que los niños en edad escolar que presentaban HL generaban mayores presiones plantares bajo el hallux en dinámica, que los sujetos sin HL.

Finalmente, la tercera hipótesis (estudio III) fue que los niños en edad escolar con HL tenían una peor calidad de vida que los sujetos sin esta patología.

8. Objetivos

Para cada artículo de esta tesis por compendio de publicaciones, se determinó un objetivo que se asocia a:

8.1 Objetivos principales

El objetivo del primer estudio fue analizar la variación de la presión plantar estática en individuos en edad escolar con y sin HLF.

El objetivo del segundo estudio fue analizar la variación de la presión plantar en dinámica entre sujetos con HLF y sujetos sin HLF en edad escolar.

Finalmente, el objetivo del tercer estudio fue evaluar la calidad de vida en individuos en edad escolar con y sin HLF utilizando el FHSQ.

8.2 Objetivos secundarios

Los objetivos secundarios que se establecieron para esta tesis por compendio de artículos fueron:

- Estudios I-III: evaluar los datos sociodemográficos y descriptivos cuantitativos de los pacientes diagnosticados de HLF, controles sanos y muestra total (edad, peso, altura, índice de masa corporal (IMC), sexo y talla de calzado).

- Estudio I: determinar las mediciones de los resultados obtenidos por plataforma de presión de los sujetos diagnosticados de HL, los controles sanos emparejados y la muestra total. Incluyendo superficie de apoyo de antepié (AP) y retropié (RP) bilateral (cm^2), fuerza de AP y RP bilateral (%), distribución de AP y RP bilateral (%), área total del pie izquierdo y derecho (cm^2), presión plantar máxima del pie izquierdo y derecho (kPa), fuerza del pie izquierdo y derecho (%).
- Estudio II: analizar el área de apoyo del pie izquierdo y derecho (cm^2), presión máxima en pie izquierdo y derecho (kPa), presión media en pie izquierdo y derecho (kPa), porcentaje de sujetos que presentan punto de máximo apoyo en: hallux, primera CMT, segunda CMT, tercera y cuarta CMT, quinta CMT-mediopie y RP izquierdo y derecho (%).
- Estudio I y II: comparar las presiones plantares en estática (estudio I) y dinámica (estudio II) entre los pacientes con y sin HLF.
- Estudio III: identificar la relación entre los sujetos con y sin HLF y los resultados del FHSQ para salud general del pie y los valores generales de salud.

9. Material y métodos

9.1 Diseño y muestra

Para llevar a cabo esta tesis por compendio de artículos se llevaron a cabo tres estudios de casos y controles entre los meses de enero de 2022 y febrero de 2023, período donde se recogieron los parámetros estáticos y dinámicos con una plataforma de presiones portátil y los resultados del FHSQ.

Para los tres estudios, se reclutaron a los participantes en múltiples centros de diferentes lugares de España y se realizó de forma consecutiva y a conveniencia siguiendo el mismo protocolo y utilizando la misma plataforma de presiones para los estudios I y II.

Los tres estudios cumplieron las directrices previstas *en "Strengthening the Reporting of Observational Studies in Epidemiology"* (STROBE) (42).

El estudio I evaluó las presiones plantares en estática de sujetos en edad escolar con y sin HLF. El estudio II analizó variaciones en las presiones plantares en dinámica de sujetos con y sin HLF en edad escolar. Finalmente, el estudio III evaluó los resultados obtenidos del FHSQ de sujetos en edad escolar con y sin HLF.

Para los tres estudios los criterios de inclusión comunes fueron: 1) edad comprendida entre 6 y 12 años, 2) sujetos sanos sin enfermedades musculoesqueléticas ni neurológicas; 3) sujetos sin intervención quirúrgica en las extremidades inferiores; 4) participantes con y sin HLF 5) haber dado su consentimiento y que sus padres o tutores hubieran firmado el formulario de consentimiento informado.

Los criterios de inclusión específicos para el estudio III fueron; 1) participantes con pies flexibles; 2) padres o tutores legales e hijos que aceptaron participar en la investigación.

Para los tres estudios los criterios de exclusión comunes fueron: 1) Sujetos menores de 6 años o mayores de 12 años; 2) síndrome de hipermovilidad; 3) tener un valor angular inferior a 10º de flexión del tobillo y de la 1ª MTF con la rodilla en extensión; 4) sujetos con lesiones musculoesqueléticas o trastornos neurológicos; 5) sujetos que rechazaron las directrices para participar en el estudio o no tener la documentación legal firmada por los padres o tutores.

Para el estudio I los criterios de exclusión específicos fueron los siguientes: 1) tener antecedentes ortopédicos que afecten a una o ambas extremidades inferiores; 2) tener patologías reumáticas.

Para el estudio II los criterios de exclusión específicos fueron: 1) sujetos que hubieran sufrido algún dolor o trastorno significativo en los pies; 2) sujetos bajo tratamiento médico que pudiera afectar a la adquisición de datos.

Para el estudio III los criterios de exclusión específicos fueron los siguientes: 1) pacientes bajo tratamiento con cualquier medicación que pudiera afectar a los resultados finales.

Los participantes incluidos en los estudios cumplieron los criterios de inclusión y exclusión determinados con anterioridad y firmaron, previa lectura y respuesta de dudas si las surgiese, la documentación necesaria para completar la fase de inclusión. La documentación es la siguiente: presentación del investigador principal, hoja de información del estudio, compromiso del investigador principal, hoja de consentimiento informado para el estudio, cuestionario de Inclusión de pacientes, documento de protección de datos y FHSQ.

9.1.1 Cálculo del tamaño muestral

Para calcular el tamaño de la muestra de los tres estudios, se aplicaron los niveles específicos de confianza, potencia y grupos de igual tamaño utilizando el software Epidat versión 4.2 (*Consellería de Sanidade, Xunta de Galicia*, España; Organización Panamericana de la Salud (OPS-OMS); Universidad CES, Colombia).

Para lograr la confianza estadística se estableció una potencia estadística del 80% con un error β de 20%, un error α de 0.05 y una prueba de dos colas.

Para el primer estudio se incluyó una muestra total de 106 niños en edad de 6-12 año divididos en dos grupos de 53 sujetos cada uno. Para el segundo artículo se incluyó una muestra de 100 niños divididos en dos grupos de 50 sujetos cada uno con edades comprendidas entre los 7 y los 12 años. En el tercer artículo se incluyó una muestra total de 116 niños del mismo rango de edad que el primero, divididos en dos grupos de 58 sujetos.

En los tres artículos, la clasificación de la muestra fue en función de la presencia o no de limitación funcional de la 1ª MTF.

9.2 Procedimiento

Para confirmar que los pacientes que se presentaron para participar en el estudio no presentaban limitación de la DF de tobillo, se llevó a cabo la medición del paciente descalzo en sedestación y con la rodilla extendida. Para ello, el investigador colocó la articulación subtalar en posición de neutralidad y realizó una DF de la articulación tibioperoneo-astragalina (43). Si esta DF era mayor de 10º el paciente fue incluido en el estudio, si por el contrario la DF era menor a 10º el paciente quedó excluido del estudio. Para descartar la presencia de HR, con la misma maniobra de neutralidad de la articulación subtalar, se realizó DF de la 1ª MTF la cual debía tener un rango de movimiento superior a 10º para ser incluidos en el estudio. La comprobación de estas mediciones se llevó a cabo con un goniómetro de brazos (8).

Una vez se seleccionó a los sujetos que cumplían los criterios de inclusión para el estudio, se llevó a cabo el test para HLF descrito por Dananberg (1) para clasificarlos en su correspondiente grupo en función de si presentaban o no la patología de estudio. Con el paciente en sedestación o en decúbito supino, el investigador colocó la articulación tibioperoneo-astragalina en posición neutra y a continuación, con la mano pasiva colocó su pulgar debajo de la 1ª CMT del pie a explorar. Con la mano activa generó una fuerza dorsal de la falange proximal del primer dedo para realizar una DF de la 1ª MTF.

Cuando la fuerza aplicada por ambas manos en sus consiguientes localizaciones era similar y permitía una DF de la 1ª MTF, flexión plantar (PF) de la 1ª CMT, pronación del AP, supinación del retropié RP y la activación del mecanismo de windlass (movimientos necesarios para una propulsión eficaz y no lesiva), se consideró una prueba negativa (HLF -). En un pie con HLF, las fuerzas aplicadas no están equilibradas, siendo superiores las necesarias para realizar la DF del 1ª MTF que la aplicada en la 1ª CMT, representó una prueba HLF positiva (HLF +).

Para la obtención de los datos se utilizó un ordenador portátil conectado mediante un puerto USB a una plataforma de presiones T-Plate® (Herbitas, Foios, Valencia) compatible con Windows. Esta plataforma de presiones dispone de Certificado de la Comunidad Europea y un sistema de auto calibrado. Las características de la ficha técnicas se especifican en la Tabla 1. Los datos estáticos y dinámicos fueron obtenidos por el mismo clínico.

Tabla 1 Especificaciones técnicas de la plataforma de presiones T-Plate®. Fuente propia.

Especificaciones	**Descripción**
Dimensiones (largo/ancho/alto)	610 x 580 x 10 mm
Peso	2 Kg
Tipo de sensor	Resistivo (autocalibrables)
Superficie activa	400 x 400 mm
Dimensiones del sensor	10 x 10 mm
Número de sensores	1600
Rango de presión por sensor	0,4 N/m^2 (0.0004 kPa) a 100 N/m^2 (0.1 kPa)
Temperatura de funcionamiento	0ºC - 60ºC
Frecuencia de Muestreo	60 Hz
Alimentación	Universal Serial Bus (USB)
Requerimientos del sistema operativo	Windows XP, Vista, Windows 7, 8 y 10

Para la evaluación de la medición en estática, cada participante permaneció descalzo sobre la plataforma de presiones plantares, en posición relajada, posición recta, mirando al frente y con los brazos a los lados del tronco (Figura 1). Las mediciones plantares del pie se recogieron simultáneamente para ambos pies y cada prueba tenía una duración de 30 segundos. Si el participante se movía durante la prueba, se descartaban los datos y se repetía el proceso.

Figura 1 Sujeto en bipedestación y posición relajada durante la toma de muestras en estática con la plataforma de presiones. Fuente propia.

Para la evaluación dinámica, cada sujeto caminó descalzo sobre la plataforma de forma relajada. Si el sujeto realizaba algún movimiento de forma alterada durante la adquisición de datos, se descartaban los datos finales y se repetía de nuevo el ensayo. Si el sujeto se mostraba incómodo o inquieto, también se descartaban los datos.

Este proceso se repitió hasta que el sujeto reprodujo una marcha relajada y cómoda.

Figura 2 Sujeto en dinámica durante la toma de muestras del estudio II con la plataforma de presiones. Fuente propia.

Las medidas en estática tomadas para el estudio I, registraron las siguientes variables incluidas en la Figura 3: superficie de apoyo de AP y RP del pie izquierdo y derecho (medida en cm^2), porcentaje de fuerza de AP y RP del pie izquierdo y derecho, porcentaje de distribución de AP y RP del pie izquierdo y derecho, área total del pie izquierdo y derecho (medida en cm^2), presión plantar máxima del pie izquierdo y derecho (medida en kPa), fuerza del pie izquierdo y derecho (medida en %) y peso de cada pie (Kg).

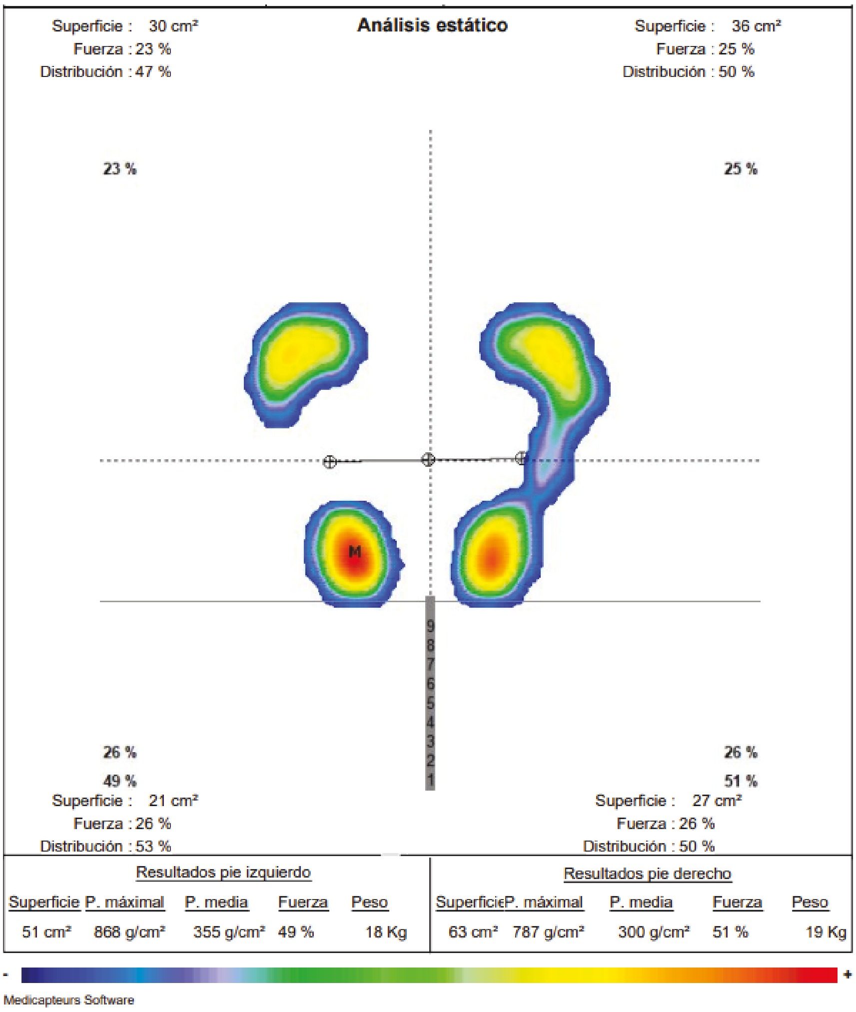

Figura 3 Variables obtenidas con el estudio estático en plataforma de presiones. Fuente propia.

Para evaluar los patrones dinámicos de la marcha de los sujetos incluidos en el estudio II se obtuvieron las siguientes variables (Figura 4): área de apoyo del pie izquierdo y derecho (medida en cm^2), presión máxima en pie izquierdo y derecho (medida en kPa), presión media en pie izquierdo y derecho (medida en kPa).

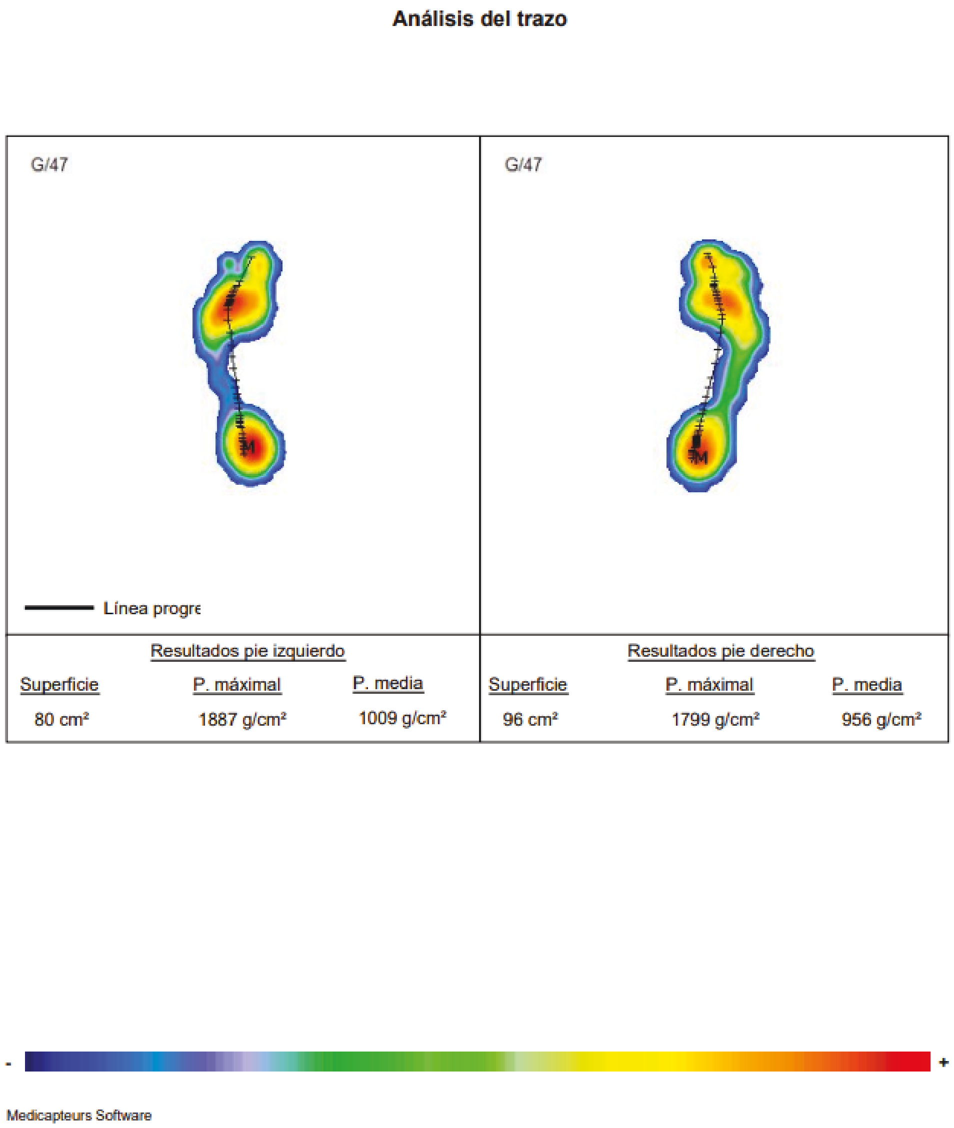

Figura 4 Variables que ofrece la plataforma de presiones en el análisis dinámico. Fuente propia.

El clínico también dividió cada pie en siete regiones como se observa en la Figura 5 para determinar la localización de la presión máxima en dinámica de cada sujeto obtenida con la plataforma T-Plate®.

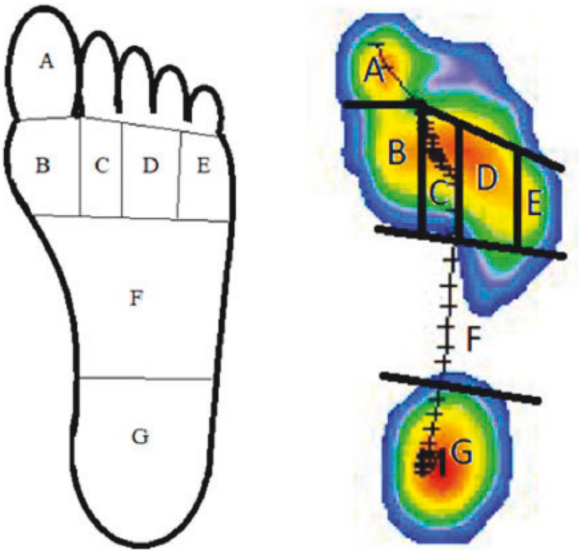

Figura 5 División del pie en siete regiones: hallux (A), primera CMT (B), segunda CMT (C), tercera y cuarta CMT (D), quinta CMT (E), mediopie (F) y RP (G). Fuente propia.

Para el estudio de la calidad de vida relacionada con la presencia de HLF (estudio III) se utilizó el FHSQ. Esta herramienta autoadministrada se desarrolló para evaluar la calidad de vida relacionada con la salud del pie y se compone de varias subescalas que abordan diferentes aspectos de la salud y funcionalidad del pie (44) respecto a dolor, función, calzado y salud del pie general.

La obtención de los datos del FHSQ se realizó introduciendo la puntuación que cada individuo seleccionó previamente cuando se le entregó la documentación legal y el FHSQ. A continuación, se introdujo cada pregunta específica en un programa informático especial *(The Foot Health Status Questionnaire*, Versión 1.03), que transforma las puntuaciones brutas y las suma en secciones. Las puntuaciones oscilan entre 0 y 100, siendo 0 el peor valor y 100 el mejor.

Además, el programa proporciona representaciones gráficas de los resultados (39,44). Para facilitar la respuesta y adaptarla a los participantes en este estudio, el FHSQ se tradujo al español.

Las medidas de resultado para los sujetos diagnosticados de HLF y los controles sanos emparejados incluyeron dolor en el pie, función del pie, calzado, salud general del pie, salud general, función física, capacidad social y vigor.

9.3 Aspectos éticos y legales

Este Proyecto de Investigación obtuvo el informe favorable del Comité de Bioética de la Universidad de Barcelona el 21 de diciembre de 2021 (IRB00003099). Todas las acciones cumplieron la normativa vigente de experimentación humana, así como la Declaración de Helsinki y la Ley Orgánica 3/2018 de 5 de diciembre, de protección de datos personales y garantía de los derechos digitales (45).

9.4 Análisis estadístico

Los análisis estadísticos para los tres estudios se efectuaron con el programa *Statistical Package for the Social Sciences* (SPSS, versión 19.0). Los datos paramétricos se describieron como media, desviación estándar (DE) y rango de los valores mínimo a máximo. La normalidad se comprobó con la prueba de *Kolmogorov-Smirnov* en las variables estudiadas ($p > 0,05$) en los datos sobre las presiones estáticas. Se utilizaron pruebas *t-test* para las variables de resultado que se distribuían normalmente. Se realizó la prueba no paramétrica *"U" de Mann-Whitney* para considerar los contrastes entre los dos grupos con o sin HLF.

En todos los análisis, se consideró estadísticamente significativa una $p < 0,05$ y con un intervalo de confianza del 95%.

Para el análisis de los datos del FHSQ (estudio III), se utilizó el programa informático llamado "*The Foot Health Status Questionnaire*, Versión 1.03" para obtener los resultados correspondientes a cada dimensión vinculadas a la calidad de vida relacionada con la salud del pie.

10. Resultados

10.1 Estudio I

De los 106 participantes reclutados, 53 fueron diagnosticados de HLF y los 53 restantes fueron clasificados como controles sanos. La muestra estaba compuesta por 55 niños y 51 niñas. Las edades de los participantes oscilaban entre los seis y los doce años.

10.1.1 Datos sociodemográficos y descriptivos

No se obtuvieron resultados significativos al estudiar los datos sociodemográficos (Tabla 2) pero sí hubo diferencia en las edades entre ambos grupos de estudio con un p-valor de 0.031. También se observó una diferencia con un p-valor de 0.099 para la talla de calzado.

Tabla 2 Datos sociodemográficos de la muestra total de los sujetos incluidos en este estudio, sujetos con HLF y sujetos sanos.

Características de la muestra	Grupo total (n=106) Media ± DE (rango)	HLF (n=53) Media ± DE (rango)	Sanos (n=53) Media ± DE (rango)	p-Valor
Edad (años)	9.47 ± 1.501 (6 - 12)	9.81 ± 1.27 (8- 12)	9.13 ± 1.64 (6 - 12)	0.031†
Peso (Kg)	36.38 ± 11.31 (17.95- 90.00)	36.69 ± 8.50 (22.00 - 56.60)	36.98 ± 13.63 (17.95- 90.00)	0.542†
Altura (cm)	140.14 ± 11.44 (113.00– 176.00)	141.26 ± 9.50 (121.00 – 167.00)	139.02 ± 13.10 (113.00 – 176.00)	0.231†
IMC (kg/m^2)	18.50 ± 3.91 (11.00 - 40.00)	18.11 ± 2.81 (14.00 - 25.00)	18.89 ± 4.77 (11.00 - 40.00)	0.729†
Sexo (niño/niña)	55/51 (51.9/48.1)	23/30 (43.4/56.6)	32/21 (60.4/39.6)	0.120‡
Talla de calzado	35.63 ± 3.58 (15.00 - 44.0)	36.18 ± 2.38 (30.0 - 43.0)	35.09 ± 4.42 (15.00 - 44.0)	0.099†

Abreviaturas: kg, kilogramo; cm, centímetro; m^2, metro cuadrado; %, porcentaje; DE, desviación estándar; n, número; †, prueba U de Mann-Whitney; ‡, prueba exacta de Fisher. En todos los análisis, p < 0,05 (con un intervalo de confianza del 95%) se consideró estadísticamente significativo.

10.1.2 Medidas de resultados primarios

En la Tabla 3 se presentan las medidas de resultado primarias de los sujetos diagnosticados de HLF, los controles sanos emparejados y la muestra total. Los resultados de la presión plantar estática no indicaron diferencias significativas entre los grupos, pero sí un ligero aumento de presión en el pie izquierdo entre ambos grupos.

No se encontraron diferencias estadísticamente significativas entre los grupos en la superficie bilateral del antepié y retropié, fuerzas reactivas del suelo bilateral del antepié y retropié, distribución del peso corporal en el antepié y el retropié bilaterales, la superficie total izquierda y derecha, la presión máxima del pie izquierdo y derecho, presión media del pie izquierdo y derecho, fuerzas de reacción del pie izquierdo y del pie derecho, y el peso de cada pie.

Tabla 3 Mediciones de los resultados en sujetos diagnosticados de HLF, controles sanos emparejados y la muestra total.

Datos cuantitativos descriptivos	**Grupo total (n=106) Media ± DE (rango)**	**HLF (n=53) Media ± DE (rango)**	**Sanos (n=53) Media ± DE (rango)**	**p-Valor**
Superficie AP izquierdo (cm^2)	31.36 ± 10.83 (6 – 66)	31.85 ± 9.39 (14 – 64)	30.87 ± 12.17 (6 – 66)	0.450†
Superficie AP derecho (cm^2)	30.08 ± 12.33 (0 – 76)	30.06 ± 11.54 (8 – 76)	30.11 ± 13.18 (0 – 66)	0.889†
Superficie RP izquierdo (cm^2)	32.46 ± 10.04 (17 – 70)	32.66 ± 9.49 (17 – 55)	32.26 ± 10.65 (19 – 70)	0.565†
Superficie RP derecho (cm^2)	29.95 ± 10.51 (12 – 64)	29.11 ± 8.77 (15 – 49)	30.79 ± 12.03 (12 – 64)	0.697†
Fuerza AP izquierdo (%)	20.17 ± 7.12 (3 - 46)	20.58 ± 6.50 (7 - 39)	19.75 ± 7.72 (3 - 46)	0.360†
Fuerza AP derecho (%)	18.33 ± 6.80 (0 – 38)	17.81 ± 6.20 (5 – 38)	18.85 ± 7.37 (0 – 33)	0.233†
Fuerza RP izquierdo (%)	33.50 ± 8.49 (17 – 63)	33.42 ± 7.49 (17 – 51)	33.58 ± 9.45 (17 – 63)	0.907†
Fuerza RP derecho (%)	27.98 ± 7.07 (6 – 48)	28.27 ± 6.46 (15.00 – 42)	27.70 ± 7.69 (6 – 48)	0.716†
Distribución AP izquierdo (%)	37.79 ± 12.41 (5 – 72)	38.19 ± 11.25 (15 – 66)	37.40 ± 13.57 (5 – 72)	0.704†

Distribución AP derecho (%)	39.40 ± 13.77 (0 – 79)	38.47 ± 11.79 (12 – 71)	40.32 ± 15.56 (0 – 79)	0.349†
Distribución RP izquierdo (%)	62.21 ± 12.41 (28 – 95)	61.81 ± 11.25 (34 – 85)	62.60 ± 13.57 (28 – 95)	0.704†
Distribución RP derecho (%)	59.75 ± 14.80 (7 – 100)	59.66 ± 14.21 (7 – 88)	59.85 ± 15.50 (21 – 100)	0.752†
Superficie pie izquierdo (cm^2)	64.10 ± 18.87 (26 - 136)	64.89 ± 15.92 (31 – 91)	63.32 ± 21.55 (26 – 136)	0.321†
Superficie pie derecho (cm^2)	60.13 ± 20.33 (14– 130)	59.17 ± 17.11 (32 – 107)	61.09 ± 23.24 (14 – 130)	0.899†
Presión plantar máxima izquierdo (kPa)	813.63 ± 212.67 (73 – 1357)	816.19 ± 184.59 (360.10 – 1357)	811.06 ± 239.25 (73 – 1217)	0.830†
Presión plantar máxima derecho (kPa)	754.59 ± 185.56 (332.42 – 1424.00)	783.28 ± 183.47 (484.40– 1357.00)	725.91 ± 184.89 (332.42– 1424.00)	0.129†
Presión plantar media izquierdo (kPa)	314.88 ± 64.80 (146.00 – 506.00)	314.50 ± 60.15 (182.50 – 506.00)	315.26 ± 69.72 (146 – 463.00)	0.691†
Presión plantar media derecho (kPa)	323.21 ± 333.54 (151.00 – 3671.00)	294.21 ± 57.25 (191 – 437)	352.21 ± 468.67 (151.00 – 3671.00)	0.793†
Fuerza izquierdo (%)	53.81 ± 6.72 (34.00 – 70.00)	54.08 ± 6.37 (42 – 70)	53.55 ± 7.10 (34.00 – 69.00)	0.628†
Fuerza derecho (%)	46.28 ± 6.72 (30 – 66)	45.92 ± 6.37 (30 – 58)	46.64 ± 7.09 (31 – 66)	0.498†
Peso izquierdo (Kg)	19.76± 6.25 (9 - 44)	19.96 ± 5.60 (9 - 31)	19.57 ± 6.89 (11 - 44)	0.350†
Peso derecho (Kg)	17.11 ± 6.29 (6 – 46)	16.83 ± 4.63 (9 – 26)	17.40 ± 7.62 (6 – 46)	0.730†

Abreviaturas: kPa, kilopascales; Kg, kilogramo; cm, centímetro; cm^2, centímetro cuadrado; % Porcentaje; DE, desviación estándar; N, número; †, prueba U de Mann-Whitney. En todos los análisis, P < 0,05 (con un intervalo de confianza del 95%) se consideró estadísticamente significativo.

10.2 Estudio II

Se seleccionó una muestra total de 100 sujetos con una edad entre siete y doce años y una DE media de 9,62 ± 1,37 años. De los 100 sujetos incluidos 50 presentaron HL y los restantes constituyeron el grupo de control. La muestra completa estaba integrada por 50 sujetos de sexo masculino y 50 de sexo femenino.

10.2.1 Datos sociodemográficos y descriptivos

Los resultados cuantitativos sociodemográficos, antropométricos y descriptivos se muestran en la Tabla 4, incluyendo edad, peso, altura, IMC, sexo y talla de calzado.

Tabla 4 Datos sociodemográficos y descriptivos cuantitativos de pacientes diagnosticados de HLF, controles sanos y muestra total.

Características de la muestra	**Grupo total (n=100) Media ± DE (rango)**	**HLF (n=50) Media ± DE (rango)**	**Sanos (n=50) Media ± DE (rango)**	**p-Valor**
Edad (años)	9.62 ± 1.37 (7 - 12)	9.68 ± 1.29 (7- 12)	9.56 ± 1.46 (7 - 12)	0.607†
Peso (Kg)	37.84 ± 11.04 (20.50- 90.00)	37.12 ± 8.53 (23.30 - 56.60)	38.57 ± 13.13 (20.50- 90.00)	0.809†
Altura (cm)	140.37 ± 10.75 (118.0– 176.00)	140.10 ± 9.54 (121.00 – 167.00)	140.64 ± 11.92 (118.00 – 176.00)	0.885†
IMC (kg/m^2)	18.83 ± 3.68 (11.00 - 40.00)	18.64 ± 2.68 (14.00 - 25.00)	19.02 ± 4.48 (11.00 - 40.00)	0.803†
Sexo (niño/niña)	50/50 (50.0/50.0)	22/28 (44.0/56.0)	28/22 (56.0/44.0)	0.317‡
Talla de calzado	35.99 ± 2.67 (28.00 - 43.0)	36.09 ± 2.20 (31.0 - 43.0)	35.88 ± 3.08 (28.00 - 42.0)	0.665†

Abreviaturas: Kg, Kilogramo; Cm, Centímetro; m2, Metro cuadrado; % Porcentaje; DE, Desviación estándar; N, Número; †, prueba U de Mann-Whitney; ‡, prueba exacta de Fisher. En todos los análisis, P < 0,05 (con un intervalo de confianza del 95%) se consideró estadísticamente significativo.

10.2.2 Medidas de resultados primarios

Según los resultados obtenidos en la Tabla 5, la variable del peso corporal en la 3ª y 4ª CMT mostró un resultado significativo con un p-valor de 0.031. La mayor incidencia de esta localización se encontró en los sujetos sanos.

El aumento de apoyo en el talón también obtuvo resultados significativos con un p-valor de 0.023, indicando una mayor incidencia en los sujetos con HLF.

El resto de las variables no mostraron diferencias significativas, no obstante, el siguiente valor cercano al <0.05 fue un p-valor de 0.127, aunque no se encontró una diferencia estadísticamente significativa indica que puede existir una tendencia hacia una mayor presión en el hallux en sujetos con HLF.

Tabla 5 Principales resultados medidos para el grupo de control, los sujetos con HL y grupo total.

Variables	Grupo total (n=100) Media ± DE (rango)	HLF (n=50) Media ± DE (rango)	Sanos (n=50) Media ± DE (rango)	p-Valor
Superficie izquierda (cm^2)	88.59 ± 19.63 (37– 141)	89.54 ± 18.12 (51 – 127)	87.64 ± 21.17 (37 – 141)	0.634†
Superficie derecha (cm^2)	89.72 ± 19.99 (29 – 135)	90.38 ± 19.58 (44 – 125)	89.06.11 ± 20.57 (29 – 135)	0.796†
Pico máximo de presión izquierdo (kPa)	1792.72 ± 479.28 (17.0 – 3566.0)	1789.92 ± 308.41 (1160 – 2503)	1795.51 ± 307.43 (17 – 3566)	0.751†
Pico máximo de presión derecho (kPa)	1757.88 ± 482.93 (12 – 3854)	1759.10 ± 366.86 (262 – 2616)	1756.66 ± 580.19 (12 – 64)	0.697†
Pico medio de presión izquierdo (kPa)	1089.47 ± 862.36 (46 -9310)	1162.89 ± 1188.17 (716 - 9310)	1016.06 ± 282.42 (46 - 1945)	0.560†
Pico medio de presión derecho (kPa)	1000.88 ± 237.94 (24 – 1906)	1002.08 ± 180.93 (683 – 1516)	999.69 ± 285.74 (24 – 1906)	0.890†
Peso corporal en el primer dedo (izquierdo/derecho) (%)	11/14 (11.0/14.0)	10/8 (20.0/16.0)	1/6 (2.0/12.0)	0.127‡
Peso corporal en 1ª CMT (izquierdo/derecho) (%)	9/7 (9.0/7.0)	8/5 (16.0/10.0)	1/2 (2.0/4.00)	0.354‡
Peso corporal en 2ª CMT (izquierdo/derecho) (%)	11/23 (11.0/23.0)	4/12 (8.0/24.0)	7/11 (14.0/22.0)	0.156‡
Peso corporal en 3ª y 4ª CMT (izquierdo/derecho) (%)	37/22 (37.0/22.0)	11/7 (22.0/14.0)	26/15 (52.0/30.0)	0.031‡
Peso corporal en 5ª CMT (izquierdo/derecho) (%)	1/1 (1.0/1.0)	0/0 (0.0/0.00)	1/2 (2.0/4.00)	1.325‡
Peso corporal en mediopie (izquierdo/derecho) (%)	0/1 (0.0/1.0)	0/0 (0.00/0.00)	0/1 (0.00/2.00)	1.432‡
Peso corporal en talón (izquierdo/derecho) (%)	31/31 (31.0/31.0)	17/18 (34.0/36.0)	14/13 (28.0/26.0)	0.023‡

Abreviaturas: kPa, kilopascales; Kg, kilogramo; cm, centímetro; cm2, centímetro cuadrado; % Porcentaje; DE, desviación estándar; N, número; †, prueba U de Mann-Whitney; ‡, prueba exacta de Fisher. En todos los análisis, P <,05 (con un intervalo de confianza del 95%) se consideró estadísticamente significativo.

10.3 Estudio III

De los 116 participantes seleccionados para este estudio, un total de 58 fueron diagnosticados de HLF y otros 58 resultaron sanos. La muestra total estaba compuesta por 54 niños y 62 niñas de edades comprendidas entre los seis y los doce años con una media y DE de 9.55 y 1.54 respectivamente.

10.3.1 Datos sociodemográficos y descriptivos

La presencia o ausencia de HLF no parece estar relacionada de manera significativa con el peso, la altura, el IMC, el sexo o la talla de calzado en la muestra de estudio.

Tabla 6 Datos sociodemográficos y descriptivos cuantitativos de pacientes diagnosticados de HLF, controles sanos y muestra total.

Características de la muestra	Grupo total (n=116) Media ± DE (rango)	HLF (n=58) Media ± DE (rango)	Sanos (n=58) Media ± DE (rango)	p-Valor
Edad (años)	9.55 ± 1.54 (6 - 12)	9.72 ± 1.36 (7- 12)	9.38 ± 1.69 (6 - 12)	0.302†
Peso (Kg)	36.73 ± 11.40 (17.95 - 90.00)	36.72 ± 9.53 (20.00 - 66.00)	36.74 ± 13.09 (17.95 - 90.00)	0.515†
Altura (cm)	140.64 ± 11.03 (113.0– 176.00)	140.90 ± 9.78 (120.00 – 167.00)	140.40 ± 12.22 (113.00 – 176.00)	0.730†
IMC (kg/m^2)	18.29 ± 4.01 (11.00 - 40.00)	18.21 ± 3.26 (14.00 - 30.00)	18.38 ± 4.67 (11.00 - 40.00)	0.764†
Sexo (niño/niña)	54/62 (46.6/53.4)	24/34 (41.4/58.6)	30/28 (51.7/48.3)	0.264‡
Talla de calzado	35.86 ± 3.35 (15.00 - 43.0)	36.22 ± 2.34 (30.0 - 43.0)	35.50 ± 4.11 (15.00 - 42.0)	0.418†

Abreviaturas: Kg, Kilogramo; Cm, Centímetro; m2, Metro cuadrado; % Porcentaje; DE, Desviación estándar; N, Número; †, prueba U de Mann-Whitney; ‡, prueba exacta de Fisher. En todos los análisis, P < 0,05 (con un intervalo de confianza del 95%) se consideró estadísticamente significativo.

10.3.2 Medidas de resultados primarios

La Tabla 7 muestra la relación entre las muestras de población estudiadas y los resultados del FHSQ obtenidos para cada dominio. La primera sección (A) agrupa los resultados específicos del pie, dolor, función, salud y calzado, mientras que la segunda sección (B) agrupa los valores generales de salud, como salud general, función física, capacidad social y vigor.

Se encontró una diferencia significativa respecto a la salud general del pie en los sujetos con HLF, ya que el p-valor obtenido fue de 0,024. Esto indica que existe una relación entre la presencia del HLF y una peor salud general del pie.

Por otro lado, al evaluar la funcionalidad del pie entre ambos grupos, se obtuvo un valor no significativo con un p-valor de 0,098. Es decir que se observó un peor valor para los sujetos con HLF en comparación con aquellos sin el trastorno.

No se encontraron diferencias estadísticamente significativas entre los grupos de estudio en el resto de los resultados específicos del pie (dolor, función y calzado) ni en los valores de salud general (salud general, función física, capacidad social y vigor).

En cuanto a la comparación de los grupos que se evaluaron en la siguiente tabla, los resultados sugieren que los sujetos con HLF tuvieron puntuaciones medias más bajas en los cuatro dominios evaluados (dolor, función, salud y calzado), en comparación con el otro grupo sin la patología. Además, los sujetos con HLF presentaron puntuaciones medias más bajas en salud general y función física.

En cambio, se obtuvieron puntuaciones más altas en competencia social y vigor, en comparación con el grupo sano.

Tabla 7 La relación entre los pacientes con HLF positivo y negativo y las puntuaciones del FHSQ.

	Grupo total (n=116) Media ± DE (rango)	HLF (n=58) Media ± DE (rango)	Sanos (n=58) Media ± DE (rango)	p-Valor
Dolor de pie	90.26 ± 16.15 (10.00 -100)	88.15 ± 17.99 (10.00 -100)	92.37 ± 13.90 (10.00 -100)	0.285†
Funcionalidad del pie	94.02 ± 12.62 (43.75 -100)	92.56 ± 14.22 (43.75 -100)	95.47 ± 10.72 (43.75 -100)	0.098†
Calzado	60.42 ± 17.68 (8.33 -75)	58.48 ± 18.37 (16.67 -75.00)	62.36 ± 16.90 (8.33 -75)	0.285†
Salud general del pie	78.45 ± 21.07 (25 -100)	73.14 ± 23.87 (25-100)	83.75 ± 16.43 (25 -100)	0.024†
Salud general	84.91 ± 18.90 (30-100)	84.31 ± 17.58 (30-100)	85.52 ± 20.28 (30-100)	0.255†
Función física	94.88 ± 11.88 (22.22 -100)	94.44 ± 10.96 (55.56 -100)	95.31 ± 12.82 (22.22 -100)	0.254†
Capacidad social	93.32 ± 14.03 (25 -100)	94.61 ± 13.87 (25 -100)	92.03 ± 14.18 (37.50 -100)	0.186†
Vigor	78.40 ± 17.30 (25 -100)	79.53 ± 16.79 (25 -100)	77.26 ± 17.86 (37.50 -100)	0.515†

Abreviaturas: DE, desviación estándar; N, número; †, prueba U de Mann-Whitney; ‡, prueba exacta de Fisher. En todos los análisis, $P < 0,05$ (con un intervalo de confianza del 95%) se consideró estadísticamente significativo.

11. Discusión

En base a la revisión del estado del arte y a la vista de los resultados obtenidos, esta es la primera investigación en relacionar la presencia de HLF en edad escolar con las medidas tomadas con una plataforma de presiones tanto en estática como en dinámica y también en relacionarla con la calidad de vida y la salud del pie en este rango de edad de 6 a 12 años. No obstante, la herramienta de investigación utilizada para el estudio III, el FHSQ, sí fue utilizado en otra ocasión por López-López y cols. (34) para estudiar la calidad de vida relacionada con la altura del arco del pie en edades comprendidas entre los 6 y 12 años.

Estudios previos realizados por distintos autores como Gatt y cols. (37), Gerbert (11), Okamura y cols. (36) y Merker y cols. (7) son relevantes por su asociación entre la pronación del pie y la limitación del rango de DF de la 1ª MTF en dinámica y en sujetos adultos, aumentando la incidencia de limitación y la falta de funcionalidad del pie y activación del mecanismo de windlass cuanto mayor fuese la pronación. En cambio, Akino y cols. indican que la hiperpronación no siempre afecta a una mala activación del mecanismo de windlass dado que la función musculesquelética puede ser correcta, independientemente de un movimiento insuficiente de la 1ª MTF (46).

Hay muy poco consenso entre autores respecto a la etiología, causa y tratamiento del HL (13,29,47–50) pero todos están de acuerdo en que la etiología del HL es multifactorial (18,51–54).

En el estudio I, los sujetos se encontraban en estática y no se observaron cambios significativos en las presiones plantares, superficies ni fuerzas. De manera que, si hay una relación entre ambos conceptos, no se puede concluir que en estática se mantenga. No obstante, se obtuvieron datos discretamente superiores en el pie izquierdo entre los grupos.

Halstead y cols. concluyeron que el rango de DF pasiva de hallux sin carga de peso y en posición relajada era la misma que durante la dinámica (55). Sin embargo, Durrant y cols. concluyeron en su investigación que el rango de movimiento de la 1ª MTF en estática es mayor que en dinámica (5), por lo que las mediciones estáticas pueden no ser una buena evaluación para determinar la funcionalidad del pie en patologías dinámicas.

Durrant y cols. (5) concluyeron en su estudio con sujetos en edad escolar, que las FRS que actúan en el pie son menores en situaciones de bajo peso del sujeto de estudio, siendo dificultoso que la plataforma de presiones capture los kPa necesarios para obtener resultados e imágenes precisas en sujetos de menor edad y peso. Agostini y cols. (56) también consideran como un factor clave para su estudio la plataforma de presiones. Al tratarse de sujetos en edad escolar y por lo tanto de bajo peso (Agostini usó una muestra con edades comprendidas entre 6 y 7 años), puede ser que los sensores no obtuvieran toda la información habitual en cada toma de muestra debido a la disminución de las FRS. Visscher y cols. (57) concluyeron en sus estudios que los métodos de identificación clínica comúnmente utilizados durante los estudios biomecánicos que utilizaban una plataforma de presión eran a menudo subjetivos y requerían mucho tiempo.

En esta investigación el sistema de valoración con plataforma de presiones resultó un sistema fiable (30), se observaron diferencias en los datos sociodemográficos cuantitativos en relación con la edad, el número de calzado, la altura y el peso entre los grupos de sujetos con HLF y los sujetos sanos. No obstante, debido a la plataforma utilizada durante este estudio, hubo datos como la velocidad que no se pudieron obtener y hubieran sido muy interesantes para comparar la velocidad en el momento de propulsión entre ambos grupos.

Al estudiar las presiones plantares en estática no se obtuvieron resultados significativos para los valores objeto de estudio incluidos en la Tabla 2. Esto podría estar relacionado con alteraciones de la movilidad articular del pie y alteraciones posturales en sujetos con HLF.

Debido a que el HLF es una limitación funcional y aparece en cadena cinética cerrada, el estudio en dinámica de las presiones plantares se consideró esencial y fue el siguiente que se llevó a cabo durante esta investigación (estudio II).

Varios autores realizaron sus investigaciones basándose en el ciclo de la marcha y determinaron que caminar es una actividad compleja e inconsciente que se adquiere con el desarrollo. Gibson y cols. indicaron que es un hito que se adquiere (58) y Samson y cols. indican que los cambios biomecánicos de la dinámica articular se producen a la edad de 4 años en la articulación del tobillo, y en la articulación de la rodilla y de la cadera entre los 6 y 7 años, respectivamente (59).

La marcha se realiza de forma automática y no requiere un pensamiento consciente en cada paso. El cuerpo aprende y se adapta a este patrón de movimiento a través de la experiencia y la práctica, lo que permite a las personas desarrollar, interactuar y participar en actividades cotidianas (58,60,61).

Ito y cols. y Samson y cols. (59,60) determinaron que, en individuos sanos, estos parámetros se comienzan a estabilizar entre los 5 y los 7 años. Esto sugiere que a medida que los niños crecen y ganan experiencia caminando, los patrones de movimiento se vuelven más consistentes y se estabilizan. Con el fin de tener en cuenta la estabilización de los parámetros biomecánicos articulares y reducir el sesgo debido a la inmadurez dinámica, los investigadores del presente estudio decidieron que los sujetos que participarían deberían tener edades comprendidas entre los 6 y los 12 años. Al seleccionar a niños en este rango de edad, se busca que la marcha ya esté integrada como una actividad inconsciente, lo que ayuda a tener resultados más consistentes y representativos.

Beurskens y cols. (62) demostraron que en los niños que consciente o inconscientemente realizan tareas duales durante la dinámica, la velocidad de la marcha, la longitud de la zancada y la cadencia pueden verse reducidas. Por lo tanto, la variabilidad puede aumentar durante las mediciones de la presión de la plataforma en los niños. Para el actual estudio II, no se realizaron tareas duales mientras se recogían las mediciones en la plataforma de presiones, pero podría ser que los voluntarios estuvieran distraídos por un impulso incontrolado o inadvertido.

Bryant y cols. (35) estudiaron y compararon las presiones plantares de sujetos adultos con HL, HV y sujetos con un rango articular de la 1ª MTF fisiológico. En sus resultados obtenidos, apreciaron un mayor pico de presión debajo de la primera, segunda y tercera CMT en pies no patológicos. En cambio, una mayor presión debajo del hallux, tercera, cuarta y quinta CMT en sujetos con afectación de la 1ª MTF. Sin embargo, en la presente investigación se obtuvieron cambios donde se pudo sugerir que los sujetos en edad escolar con HLF mostraban un mayor pico de presión debajo del hallux y la 1ª MTF. También se obtuvieron resultados significativos que indicaron que los sujetos sanos presentaban un mayor pico de presión debajo de la tercera y cuarta CMT, además de una mayor presión en RP del grupo con HLF.

El estudio desarrollado por Findlow y cols. (63) determinó que los pies más flexibles presentaban un mayor movimiento de eversión de talón y un arco medial bajo. Estos pies flexibles mostraron una mayor diferencia cinemática en el AP debido a la medialización del avance de las FRS provocada por la eversión de AP que genera una DF del primer metatarsiano, transmitiendo las FRS al segundo metatarsiano y generando una mayor presión sobre éste y también sobre el tercer metatarsiano. Por otro lado, los pies supinados lateralizan el avance de las FRS. En el momento en que el AP contacta con el suelo, el quinto metatarsiano puede DF de manera limitada, a consecuencia, el AP caerá hacia medial generando un movimiento de PF del primer metatarsiano, factor que favorecerá la DF de la 1ª MTF. Este movimiento generará un mecanismo de windlass más eficaz en pies con cargas lateralizadas.

Para explicar la propulsión, Bojsen Moller (64) dividió el pie en dos ejes; uno transversal y otro oblicuo. El primero lo compone la primera y segunda CMT y el segundo la tercera, cuarta y quinta CMT. Cuando el avance de las FRS se produce medial al eje del pie debido a una medialización de cargas, se produce un bloqueo de la columna medial del pie actuando como una palanca rígida y generando un momento de propulsión correcto. Cuando las FRS avanzan lateralizadas, este bloqueo no se lleva a cabo, resultando un pie flexible e inestable que genera una propulsión por el eje oblicuo y como resultado, una marcha apropulsiva. Cuando las cargas están lateralizadas, puede ser a consecuencia de la transmisión de cargas hacia lateral provocadas por una limitación de la 1ª MTF.

Otros autores como Roukis y cols. (65) relacionaron como una disfunción del 1R (hipermovilidad o insuficiencia) podía lateralizar las FRS aumentando de esa manera las presiones bajo los metatarsianos menores. Menz y cols. (8) relacionaron que, aunque hubiera disfunción de la 1ª MTF, si ésta era asintomática, las cargas no se lateralizaban y se producía un pico de presión debajo del hallux. En cambio, si era sintomática la marcha antiálgica lateralizaba el avance de las FRS, generando hiperpresiones laterales.

Esto puede dar respuesta a los resultados obtenidos en el estudio actual, dado que la limitación funcional estudiada en los niños no produce dolor, es poco probable que la marcha antiálgica que puede producirse en adultos con HL se reproduzca en pacientes en edad escolar con HL.

Bryant y cols. en su estudio, dividieron el pie en diez regiones para clasificar y diferenciar los picos de presión en cada una de ellas en pies sanos, con HL y HR (35). En esta investigación, en cambio, se dividió el pie en siete regiones tal y como se observa en la Figura 5 ya que parecía más apropiado para niños con, en su mayoría, pies pequeños y sería difícil diferenciar entre la tercera y cuarta CMT y los dedos menores.

Los trastornos del AP pueden llegar a deteriorar la calidad de vida de los sujetos que lo padecen, incluso disminuyendo la independencia y capacidad de realizar actividades físicas diarias. Para determinar cómo afecta la presencia de la patología de estudio en población escolar se utilizó el FHSQ.

Otros autores concluyeron en sus estudios que patologías como el HV en edad adulta influían negativamente en la calidad de vida de los sujetos incluidos en sus estudios (66,67). En la presente investigación, se pudo establecer una relación entre la salud general del pie y la función del pie, observando peores resultados en los sujetos que presentaban HLF en comparación a los sujetos sanos. Por lo tanto, se sugirió que podría haber una tendencia hacia una asociación entre el HLF en la edad escolar y consecuencias en la salud general y funcional del pie a medida que los individuos envejecen.

Rodríguez-Sanz y cols. (68) concluyeron que, en edades entre los 18 y 30 años, la calidad de vida en relación con la patología del pie empeora, principalmente en el sexo femenino. Palomo-López y cols. (40) obtuvieron resultados significativos en relación con el calzado al estudiar la calidad de vida del pie en individuos adultos (18-35 años).

López-López y cols. (34) estudiaron la calidad de vida en sujetos de edad escolar comprendida entre los 6 y los 12 años con un arco interno elevado y concluyeron que era un factor negativo. Sin embargo, ni el peso ni el sexo presentaron una relación significativa entre estas dos características estudiadas por los autores. Del mismo modo que en esta investigación, se determinó que no existe relación significativa entre los datos cuantitativos sociodemográficos y descriptivos obtenidos entre ambos grupos de estudio, tales como edad (años), peso (kg), altura (cm), IMC (kg/m2), sexo (masculino/femenino) y talla de calzado.

Sánchez-Gómez y cols. (4) también estudiaron los signos y síntomas del HLF en población adulta, concluyendo que el callo en pellizco o *pinch callus* (localizado en la zona medial del hallux) es el más prevalente en esta población. Sin embargo, esta característica no fue incluida para valorar en el estudio III, dado que, al tratarse de sujetos en edad escolar, los sujetos con HLF no se encontraban en un estadio avanzado de afectación y la piel, aún inmadura en la mayoría de los sujetos, todavía no había generado hiperqueratosis. Por otro lado, se observaron los mecanismos compensatorios determinados por Payne y cols. (3), como la excesiva pronación tardía del medio tarso, el despegue precoz del talón, el *abductory twist* o la hiperextensión de la rodilla durante la propulsión.

González-Martín y cols. (69) realizaron un estudio en el que encontraron resultados significativos en distintas áreas del FHSQ, pero especialmente en lo que respecta al calzado y la salud general del pie. Los pacientes sin HV obtuvieron resultados más altos en comparación con los pacientes que sí tenían HV, cuyos resultados fueron claramente más bajos.

Por otro lado, Gilheany y cols. (19) también llevaron a cabo un estudio mediante el FHSQ en pacientes adultos que padecían HV y HR, los cuales eran candidatos para someterse a una cirugía para tratar la patología. El cuestionario se cumplimentó antes y después de la cirugía. Las puntuaciones en HV fueron bajas y en los sujetos con HR fueron todavía más inferiores, destacando que cuanto más avanzada y estructurada es la limitación en el pie, mayor es la diferencia significativa en los resultados del FHSQ.

Esto sugiere que a medida que la alteración funcional del pie progresa hacia una etapa más severa y estructurada, es más probable que se observen diferencias significativas en la calidad de vida relacionada con la salud del pie. Por lo tanto, en el presente estudio puede suponer que los pies que desarrollan patología en edades tempranas pueden tener consecuencias a largo plazo, afectando negativamente la calidad de vida en etapas posteriores.

El uso del FHSQ como herramienta de trabajo para estudiar las afecciones de los pies sin marcada afectación o discapacidad parece ser apropiado según lo indicado por Landorf y cols. (39). Esto sugiere que el cuestionario es útil para evaluar la calidad de vida relacionada con los pies en sujetos en edad escolar con y sin HLF.

En relación con la hipótesis inicial del estudio I, no se mostraron diferencias estadísticamente significativas entre las presiones plantares estáticas en niños en edad escolar con y sin HLF. Sin embargo, al observar las imágenes obtenidas en la plataforma de presiones, los individuos de mayor edad y peso mostraron una menor superficie de contacto en AP y mayor presión debajo del hallux en individuos con HLF. En los sujetos sin HLF, la superficie de apoyo del AP era más amplia y difusa. No obstante, estos resultados no son significativos, de manera que no son válidos. Quizá porque las edades y los pesos de los participantes eran dispersos debido a la amplitud de características de los individuos analizados.

En cuanto a la investigación del estudio II, se afirma que el método de evaluación mediante plataforma de presiones obtuvo resultados positivos como instrumento para la evaluación cuantitativa de HL en niños en edad escolar. Se obtuvieron resultados significativos para las variables peso corporal en la 3ª y 4ª CMT, con una mayor incidencia en los sujetos sanos. En cambio, los sujeto con HLF mostraban un aumento de apoyo en talón. El resto de los resultados, sugieren que puede existir una tendencia hacia una mayor presión en el hallux en sujetos con HLF, pero no son válidos.

El estudio III encontró una diferencia significativa respecto a la salud general del pie en los sujetos con HLF y concluyó que existe una relación directa entre la presencia del HLF y una peor salud general del pie.

Además, se observó un peor valor al evaluar la funcionalidad del pie para los sujetos con HLF en comparación con aquellos sin el trastorno. Es posible que en la etapa de desarrollo de los sujetos en que se realizó la investigación, los cambios funcionales en el pie no hayan alcanzado un nivel de gravedad que resulte en mayores diferencias significativas en los resultados del FHSQ.

Aunque existen varios estudios y revisiones relacionados con la postura del pie y la presión plantar en adultos (70–72), actualmente existe una cantidad limitada de investigaciones sobre las patologías que afectan a la población en edad escolar y las alteraciones biomecánicas secundarias, así como las anomalías en las presiones plantares estáticas (73) y patologías posteriores que ayuden a evitar compensaciones biomecánicas perjudiciales a largo plazo.

Es esencial investigar más en esta área para entender mejor cómo prevenir las compensaciones biomecánicas perjudiciales en etapas tempranas y evitar problemas de salud en el futuro.

La calidad y precisión de los resultados pueden verse afectadas por diversos factores, como la edad de los participantes, la configuración de la plataforma de presiones, la altura de los sujetos y otros posibles factores. Además, el método de muestreo consecutivo utilizado en el estudio podría considerarse aleatorio en futuras investigaciones para obtener resultados más representativos.

Esta investigación se llevó a cabo en una población escolar de entre 6 y 12 años y no se tuvieron en cuenta los cambios en la etapa puberal entre los sexos, especialmente el femenino.

En cuanto a la presente investigación, se afirma que este método de evaluación mediante plataforma de presiones obtuvo resultados positivos como instrumento para la evaluación cuantitativa del HL en niños en edad escolar durante la dinámica.

La autoevaluación realizada por los pacientes junto con sus tutores legales puede generar cierta variabilidad en las respuestas, especialmente debido a la corta edad de los sujetos estudiados. Además, ciertas preguntas del FHSQ pueden conducir a una puntuación poco fiable, lo que puede plantear dudas sobre su aplicación en pacientes pediátricos. No obstante, al estar científicamente validado, los resultados obtenidos se consideran uniformes y concretos, lo que proporciona una base sólida para el análisis de la calidad de vida relacionada con los pies en los sujetos estudiados.

En futuras investigaciones, debería tenerse en cuenta las limitaciones comentadas anteriormente y acotar las características de cada grupo para que los resultados no fuesen tan dispares debido al amplio rango de edad como se ha comentado durante esta investigación. También sería interesante realizar un seguimiento a largo plazo de los sujetos incluidos en estos estudios para evaluar cómo los resultados evolucionan con el tiempo y cómo varía la distribución de carga en estática y dinámica. También evaluar su calidad de vida en etapas posteriores de la vida.

12. Conclusions

In the images visualized and obtained individually in study I, changes were observed in the location of the maximum pressure, especially in the older participants with the presence of FHL, which was located below the hallux. However, although these changes are relevant, the results obtained in the study were not significant enough to draw valid conclusions but suggest changes between the study groups.

The dynamic baropodometry used for study II is a useful tool in biomechanical studies because it facilitates the identification of gait abnormalities. School-aged subjects with FHL during gait show higher mean plantar pressure at the heel and lower mean plantar pressure at the third and fourth metatarsal heads compared to healthy children studied.

There is a relationship between foot health and FHL in children, as demonstrated in study III. In this study, significant results were obtained related to overall foot health being worse in subjects with FHL. In addition, changes were observed in the outcomes studied between both groups, with lower scores being obtained in the foot-specific outcome sections (pain, function, health and footwear) or in the general health values (global health and physical function) for subjects with the presence of FHL. However, in the remaining general health values (social ability and vigor) slightly lower scores were observed in the healthy subjects.

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14. Actividad y producción científica

14.1 Publicaciones en revistas en *Journal Citations Reports*

- Cuevas-Martínez, C.; Becerro-de-Bengoa-Vallejo, R.; Losa-Iglesias, M.E.; Casado-Hernández, I.; Turné-Cárceles, O.; Pérez-Palma, L.; Martiniano, J.; Gómez-Salgado, J.; López-López, D. Analysis of Static Plantar Pressures in School-Age Children with and without Functional Hallux Limitus: A Case-Control Study. Bioengineering 2023,10,628. https://doi.org/10.3390/bioengineering10060628

- Cuevas-Martínez, C.; Becerro-de-Bengoa-Vallejo, R.; Losa-Iglesias, M.E.; Casado-Hernández, I.; Navarro-Flores, E.; Pérez-Palma, L.; Martiniano, J.; Gómez-Salgado, J.; López-López, D. Hallux Limitus Influence on Plantar Pressure Variations during the Gait Cycle: A Case-Control Study. Bioengineering 2023,10,772. https://doi.org/10.3390/bioengineering10070772

- Cuevas-Martínez, C.; Becerro-de-Bengoa-Vallejo, R.; Losa-Iglesias, M.E.; Casado-Hernández, I.; Navarro-Flores, E.; Pérez-Palma, L.; Martiniano, J.; López-López, D; Gómez-Salgado, J. Assessment and indicators of hallux limitus related with quality of life and foot health in school children. Front Pediatr. 2023. Artículo Aceptado

14.2 Estancias Internacionales

Estancia predoctoral durante el periodo comprendido entre el 14 de enero al 15 de abril de 2023 en la Escola Superior de Saúde da Cruz Vermelha Portuguesa (Lisboa, Portugal).

14.3 Asistencias a cursos

- Curso-taller "Predeterminación del tamaño muestral en estudios biomédicos". Universidade da Coruña. Online. 2 horas. Septiembre 2022.
- Curso "Actualización en dermatoscopia-onicoscopía como herramienta para el diagnóstico de la patología cutánea del pie". Colegio Oficial de Podólgos de Cataluña. Barcelona. 4 horas. Febrero 2022.
- Curso "tendinopatías en Podología: Tendón de Aquiles y Fascia Plantar". Colegio Oficial de Podólogos de Cataluña. Barcelona. 3 horas. Mayo 2022.
- Curso "Calzado infantil". Colegio Oficial de Podólogos de Cataluña. Barcelona. 4 horas. Diciembre 2022.
- Revisión sistemática da literatura e análise bibliométrica con VOSViewer. CUFIE. Universidade da Coruña. Online. 12 horas. Enero 2023.
- Curso "Principales alteraciones de la marcha infantil". Colegio Oficial de Podólgos de Cataluña. Barcelona. 12 horas. Enero 2023.
- Recursos para a xestión da investigación. CUFIE. Universidade da Coruña. Online. 12 horas. Febrero 2023.
- 'Garanties ètiques de la recerca: preparació d'un projecte per ser presentat a la Comissió de Bioètica de la Universitat de Barcelona o un CEIm'. Universidad de Barcelona. 3 horas. Junio 2023.

- BLS (Basic Life Support), 08013 Barcelona.Junio 2023.
- 'Preparant-nos per a Moodle 4: noves maneres d'ensenyar'. Universidad de Barcelona. Barcelona. 4 horas. Julio 2023.
- Podologia Infantil: Del pie plano infantil al pie cavo. Colegio Oficial de Podólgos de Cataluña. Barcelona. 12 horas. Septiembre 2023.

14.4 Asistencias a congresos

- 52 congreso Nacional de Podología. Consejo General de Colegios Oficiales de Podólogos de España. Barcelona. 2023.
- 51 congreso Nacional de Podología. Consejo General de Colegios Oficiales de Podólogos de España. Valencia. 2022.
- Jornadas Catalanas de Podologia. Colegio Oficial de Podólgos de Cataluña. Barcelona. 2022.

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Analysis of Static Plantar Pressures in School-Age Children with and without Functional Hallux Limitus: A Case-Control Study

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Abstract: Background: The presence of hallux limitus in adulthood is frequently encountered in clinical practice, generating other biomechanical, structural, and functional compensations in dynamics secondary to blockage of the main pivot in the sagittal plane, the first metatarsophalangeal joint. In addition, the presence of functional hallux limitus (FHL) in school-age children is also increasing. Currently, there is a lack of scientific literature about this condition in the pediatric population, and early diagnosis is necessary to reduce future biomechanical disorders and avoid the development of foot arthritis. The purpose of this research was to identify static plantar pressures in school-age children with and without hallux limitus. Methods: A total sample of 106 children aged between six and twelve years old was divided into two groups: the case group (53 subjects with functional hallux limitus) and the control group (53 subjects without functional hallux limitus). Data were acquired with the participants in a standing barefoot position on the pressure platform, and the hallux limitus functional test was performed in a sitting position to classify the individuals into the determined study group. The variables analyzed in the research were: plantar pressure, bilateral forefoot and rearfoot surface area, bilateral forefoot and rearfoot ground reaction forces, bilateral forefoot and rearfoot distribution of body weight, total left and right surface area, maximum pressure of the left foot and right foot, medium pressure of the left foot and right foot, ground reaction forces of the left foot and right foot, and the weight of each foot. Results: Age was the only descriptive quantitative variable that showed a significant difference between the two study groups, with a p-value of 0.031. No statistically significant differences were found between groups in the bilateral forefoot and rearfoot surface area, ground reaction forces, distribution of body weight, or maximum and medium plantar pressure in the left and right foot. Conclusions: Changes in the location of the maximum pressure were observed, particularly in older participants with FHL, but these results were not significant. The findings of this study did not show significant differences between the static plantar pressures of school-age individuals with and without functional hallux limitus.

Keywords: static; plantar pressure; foot pressure; children; hallux limitus

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Citation: Cuevas-Martínez, C.; Becerro-de-Bengoa-Vallejo, R.; Losa-Iglesias, M.E.; Casado-Hernández, I.; Turné-Cárceles, O.; Pérez-Palma, L.; Martiniano, J.; Gómez-Salgado, J.; López-López, D. Analysis of Static Plantar Pressures in School-Age Children with and without Functional Hallux Limitus: A Case-Control Study. *Bioengineering* **2023**, *10*, 628. https://doi.org/10.3390/bioengineering10060628

Academic Editor: Massimiliano Pau

Received: 11 April 2023
Revised: 18 May 2023
Accepted: 22 May 2023
Published: 23 May 2023

1. Introduction

Dorsiflexion (DF) limitation in the movement of the first metatarsophalangeal joint (MTPJ) is defined as hallux limitus (HL) [1,2]. HL is a common foot disorder suffered by the adult population, and it is characterized by an increase in incidence with age [3]. In addition, HL is the second most common cause of pathology related to the first ray and is characterized by a build-up of peak plantar pressure in the hallux instead of the first metatarsal head, which is greater and occurs at a faster rate [4,5]. One of the main biomechanical characteristics of HL is the first MTPJ blockage in the sagittal plane [6]. This foot disorder is one of the main causes of the premature development of foot arthritis, which occurs in 1 in 40 subjects over the age of 50 [3,7,8]. The first MTPJ plays a fundamental role in gait patterns [9], specifically in the terminal stance and pre-swing gait phases. When the center of gravity is changing to propel the body forward, the first MTPJ has to provide suitable dorsiflexion, which is necessary to generate the correct moment of propulsion [2,10,11]. The correct first MTPJ range of motion (ROM) is between 50° and 90°, and as a result, the joint has to support from 40% to 60% of the body weight [3,12–14].

Previous studies correlated a limitation of the first MTPJ dorsiflexion movement with pronated or very pronated foot development because of biomechanical maladjustment and structural blockage that decrease movement [1,15–17] accompanied by an incorrect windlass mechanism [2].

According to previous research, there is a significant correlation between subjects who have developed HL and plantar fascia tightness. Subjects whose extension of the hallux is decreased usually present higher tension in the plantar fascia compared to subjects without HL [2].

This limitation prior to the development of HL is called functional hallux limitus (FHL) [18], which can be diagnosed clinically in the pediatric population [11,19,20]. The movement of FHL is restricted in a closed kinetic chain [21] and is characterized by limitations in the movement of the first MTPJ in the dynamic gait stage [17].

Portable pressure platforms are devices used to evaluate plantar pressure in stance and dynamic gait patterns with high reliability in the data collected, which is more reliable in subjects in stance situations than in different gait phases due to variability in dynamic gait [22].

However, to the best of our knowledge, there are no previous studies to determine the surface area, average peak pressure, and body weight of the lower limbs regarding this foot pathology in the pediatric population.

The purpose of this research was to analyze the static plantar pressure variation in school-age individuals with and without functional hallux limitus.

Our hypothesis was that school-age subjects with hallux limitus would have increased plantar pressures.

2. Material and Methods

2.1. Study Design

A case-control study was developed between January 2022 and February 2023. The recruitment of the participants was carried out in multiple centers in different places in Spain and was performed consecutively and conveniently using the same protocol and platform.

This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [23]. This case-control study assessed the static plantar pressures in school-age children with and without functional hallux limitus.

This research was approved by the Bioethics Committee of the University of Barcelona on 21 December 2021, with ID: IRB00003099. It complied with all current regulations on human experimentation, as well as the Declaration of Helsinki and Organic Law 3/2018, of 5 December, on the protection of personal data and the guarantee of digital rights [24].

All the subjects were previously screened by an expert podiatrist with 10 years' experience. For this study, the following inclusion criteria were met: (1) to be healthy subjects without musculoskeletal or neurological diseases; (2) to be without foot disorders and with functional hallux limitus; (3) to be more than 4 years old and less than 12 years old; and (4) to have given their assent and whose parents or guardians had signed the informed consent form. The exclusion criteria were: (1) to have hypermobility syndrome; (2) to have a neurological disease; (3) to have previous orthopedic history affecting one or both lower extremities; (4) to have rheumatic pathologies; (5) to have a first MTPJ angular value of less than 10° with ankle flexion and less than 10° with the knee in extension; (6) to be older than 12; and (7) to refuse to participate and have the consent form signed by their parents or guardians. FHL was evaluated by an expert podiatrist with more than 10 years' experience. For diagnostic purposes, FHL was defined as restricted movement in the first MYPJ in a closed kinetic chain [21], and this pathology was diagnosed by performing the FHL test [18].

To calculate the sample size, the specific levels of confidence, power, and groups of equal size were applied using Epidat version 4.2 software (Consellería de Sanidade, Xunta de Galicia, Spain; Pan American Health Organization (PAHO-WHO); University CES, Colombia). To accomplish this with statistical confidence, an 80% statistical power analysis with a β error of 20%, an α error of 0.05, and a two-tailed test were required. A total sample size of 106 children aged between six and twelve years was included in the study. The subjects were divided into two groups: 53 with FHL and 53 healthy subjects.

2.2. Method

The functional hallux limitus test was performed with the patient in a sitting or supine position, and the investigator applied force below the first metatarsal head (MTH) with the passive and active hands, performing a DF of the proximal phalanx of the first toe. When there was no limitation, the force applied under the first MTH was approximately the same as used to perform the DF of the proximal phalanx, which allows a DF of the first MTPJ, plantar flexion (PF) of the first MTH, pronation of the forefoot (FF), supination of the rearfoot (RF), and activation of the windlass mechanism, a series of movements necessary for effective and non-injurious propulsion, which was considered a negative test (HLF -). In a foot with HLF, the applied forces were not balanced, being greater than that necessary to perform the DF of the first MTPJ than that applied under the first MTH [18], and represented a positive HLF test (HLF +).

Data acquisition was performed using a laptop linked via USB to a portable pressure platform. The commercially available software program T-Plate® for Windows was used to collect and manage the data. Autocalibration was performed before each use. The static plantar pressure was measured by the same clinician.

The outcome measurements for subjects diagnosed with functional hallux limitus and healthy matched-paired controls included static plantar measurements: plantar pressure, bilateral forefoot and rearfoot contact surfaces, bilateral forefoot and rearfoot ground reaction forces, bilateral forefoot and rearfoot distribution of body weight, total left and right surface area, maximum pressure of the left foot and right foot, medium pressure of the left foot and right foot, ground reaction forces of the left foot and right foot, and the weight of each foot (Figure 1).

During the static plantar pressure measurement assessment, the participant was standing barefoot on the plantar pressure platform in a relaxed position with the arms at the sides of the trunk. The plantar foot measurements were simultaneously collected for both feet. If the participant moved during testing, the data were discarded and the trial was repeated.

Three static analyses of each participant were performed in order to have a more reliable and representative result. The total time for each data acquisition of the subject in a static position was 30 s. If any analysis was very dispersed, it was classified as an outlier, and a new analysis was performed on the participant.

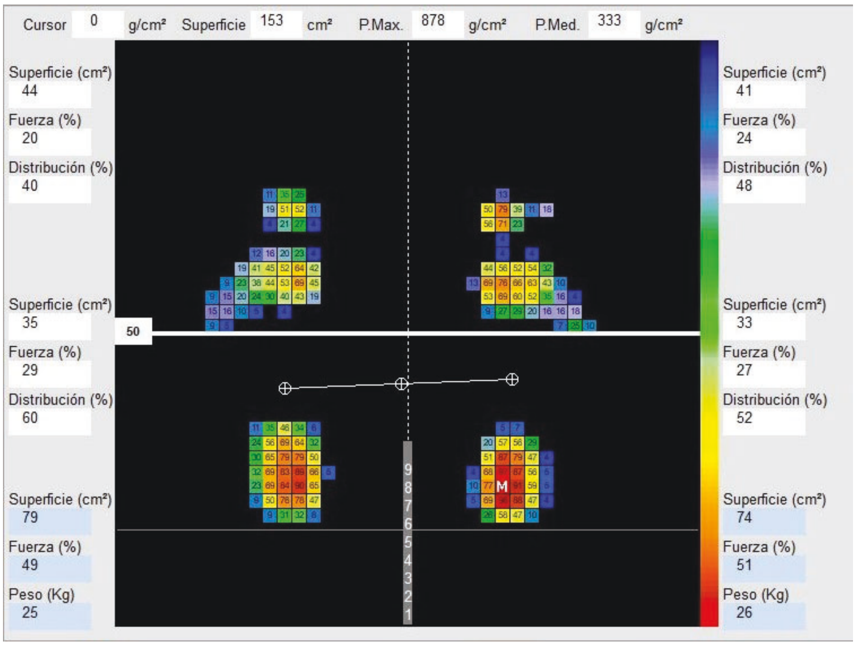

Figure 1. This figure shows the plantar pressure data regarding surface, force, and distribution from the forefoot and rearfoot areas and the percentages between areas and feet.

When the participant was uncomfortable or restless, the measurements were discarded (Figure 2).

Figure 2. Subject in a relaxed standing position during the acquisition of plantar pressure data from the portable pressure platform.

The output software included mapping pressures, which provided the plantar pressure magnitude of the forefoot and rearfoot surface area of each foot, forefoot and rearfoot ground reaction forces (GRF) of each foot (percentage), forefoot and rearfoot distribution of body weight of each foot (percentage), surface area of each foot (square centimeters), maximum plantar pressure of each foot (grams/square centimeters), medium plantar pressure of each foot, GRF of each foot (percentage), and weight of each foot (kilograms).

2.3. Statistical Analysis

The statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS software, version 19.0). Parametric data were described as mean ± standard deviation (SD) and range (minimum–maximum values). Normality was checked with the Kolmogorov-Smirnov test on the variables studied ($p > 0.05$) in the data on static plantar measurements. Independent t-tests were used for the outcome variables that were normally distributed. The non-parametric Mann-Whitney "U" test was performed to consider contrasts among the two groups with or without HLF.

In all analyses, $p < 0.05$ (with a 95% confidence interval) was considered statistically significant.

3. Results

3.1. Sociodemographic and Descriptive Data

Out of the 106 recruited participants, only 53 were diagnosed with FHL, and the other 53 were healthy controls. The sample size was composed of 55 boys and 51 girls. The ages of the participants were between 6 and 12 years old. No significant differences were observed between groups in relation to the quantitative sociodemographic and descriptive data, just in the age data (Table 1).

Table 1. Quantitative sociodemographic and descriptive data for subjects diagnosed with functional hallux limitus, healthy controls, and the total sample.

Quantitative Descriptive Data	Total Group (*n* = 106) Mean ± SD (Range)	FHL (*n* = 53) Mean ± SD (Range)	Healthy (*n* = 53) Mean ± SD (Range)	*p*-Value
Age (years)	9.47 ± 1.501 (6–12)	9.81 ± 1.27 (8–12)	9.13 ± 1.64 (6–12)	0.031 †
Weight (kg)	36.38 ± 11.31 (17.95–90.00)	36.69 ± 8.50 (22.00–56.60)	36.98 ± 13.63 (17.95–90.00)	0.542 †
Height (cm)	140.14 ± 11.44 (113.00–176.00)	141.26 ± 9.50 (121.00–167.00)	139.02 ± 13.10 (113.00–176.00)	0.231 †
BMI (kg/m^2)	18.50 ± 3.91 (11.00–40.00)	18.11 ± 2.81 (14.00–25.00)	18.89 ± 4.77 (11.00–40.00)	0.729 †
Sex (male/female)	55/51 (51.9/48.1)	23/30 (43.4/56.6)	32/21 (60.4/39.6)	0.120 ‡
Foot Size	35.63 ± 3.58 (15.00–44.0)	36.18 ± 2.38 (30.0–43.0)	35.09 ± 4.42 (15.00–44.0)	0.099 †

Abbreviations: kg, kilogram; cm, centimeter; m^2, square meter; %, percentage; SD, standard deviation; *n*, number. † Mann-Whitney U test was used. ‡ Fisher's exact test was used. In all the analyses, $p < 0.05$ (with a 95% confidence interval) was considered statistically significant.

Age was the only descriptive quantitative variable that showed a significant difference between the two study groups, with a *p*-value of 0.031. The remaining values were not significant enough to determine differences between the study groups. This indicates that there was no relationship between the presence or absence of an FHL and weight, height, BMI, sex, or foot size. Foot number size was the next most significant value, although it was not enough to establish a causal relationship with FHL, showing a *p*-value of 0.099.

3.2. Primary Outcome Measures

The primary outcome measurements for subjects diagnosed with functional hallux limitus, healthy matched-paired controls, and the total sample are presented in Table 2. The static plantar pressure results showed no significant differences between groups.

Table 2. Outcome measurements for subjects diagnosed with functional hallux limitus, healthy matched-paired controls, and the total sample.

Quantitative Descriptive Data	Total Group (*n* = 106) Mean ± SD (Range)	FHL (*n* = 53) Mean ± SD (Range)	Healthy (*n* = 53) Mean ± SD (Range)	*p*-Value
Left forefoot surface area (cm^2)	31.36 ± 10.83 (6–66)	31.85 ± 9.39 (14–64)	30.87 ± 12.17 (6–66)	0.450 †
Right forefoot surface area (cm^2)	30.08 ± 12.33 (0–76)	30.06 ± 11.54 (8–76)	30.11 ± 13.18 (0–66)	0.889 †
Left rearfoot surface area (cm^2)	32.46 ± 10.04 (17–70)	32.66 ± 9.49 (17–55)	32.26 ± 10.65 (19–70)	0.565 †
Right rearfoot surface area (cm^2)	29.95 ± 10.51 (12–64)	29.11 ± 8.77 (15–49)	30.79 ± 12.03 (12–64)	0.697 †
Left forefoot force (%)	20.17 ± 7.12 (3–46)	20.58 ± 6.50 (7–39)	19.75 ± 7.72 (3–46)	0.360 †
Right forefoot force (%)	18.33 ± 6.80 (0–38)	17.81 ± 6.20 (5–38)	18.85 ± 7.37 (0–33)	0.233 †
Left rearfoot force (%)	33.50 ± 8.49 (17–63)	33.42 ± 7.49 (17–51)	33.58 ± 9.45 (17–63)	0.907 †
Right rearfoot force (%)	27.98 ± 7.07 (6–48)	28.27 ± 6.46 (15.00–42)	27.70 ± 7.69 (6–48)	0.716 †
Left forefoot distribution (%)	37.79 ± 12.41 (5–72)	38.19 ± 11.25 (15–66)	37.40 ± 13.57 (5–72)	0.704 †
Right forefoot distribution (%)	39.40 ± 13.77 (0–79)	38.47 ± 11.79 (12–71)	40.32 ± 15.56 (0–79)	0.349 †
Left rearfoot distribution (%)	62.21 ± 12.41 (28–95)	61.81 ± 11.25 (34–85)	62.60 ± 13.57 (28–95)	0.704 †
Right rearfoot distribution (%)	59.75 ± 14.80 (7–100)	59.66 ± 14.21 (7–88)	59.85 ± 15.50 (21–100)	0.752 †
Left surface area (cm^2)	64.10 ± 18.87 (26–136)	64.89 ± 15.92 (31–91)	63.32 ± 21.55 (26–136)	0.321 †
Right surface area (cm^2)	60.13 ± 20.33 (14– 130)	59.17 ± 17.11 (32–107)	61.09 ± 23.24 (14–130)	0.899 †
Left maximum plantar pressure (kPa)	813.63 ± 212.67 (73–1357)	816.19 ± 184.59 (360.10–1357)	811.06 ± 239.25 (73–1217)	0.830 †
Right maximum plantar pressure (kPa)	754.59 ± 185.56 (332.42–1424.00)	783.28 ± 183.47 (484.40–1357.00)	725.91 ± 184.89 (332.42–1424.00)	0.129 †
Left medium plantar pressure (kPa)	314.88 ± 64.80 (146.00–506.00)	314.50 ± 60.15 (182.50–506.00)	315.26 ± 69.72 (146–463.00)	0.691 †
Right medium plantar pressure (kPa)	323.21 ± 333.54 (151.00–3671.00)	294.21 ± 57.25 (191–437)	352.21 ± 468.67 (151.00–3671.00)	0.793 †
Left force (%)	53.81 ± 6.72 (34.00–70.00)	54.08 ± 6.37 (42–70)	53.55 ± 7.10 (34.00–69.00)	0.628 †
Right force (%)	46.28 ± 6.72 (30–66)	45.92 ± 6.37 (30–58)	46.64 ± 7.09 (31–66)	0.498 †

Table 2. *Cont.*

Quantitative Descriptive Data	Total Group (n = 106) Mean ± SD (Range)	FHL (n = 53) Mean ± SD (Range)	Healthy (n = 53) Mean ± SD (Range)	p-Value
Left weight (kg)	19.76± 6.25 (9–44)	19.96 ± 5.60 (9–31)	19.57 ± 6.89 (11–44)	0.350 †
Right weight (kg)	17.11 ± 6.29 (6–46)	16.83 ± 4.63 (9–26)	17.40 ± 7.62 (6–46)	0.730 †

Abbreviations: kPa, kilopascals; kg, kilogram; cm, centimeter; cm^2, square centimeter; %, percentage; SD, standard deviation; n, number. † Mann-Whitney U test was used. In all the analyses, $p < 0.05$ (with a 95% confidence interval) was considered statistically significant.

No statistically significant differences were found between groups in the bilateral forefoot and rearfoot surface area, bilateral forefoot and rearfoot GRF, bilateral forefoot and rearfoot distribution of body weight, total left and right surface area, maximum pressure of the left foot and right foot, medium pressure of the left foot and right foot, ground reaction forces of the left foot and right foot, and the weight of each foot.

4. Discussion

This is the first study to relate FHL disorders to plantar pressure in a sample of school-age subjects. The aim of this study was to analyze the plantar pressure in a stationary position in subjects between 4 and 12 years old, with and without functional hallux limitus.

Functional hallux limitus disorder is characterized by a limitation of movement in the first MTPJ in the dynamic gait stage. A previous study performed by Gatt et al. corroborated the relationship between subjects with pronated feet and the dorsiflexion movement limitation in the gait and concluded that the greater the pronation of the foot in the gait, the less the first MTPJ dorsiflexion [16]. In our research, subjects were in a static position with normal pronation of the foot, and no changes in the plantar pressures were shown, besides no changes in the surface areas and forces. We found discretely higher data in the left foot between groups, but it was not statistically significant.

The research conducted by Halstead et al. analyzing the clinical test of dorsiflexion of the hallux in a passive way in stance position concluded that there were no variations in the maximum dorsiflexion performed in a relaxed weight-bearing static position and walking [25]. Our research was performed with the subjects in a static position, and the dorsiflexion MTFJ test was also realized in a static position.

According to the research by Aquino et al., excessive pronation did not always affect the establishment of the windlass mechanism in adulthood because the musculoskeletal function may be correct but not the joint movement of the first MTPJ [26].

In addition, the research performed by Durrant on school-age subjects concluded that the GFR, which acts on the foot, was relatively small owing to the low weight of some subjects and could not be captured by a pressure platform. In addition, dynamics occur when different compensatory mechanisms generated by this functional limitation are activated. Non-significant quantitative results were obtained between the two study groups, and FHL occurred in dynamics when different compensatory mechanisms generated by this functional limitation were activated [20]. In our research, the portable plantar pressure device proved to be a reliable system for plantar pressure acquisition [22].

Although previous studies have reported a limitation of the DF movement of the first MTPJ associated with a pronated or very pronated foot due to biomechanical alterations [1,15–17], currently there is very little consensus on the pathophysiology, cause, and treatment of HL in adults and younger children [3,5,27–30]. The authors do agree that the etiology of HL is multifactorial [8,31–34].

According to our research, the quantitative variables included in Table 2 did not show a significant difference between the two study groups. This may be associated with alterations in joint mobility of the foot and postural alterations in subjects with FHL.

Although there are several studies and reviews related to foot posture and plantar pressure in adults [35–37], currently there is little research on the relationship between pathologies that affect the school-age population and the consequent biomechanical alterations, anomalies in static plantar pressures [38], and subsequent pathologies to help avoid harmful biomechanical compensation in the long term.

Regarding our initial hypothesis, no statistically significant differences were shown between static plantar pressures in school-age children with and without FHL. However, in the images obtained on the pressure platform, in individuals of greater age and, therefore, greater weight and GRF, a smaller contact area was observed in the forefoot and greater pressure under the first MTH in the feet with HLF+. In subjects without HLF, the forefoot support surface was broader and more diffuse (Figure 1). No significant results were obtained in this data collection, perhaps because the ages and weights of the subjects were dispersed owing to the wide range of characteristics of the individuals studied.

Therefore, other reference parameters may be necessary to compare these values.

The ROM of the first MTPJ in static conditions is higher than in dynamic conditions, so static measurements may not be a good assessment to determine the functionality of the foot in dynamic pathologies [20].

This study has several limitations. First, the consecutive sampling method could be replaced by random sampling in the future. Second, the age range is wide, and for future research, the increase in the sample of each age group could be assessed to evaluate the range in which significant results begin to be obtained between both study groups, as well as the influence of overweight and obesity on the plantar pressure values.

In addition, the study of dynamic plantar pressures in school-age children with and without FHL is necessary since the GFRs are higher in dynamic situations and significantly different results may be obtained between both groups.

In future research, it would be interesting to study dynamic plantar pressures in school-age children with and without functional hallux limitus.

5. Conclusions

Although changes in pressure were observed, the results of the research did not show significant differences between the plantar pressures of school-age individuals with and without FHL. However, in the images viewed and obtained individually, changes in the location of the maximum pressure were observed, particularly in older participants with FHL, which was located below the first toe. These results were not significant enough to obtain valid results in this study.

Author Contributions: Conceptualization, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., O.T.-C., L.P-P., J.M., J.G.-S. and D.L.-L., methodology, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., O.T.-C., L.P-P., J.M., J.G.-S. and D.L-L.; data curation, C.C.-M. and O.T.-C., investigation, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., O.T.-C., L.P.-P., J.M., J.G.-S. and D.L.-L., writing—original draft, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., O.T.-C., L.P.-P., J.M., J.G.-S. and D.L.-L., writing—review and editing, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., O.T.-C., L.P.-P., J.M., J.G.-S. and D.L-L., visualization, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., O.T.-C., L.P.-P., J.M., J.G.-S. and D.L.-L.; supervision, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., O.T.-C., L.P-P., J.M., J.G.-S. and D.L.-L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Bioethics Committee of the University of Barcelona on 21 December 2021, with ID: IRB00003099.

Informed Consent Statement: The subjects gave their assent, and the informed consent form was signed by their parents or guardians.

Data Availability Statement: The dataset supporting the conclusions of this article is available upon request at claudia.cuevas@udc.es, Research, Health, and Podiatry Group (Department of Health Sciences, Faculty of Nursing and Podiatry, Industrial Campus of Ferrol, Universidade da Coruña).

Conflicts of Interest: The authors declare no conflict of interest.

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Hallux Limitus Influence on Plantar Pressure Variations during the Gait Cycle: A Case-Control Study

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Abstract: Background: Hallux limitus is a common foot disorder whose incidence has increased in the school-age population. Hallux limitus is characterized by musculoskeletal alteration that involves the metatarsophalangeal joint causing structural disorders in different anatomical areas of the locomotor system, affecting gait patterns. The aim of this study was to analyze dynamic plantar pressures in a school-aged population both with functional hallux and without. Methods: A full sample of 100 subjects (50 male and 50 female) 7 to 12 years old was included. The subjects were identified in two groups: the case group (50 subjects characterized as having hallux limitus, 22 male and 28 female) and control group (50 subjects characterized as not having hallux limitus, 28 male and 22 female). Measurements were obtained while subjects walked barefoot in a relaxed manner along a baropodometric platform. The hallux limitus test was realized in a seated position to sort subjects out into an established study group. The variables checked in the research were the surface area supported by each lower limb, the maximum peak pressure of each lower limb, the maximum mean pressure of each lower limb, the body weight on the hallux of each foot, the body weight on the first metatarsal head of each foot, the body weight at the second metatarsal head of each foot, the body weight at the third and fourth metatarsal head of each foot, the body weight at the head of the fifth metatarsal of each foot, the body weight at the midfoot of each foot, and the body weight at the heel of each foot. Results: Non-significant results were obtained in the variable of pressure peaks between both study groups; the highest pressures were found in the hallux with a *p*-value of 0.127 and in the first metatarsal head with a *p*-value 0.354 in subjects with hallux limitus. A non-significant result with a *p*-value of 0.156 was obtained at the second metatarsal head in healthy subjects. However, significant results were observed for third and fourth metatarsal head pressure in healthy subjects with a *p*-value of 0.031 and regarding rearfoot pressure in subjects with functional hallux limitus with a *p*-value of 0.023. Conclusions: School-age subjects with hallux limitus during gait exhibit more average peak plantar pressure in the heel and less peak average plantar pressure in the third and fourth metatarsal head as compared to healthy children aged between 7 and 12 years old.

Keywords: gait analysis; hallux limitus; school age; plantar pressure

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Citation: Cuevas-Martínez, C.; Becerro-de-Bengoa-Vallejo, R.; Losa-Iglesias, M.E.; Casado-Hernández, I.; Navarro-Flores, E.; Pérez-Palma, L.; Martiniano, J.; Gómez-Salgado, J.; López-López, D. Hallux Limitus Influence on Plantar Pressure Variations during the Gait Cycle: A Case-Control Study. *Bioengineering* **2023**, *10*, 772. https://doi.org/10.3390/bioengineering10070772

Academic Editor: Massimiliano Pau

Received: 29 May 2023
Revised: 24 June 2023
Accepted: 25 June 2023
Published: 27 June 2023

1. Introduction

Hallux limitus (HL) is a limitation of the dorsiflexion movement (DF) of the first metatarsophalangeal joint (IMTFJ) [1,2]. Functional hallux limitus (HL) was determined as the restriction of the IMTFJ motion in weight bearing and a normal IMTFJ motion in non-weight bearing [3]; HL produces limitations in gait patterns because of a restriction of closed-kinetic-chain joint motion causing functional limitations during the final phase of gait due to the blockage of the third rocker [4–6]. The blockage of the third rocker generates a variation of the axis of the first radius (1R) in the sagittal plane, causing a compensatory mechanism that helps to advance the center of mass along the extrinsic and intrinsic structures of the foot in order to improve the gait and finish it with the propulsion phase. Consequently, in order to improve the joint movement in the last phase of gait, secondary compensations generate a greater or lesser plantar pressure which can be analyzed with a baropodometric platform [6].

Pathologies such as HL, hallux valgus or hallux rigidus are secondary to a wrong position of the axis of the first radius in the sagittal plane [5]. This disorder can be balanced either distally in the interphalangeal joint or proximally in the midtarsal joints or even in the subtalar joint [7,8]. In addition, the IMTFJ disfunction motion in the sagittal plane produced by other biomechanical disorders does not cause local symptoms in the affected joint, as metatarsalgia, tendonitis or sesamoiditis, but can also produce symptoms in the retro malleolar aspect of the flexor hallucis longus tendon, knee and lumbar region [9,10].

A proper DF movement of the IMTJ in motion is necessary to stabilize the foot during the final contact phase of gait and to be effective [1]. If gait stabilization is not achieved and the different gait phases are inefficient, it will generate, in addition to a secondary pathology, a greater energy and functional expenditure during the gait, generating disorders on the muscle-ligamentous integrity of the body structures [11–13].

The adult population suffering from HL exhibit compensations that have been observed secondary to the limitation of IMT such as trunk forwarding to advance the center of gravity walking, beside decreasing the ground reactive forces (GRFs) that limit IMTJ motion and reduce the propulsion of the foot. In addition, a decrease extension movement of the hip that supports the lower limb during the gait pattern generates a lack of contraction of the biceps femoris muscle, producing a blocking of the sacroiliac joint and hyperlordosis that is caused by a prolonged muscle activation of the psoas iliacus and quadratus lumborum muscles due to the inability to counteract the action of the hip extensor muscles, causing finally an early heel elevation. Moreover, during the initial contact of the leg in support in the gait phase, the leg will be in flexion to balance the lack of hip extension [14,15].

Dynamic plantar pressure measurements between HL, hallux valgus and non-pathologic feet in the adult population have been previously studied and significant results have been obtained between the two groups, showing a higher plantar pressure under hallux, lesser toes and third and fourth metatarsal heads in subjects with HL [16].

As any restriction of motion should be compensated by other anatomical points, either proximal or distal to the initial block, it is essential to know the initial pathology of the same in IMTFJ, known as hallux limitus at school age, in order to prevent later compensations in adulthood.

The purpose of this study was to analyze the dynamic plantar pressure between subjects who have hallux limitus and subjects without hallux limitus in school age. The research hypothesis was that children in school age who have hallux limitus generate higher plantar pressures under the hallux than subjects without hallux limitus.

2. Material and Methods

2.1. Study Design

A case-control study was performed from January 2022 to February 2023 and it was carried out to analyze the plantar pressure variations in a school-age population with and without HL in a dynamic gait. This research followed all the criteria of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [17].

The research was conducted by the University of Barcelona Ethics Committee (consent no. IRB00003099). All the procedures were implemented according to all current regulations on human experimentation, as well as the Declaration of Helsinki and Organic Law 3/2018 of 5 December on protection of personal data and guarantee of digital rights [18].

An expert podiatrist in biomechanics with 10 years' experience screened all the subjects in advance. The subjects' were recruited in different private clinics by the same podiatrist.

The inclusion criteria were the following: (1) subjects older than 6 years and younger than 12 years; (2) healthy subjects without musculoskeletal disturbances or foot soreness; (3) subjects with no lower limb surgical intervention; (4) subjects with and without HL; (5) parents agreed to participation in the study and signed informed consent.

The exclusion criteria were the following: (1) subjects under 6 or over 12 years of age; (2) subjects who had suffered any pain or significant foot disorders; (3) subjects under medical treatment could affect the data acquisition; (4) subjects with musculoskeletal injuries or neurological disorders; (5) subjects with hypermobility syndrome; (6) subjects with an IMTFJ angle value lower than 10^0 flexing the ankle; (7) subjects who refused to adhere to the guidelines to participation in the study.

The levels of confidence, the potential groups of same size and the estimation of the sample size were analyzed using Epidat version 4.2 software (Consellería de Sanidade, Xunta de Galicia, Spain; Pan American Health Organization (PAHO-WHO); University CES, Colombia). In addition, an 80% statistical power analysis with a β error = 20%, an α error = 0.05 and a two tailed test were required to ensure statistical confidence. Finally, a full sample size of 100 children aged between 7 and 12 years old was composed. The groups were classified as follows: 50 subjects with HL and 50 healthy subjects.

2.2. Sociodemographic Data

A total sample of 100 subjects with an age range between seven and twelve years old and a mean age ± SD of 9.62 ± 1.37 years were included. From the 100 subjects recruited, 50 exhibited HL and the remainder did not have diseases and were the control group. The full sample size was composed of 50 male and 50 female subjects. Quantitative sociodemographic, anthropometric and descriptive outcomes are shown in Table 1 including age, weight, height, body mass index (BMI), sex and foot size.

Table 1. Sample sociodemographic characteristics across groups.

Sample Characteristics	Total Group (n = 100) Mean ± SD (Range)	HL (n = 50) Mean ± SD (Range)	Healthy (n = 50) Mean ± SD (Range)	p-Value
Age (years)	9.62 ± 1.37 (7–12)	9.68 ± 1.29 (7–12)	9.56 ± 1.46 (7–12)	0.607 †
Weight (kg)	37.84 ± 11.04 (20.50–90.00)	37.12 ± 8.53 (23.30–56.60)	38.57 ± 13.13 (20.50–90.00)	0.809 †
Height (cm)	140.37 ± 10.75 (118.0–176.00)	140.10 ± 9.54 (121.00–167.00)	140.64 ± 11.92 (118.00–176.00)	0.885 †
BMI (kg/m^2)	18.83 ± 3.68 (11.00–40.00)	18.64 ± 2.68 (14.00–25.00)	19.02 ± 4.48 (11.00–40.00)	0.803 †
Sex (male/female)	50/50 (50.0/50.0)	22/28 (44.0/56.0)	28/22 (56.0/44.0)	0.317 ‡
Foot size	35.99 ± 2.67 (28.00–43.0)	36.09 ± 2.20 (31.0–43.0)	35.88 ± 3.08 (28.00–42.0)	0.665 †

Abbreviations: kg, Kilogram; cm, Centimeter; m^2, Square Meter; % Percentage; SD, Standard Deviation; N, Number. † Mann–Whitney U test was used. ‡ Fisher exact test was used. In all the analyses, $p < 0.05$ (with a 95% confidence interval) was considered statistically significant.

Table 1 does not show statistically significant differences among groups regarding sociodemographic and quantitative descriptive data.

2.3. Procedure

Once subjects agreed to take part in the research, the podiatrist checked them to make sure the inclusion criteria were achieved. Subsequently, the subjects were barefoot to be measured and weighed. Next, the podiatrist checked the hallux joint mobility. To assess this, the clinician maintained the subtalar joint neutrality and the maximum ankle DF was performed with knee extended [19] and to verify that the DF of the IMTFJ was greater than 10^0, a goniometer was used [4].

The hallux limitus test was conducted with the subject in a resting position, and the clinician had to apply strength under the I metatarsal head (IMTH) with the non-resistive hand, and with the active hand had to perform a DF movement of the hallux. The force applied under the IMTH was approximately the same as used to carry out the DF of the hallux, which was followed by an IMTFJ dorsiflexion, IMTH plantarflexion, forefoot pronation, rearfoot supination, and windlass mechanism outset. Furthermore, when many movements were necessary to realize an effective propulsion, it was considered a negative test (HL−). On the other hand, when subjects had HL in which the forces applied were not balanced and the force needed to realize IMTFL dorsiflexion applied under IMTH was greater than usual [3], it was considered a positive test (HL+).

To conduct the research, a baropodometric portable platform composed of 1600 resistive sensors was used. Regarding the technical specification, the size of each sensor was 10 mm × 10 mm, the sample rate was from 100 Hz to 150 Hz via Wi-Fi and the interface used to connect with the laptop was a USB®; a dual amplifier was used to acquire plantar pressure data in dynamics. The portable pressure platform dimension was 565 mm length × 612 mm width × 22 mm height with a detection area of 400 × 400 mm composed of autocalibrated resistive sensors with 8 mm thickness. Autocalibration was conducted before each onset.

To transfer data from the portable pressure platform to a laptop, a USB was used. The software used to interpret the data from the platform manufacturer was T-Plate® (Herbitas, Foios, Valencia, Spain).

Dynamic data plantar pressure was obtained by the same clinician. In the dynamic test, subjects walked barefoot on the platform in a relaxed condition.

If the subject performed some altered movement during the data acquisition, the final data were erased, and the trial was once again repeated. If the subject was uncomfortable or restless, data were discarded. Three dynamic data acquisitions were taken for each subject.

This process was repeated until the subject reproduced a relaxed and comfortable gait. Four trials were recorded for each foot and the average calculated via the software was used for the analysis (Figure 1).

The T-Plate® software was used to collect and manage the surface area supported by each limb (cm^2), the maximum peak pressure of each limb (kPa), the average peak pressure of each limb (kPa), the body weight in the hallux of each foot (%), the body weight in the first metatarsal head of each foot (%), the body weight in the second metatarsal head of each foot (%), the body weight in the third and fourth metatarsal head of each foot (%), the body weight in the fifth metatarsal head of each foot (%), the body weight in the midfoot of each foot and the body weight in the heel of each foot (%).

The clinician divided the foot into seven regions (Figure 2) and compared the maximum peak pressures of each region between the two groups. To obtain the location of the pressure peaks of each foot, the body weight in the hallux, the body weight in the first metatarsal head, the body weight in the second metatarsal head, the body weight in the third and fourth metatarsal head, the body weight in the fifth metatarsal head, the body weight in the midfoot and the body weight in the heel were measured.

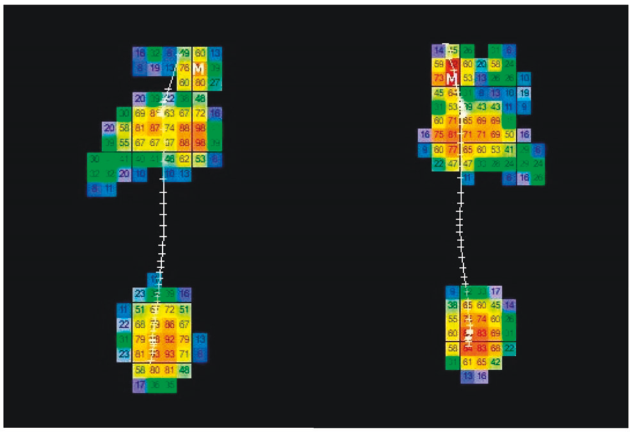

Figure 1. Descriptive analysis of the plantar pressure mapping in dynamic phase with T-Plate software.

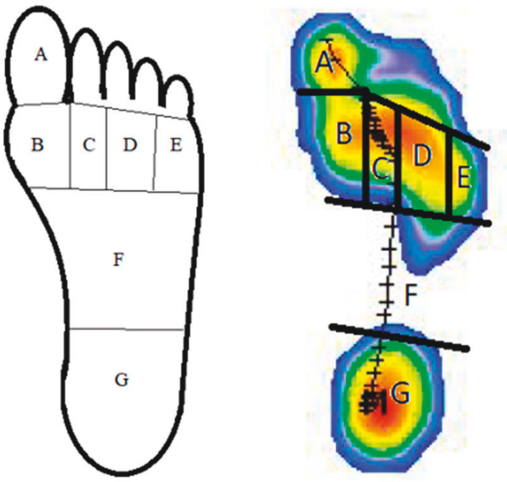

Figure 2. Foot division into seven regions to determine peak pressure location with T-Plate software. Region A: hallux; region B: first metatarsal head; region C: second metatarsal head; region D: third and fourth metatarsal head; region E: fifth metatarsal head; region F: midfoot; region G: heel.

The maximum plantar pressure was analyzed in seven foot regions while the subject walked on the platform as follows: In region A, the hallux; in region B, the first metatarsal head; in region C, the second metatarsal head; in region D, the third and fourth metatarsal head; in region E, the fifth metatarsal head; in region F, the midfoot; in the region G, the heel (Figure 2).

2.4. Statistical Analysis

Parametric outcomes were as follows: (1) mean; (2) ± standard deviation (SD); (3) range values (maximum and minimum). Normality outcomes were checked according to the Kolmogorov–Smirnov test for all the variables on static plantar measuring ($p > 0.05$). Independent t-tests were performed for the variables with normal distribution. The Mann–Whitney "U" test for non-parametric phenomena was used to contrast groups with or without HL. In addition, a p value < 0.05 with a 95% confidence interval was considered statistically significant.

To perform all the statistical analyses, the software used was SPSS 19.0.

3. Results

Measured Data's Principal Outcomes

According to the findings in Table 2, the variable body weight of the third and fourth metatarsal heads (left/right) with $p = 0.031$ and the variable body weight on the heel (left/right) with $p = 0.023$ showed a statistically significant difference between the HL and the control group. As for the other variables, none of them showed statistically significant differences.

Table 2. Principal outcomes measured for the control group and subjects with HL.

Variables	Total Group (*n* = 100) Mean ± SD (Range)	HL (*n* = 50) Mean ± SD (Range)	Healthy (*n* = 50) Mean ± SD (Range)	*p*-Value
Left surface area (cm^2)	88.59 ± 19.63 (37–141)	89.54 ± 18.12 (51–127)	87.64 ± 21.17 (37–141)	0.634 †
Right surface area (cm^2)	89.72 ± 19.99 (29–135)	90.38 ± 19.58 (44–125)	89.06.11 ± 20.57 (29–135)	0.796 †
Left maximum peak pressure (kPa)	1792.72 ± 479.28 (17.0–3566.0)	1789.92 ± 308.41 (1160–2503)	1795.51 ± 307.43 (17–3566)	0.751 †
Right maximum peak pressure (kPa)	1757.88 ± 482.93 (12–3854)	1759.10 ± 366.86 (262–2616)	1756.66 ± 580.19 (12–64)	0.697 †
Left average peak pressure (kPa)	1089.47 ± 862.36 (46–9310)	1162.89 ± 1188.17 (716–9310)	1016.06 ± 282.42 (46–1945)	0.560 †
Right average peak pressure (kPa)	1000.88 ± 237.94 (24–1906)	1002.08 ± 180.93 (683–1516)	999.69 ± 285.74 (24–1906)	0.890 †
Body weight in hallux (left/right) (%)	11/14 (11.0/14.0)	10/8 (20.0/16.0)	1/6 (2.0/12.0)	0.127 ‡
Body weight in first metatarsal head (left/right) (%)	9/7 (9.0/7.0)	8/5 (16.0/10.0)	1/2 (2.0/4.00)	0.354 ‡
Body weight in second metatarsal head (left/right) (%)	11/23 (11.0/23.0)	4/12 (8.0/24.0)	7/11 (14.0/22.0)	0.156 ‡
Body weight in third & fourth metatarsal heads (left/right) (%)	37/22 (37.0/22.0)	11/7 (22.0/14.0)	26/15 (52.0/30.0)	0.031 ‡
Body weight in fifth metatarsal head (left/right) (%)	1/1 (1.0/1.0)	0/0 (0.0/0.00)	1/2 (2.0/4.00)	1.325 ‡
Body weight in midfoot (left/right) (%)	0/1 (0.0/1.0)	0/0 (0.00/0.00)	0/1 (0.00/2.00)	1.432 ‡
Body weight in heel (left/right) (%)	31/31 (31.0/31.0)	17/18 (34.0/36.0)	14/13 (28.0/26.0)	0.023 ‡

Abbreviations: kPa, kilopascals; cm^2, Square Centimeter; %, Percentage; SD, Standard Deviation; N, Number. † Mann–Whitney U test was used. ‡ Fisher exact test was used. In all the analyses, $p < 0.05$ (with a 95% confidence interval) was considered statistically significant.

4. Discussion

This study is the first that has been conducted with school-aged subjects with HL disorders, and plantar pressure variations in dynamic conditions were measured. The main goal of this research was to analyze the plantar pressure in dynamic conditions in a population of children with hallux limitus disorder with aged between seven and twelve years old.

The authors performed similar research and concluded that the gait cycle creates a complex and unconscious motor pattern that allows people to develop, interact and participate in daily activities [20–22]. Gibson et al. [22] also specify that gait development has a temporal acquisition process and Samson et al. also indicate that biomechanical growing changes of joint dynamics occur at the age of 4 years old in the ankle joint, and in the knee and hip joint among 6 and 7 years old, respectively; Ito T et al. [20] and Samson et al. [23] determined that in healthy individuals, the biomechanical joint parameters start to stabilize between 5 and 7 years of age. For this reason, the subjects who participated in the study were aged between 7 and 12 years old, so that gait was already integrated as an unconscious activity, reducing the bias due to dynamic immaturity.

Bryant et al. [16] compared plantar pressures in adults with hallux valgus, hallux limitus and in normal IMTJ motion feet, and the results showed rise peak plantar pressures under the first, second and third MTH in non-pathologic feet subjects and under hallux and third, fourth and fifth MTH in hallux limitus feet subjects. However, in our research, we found non-significant results in the location of plantar pressure peaks between both study groups, where there were higher pressure points at hallux and IMTH in subjects with HL. There were significant results showing increased pressure at third and fourth MTH in healthy subjects and higher pressure in the rearfoot in subjects with HL. Thus, data showed non-statistically significant differences between groups; subjects with HL showed a rise in pressure peaks under the hallux and IMTH compared to the control group.

Findlow et al. [24] reported the characteristics of the kinematic differences between flexible feet and feet with greater restriction of movement, the former being feet with heel eversion and a low medial arch. The kinematic difference appears mainly in the forefoot; in flexible feet, the GRFs advance medially and due to forefoot eversion a DF movement of the IMTH is generated; the ground force reaction passes to the second MTH, generating a greater pressure on this and also on the third MTH. On the other hand, supinated feet lateralize the GRF. DF movement of the fifth metatarsal was limited and the consequent drop of the forefoot favors a PF of the first metatarsal as the IAMTJ dorsiflexes during the final phase of gait, generating greater pressure on the first and fifth MTH. This movement will generate a more effective windlass mechanism in feet with lateralized loads.

Bojsen-Moller [25] divided the foot into two axes across which it can propel a transverse axis (through the first and second MTH) and an oblique axis (third, fourth and fifth MTH). Propulsion through the transverse axis was produced by medializing the physiological loads to effect the propulsive moment; the medial side of the foot was locked, acting as a rigid lever ready to propel effectively. When this physiological medialization was not generated, the medial area of the foot acted as a flexible and unstable lever, which would generate an apropulsive gait that must be carried out via the oblique axis, which was accompanied by the blocking and levering of the lateral column. When there was a limitation of IMTJ, the forces could be lateralized to be able to perform the propulsion from an oblique axis.

Roukis et al. [26] concluded that an alteration in the normal functioning of the first radius, such as hypermobility or insufficiency, could generate a lateralization of GRF and increased pressure on the lesser metatarsals in adult subjects; Menz et al. [4] indicated that if asymptomatic IMTJ was present, there was an increased pressure peak under the hallux, but if this area caused pain, an antalgic gait was adopted which shifted the pressure peak to the side. According to our findings, the functional limitation we studied in children does not result in pain, so the antalgic gait that can occur in adults with HL is unlikely to be reproduced in school-aged patients with HL.

Bryant et al. [16] divided the foot into ten regions to classify and differentiate the pressure peaks in each of them in healthy feet, with LH and HR. In our research, we divided the foot into seven regions as this seemed more appropriate for children with mostly small feet and it would be difficult to differentiate between the third and fourth MTHs and lesser toes.

Furthermore, Visscher et al. [27] reported that clinical identification methods commonly used during biomechanical studies were often subjective and time-consuming and used a pressure platform. Therefore, research in this field should continue to validate biomechanical studies and ensure that results can be unified and homogeneous for researchers.

Agostini et al. [28] performed a study with a sample size of 85 children, 42 male and 43 female, aged between 6 and 7 years old. According to the measurements obtained with a pressure platform and regarding the height of the children, they concluded that their findings must be considered as a key factor to obtain gait data because the sensors did not obtain all the information and did not establish a correct relationship such as speed. Related to our findings, there were data that we were unable to obtain due to the platform used, and that would have been very useful for comparing the propulsion phase between both groups, with respect to having been able to check the speed–time factor.

Beurskens et al. [29] demonstrated that in children who consciously or unconsciously perform dual tasks during dynamics, gait velocity, stride length and cadence may be reduced. Thus, variability may increase during platform pressure measurements in children. For this study, there were no dual tasks while collecting pressure platform measurements, but it could be that they were distracted by uncontrolled or unnoticed momentum. For this reason, further studies should be conducted with this population to validate the shape, spacing, length and other characteristics that may vary during pressure measurement with a platform.

Several limitations were found in our research. One of the main limitations was age. Our research was conducted in a school-age population aged between 7 and 12 years old and pubertal stage changes were not considered between sexes, especially in females. In future research, the influence of pubertal stages should be taken into account. On the other hand, in our research all the subjects had good health condition with a normal BMI, but nevertheless physical activity and body conditions such as the lean mass of the body and lower limb were not considered; for future research, these factors could be interesting for the final outcomes. Regarding our research, we assert that this method of assessment obtained positive results as an instrument for the quantitative assessment of HL in school-aged children. These findings can be explained by biomechanics; given that there is functional limitation of movement in the IMTJ in a school-age population, there is no pain and therefore nothing to compensate for and thus no antalgic gait. In addition, the limitation is not sufficiently rigid to transfer loads to other more mobile joints by lateralizing the loads; therefore, pressure peaks are produced in the hallux and IMTH during the moment of propulsion, generating inefficient propulsion with this toe acting as a rigid lever. Therefore, it is necessary to carry out a good individualized podiatric study for each patient to diagnose the pathology and apply the appropriate treatment in each case. Moreover, in children, limitation of movement in any joint implies blockages of a higher or lower level, increasing the likelihood of a future pathology.

5. Conclusions

Dynamic baropodometry is a useful tool in biomechanical studies because it facilitates the identification of gait abnormalities. School-age subjects with hallux limitus during gait exhibit more average peak plantar pressure in the heel and less peak average plantar pressure in the third and fourth metatarsal heads as compared to healthy children aged between 7 and 12 years old.

Author Contributions: Conceptualization, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., E.N.-F., L.P-P., J.M., J.G.-S. and D.L.-L., methodology, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., E.N.-F., L.P-P., J.M., J.G.-S. and D.L.-L.,; data curation, C.C.-M. and L.P-P., investigation, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., E.N.-F., L.P.-P., J.M., J.G.-S. and D.L.-L., writing—original draft, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., E.N.-F., L.P.-P., J.M., J.G.-S. and D.L.-L. writing—review and editing, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., E.N.-F., L.P.-P., J.M., J.G.-S. and D.L.-L. visualization, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., E.N.-F., L.P.-P., J.M., J.G.-S. and D.L.-L.; supervision, C.C.-M., R.B.-d.-B.-V., M.E.L.-I., I.C.-H., E.N.-F., L.P.-P., J.M., J.G.-S. and D.L.-L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Bioethics Committee of the University of Barcelona on 21 December 2021, with ID: IRB00003099.

Informed Consent Statement: The subjects gave their assent, and the informed consent form was signed by their parents or guardians.

Data Availability Statement: The dataset supporting the conclusions of this article is available upon request at claudia.cuevas@udc.es, Research, Health, and Podiatry Group (Department of Health Sciences, Faculty of Nursing and Podiatry, Industrial Campus of Ferrol, Universidade da Coruña).

Conflicts of Interest: The authors declare no conflict of interest.

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Lausanne, 25 November 2023

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I remain at your disposal for further clarification.

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Assessment and indicators of hallux limitus related with quality of life and foot health in school children

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Submitted to Journal:
Frontiers in Pediatrics

Specialty Section:
Pediatric Orthopedics

Article type:
Original Research Article

Manuscript ID:
1295832

Received on:
19 Sep 2023

Revised on:
24 Nov 2023

Journal website link:
www.frontiersin.org

Scope Statement

This manuscript is link to scope of the section Injury prevention and control

Conflict of interest statement

The authors declare a potential conflict of interest and state it below

The author(s) declared that they were not an editorial board member of Frontiers, at the time of submission.

CRediT Author Statement

Claudia Cuevas-Martínez: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Daniel López-López**: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Emmanuel Navarro-Flores**: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Israel Casado-Hernández**: Conceptualization, Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **João Martiniano**: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Laura Pérez-Palma**: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Marta Losa Iglesias**: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Ricardo Becerro De Bengoa Vallejo**: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Juan Gómez-Salgado**: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Keywords

FHSQ, Foot, Health related quality of life, Functional hallux limitus, Hallux Limitus

Abstract

Word count: 350

Background:Functional Hallux Limitus (FHL) is a dynamic foot dysfunction characterized by a limitation of hallux dorsiflexion when the first metatarsal head is under load. FHL plays a role in the development of osteoarthrosis in the first metatarsophalangeal joint (IMTPJ). Forefoot disorders can significantly impact an individual's quality of life, leading to dysfunction and pain. The aim of this project was to evaluate the quality of life of school-aged individuals with and without FHL using the Foot Health Status Questionnaire(FHSQ).Methods: A case-control study was conducted to evaluate the outcomes in paediatric age. A total sample of 116 children between 6-12 years old was used to conduct this research. The sample was divided into two groups: (i) the healthy group (n=58) and the FHL group (n=58).The FHSQ was completed and the FHL test was performed in a seated position to classify the patients into the selected group. Results:Non-significant changes were observed when the mean values of the FHSQ domains were compared between the groups with and without FHL, except for the "general foot health" domain (p=0,024) associated with the specific foot health section (section 1) of the Questionnaire. For the domains linked with the general well-being section (section 2), there was not a statistically difference in the mean of the scores obtained between the two school-aged groups with and without FHL, being slightly lower in the group with the presence of FHL for the overall health and physical function domains. Both the healthy and case groups obtained and identical range of scores (10-100) for the "foot pain" domain. Nevertheless, the mean of the score was lower for the participants with FHL.Conclusions:The perception of the quality of general foot health 3 was poorer in the school-aged group with FHL. Variables such as foot pain and footwear are likely contributors influencing the perception of foot health quality. The school-aged population with FHL faces a decline in the quality of foot life. Ensuring adequate foot control in children and implementing future foot programs for this population are imperative for enhancing school children's perception of foot health and managing the development of pain and footwear-related issues.

Funding information

The sponsors played no part in the design, methods, subject recruitment, data collections, analysis and preparation of the paper or have any personal relationships with other people or organizations that could inappropriately influence (bias) their work.

Funding statement

The author(s) declare financial support was received for the research, authorship, and/or publication of this article.

Ethics statements

Studies involving animal subjects
Generated Statement: No animal studies are presented in this manuscript.

Studies involving human subjects
Generated Statement: The studies involving humans were approved by Human Ethics Committee of the Universitat de Barcelona, Barcelona, Spain (Ethics Code: IRB 00003099. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Inclusion of identifiable human data
Generated Statement: No potentially identifiable images or data are presented in this study.

Data availability statement

Generated Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Original Article

Assessment and indicators of hallux limitus related with quality of life and foot health in school children

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Original Article

Assessment and indicators of hallux limitus related with quality of life and foot health in school children

Abstract:

Background: Functional Hallux Limitus (FHL) is a dynamic foot dysfunction characterized by a limitation of hallux dorsiflexion when the first metatarsal head is under load. FHL plays a role in the development of osteoarthrosis in the first metatarsophalangeal joint (IMTPJ). Forefoot disorders can significantly impact an individual's quality of life, leading to dysfunction and pain. The aim of this project was to evaluate the quality of life of school-aged individuals with and without FHL using the Foot Health Status Questionnaire (FHSQ). Methods: A case-control study was conducted to evaluate the outcomes in paediatric age. A total sample of 116 children between 6-12 years old was used to conduct this research. The sample was divided into two groups: (i) the healthy group (n=58) and the FHL group (n=58). The FHSQ was completed and the FHL test was performed in a seated position to classify the patients into the selected group. Results: Non-significant changes were observed when the mean values of the FHSQ domains were compared between the groups with and without FHL, except for the "general foot health" domain (p=0,024) associated with the specific foot health section (section 1) of the Questionnaire. For the domains linked with the general well-being section (section 2), there was not a statistically difference in the mean of the scores obtained between the two school-aged groups with and without FHL, being slightly lower in the group with the presence of FHL for the overall health and physical function domains. Both the healthy and case groups obtained and identical range of scores (10-100) for the "foot pain" domain. Nevertheless, the mean of the score was lower for the participants with FHL. Conclusions: The perception of the quality of general foot health was poorer in the school-aged group with FHL. Variables such as foot pain and footwear are likely contributors influencing the perception of foot health quality. The school-aged population with FHL faces a decline in the quality of foot life. Ensuring adequate foot control in children and implementing future foot programs for this population are imperative for enhancing school children's perception of foot health and managing the development of pain and footwear-related issues.

Keywords: FHSQ; foot; health related quality of life; functional hallux limitus; hallux limitus

1. Introduction

Functional hallux limitus (FHL) pathology is described as a functional inability of the proximal phalanx of the hallux to perform the dorsiflexion movement (DF) during the complete gait cycle and the final phase of propulsion (1,2). Therefore, this impairment only occurs in a closed kinetic chain. In an advanced limitation phase of the first metatarsophalangeal joint (IMTPJ) and mainly in adulthood, FHL can develop and degenerate into hallux limitus, followed by hallux rigidus and even hallux valgus (3). Joint osteoarthrosis is very common in adulthood, being present in 10% of people between the ages of 20 and 34 years and increasing in incidence proportionally with age (3). When this limitation appears in both closed and open kinetic chains, it is called hallux limitus and is the previous step to culminating in total restriction of movement in this joint, called hallux rigidus (4).

Forefoot disorders can deteriorate the quality of life of individuals causing dysfunction and even pain (4) but the incidence and prevalence of FHL remain unclear and very poorly understood (5).

In the initial approach, the foot has important functions for cushioning and transmitting ground reaction forces when standing and throughout the whole gait cycle. FHL is fundamental to the study of foot biomechanics in the sagittal plane. Dananberg described in his sagittal plane theory that a block in any joint that generates a movement in this plane will cause a compensation in another joint that may be located above or below the affected joint (6). A biomechanical decompensation that generates high plantar fascia tension, for example, will result in greater opposing forces between the downward vertical forces of the plantar flexion motion of the first metatarsal head compared to the upward vertical forces of hallux extension, causing a limitation or restriction of the IMTPJ DF motion (7). A decreased DF range of the IMTPJ causes insufficient physiological locking of the lateral column of the foot and hinders the correct advancement of forces and center of mass during dynamics, in addition to an insufficient windlass mechanism. Consequently, the foot will be unstable during the stance phase and the IMTPJ pivot during the propulsive phase will be ineffective (7).

Based on these antecedents, it is necessary to study the effects of the presence or absence of FHL at school age, to know if at early ages with a functional limitation of the IMTPJ , quality of life can be negatively affected and to avoid, as far as possible, greater future affectations, such as osteoarthrosis, among other biomechanical compensations that cause pain and secondary pathologies.

Finally, our hypothesis was that school children with FHL would show poor values associated with foot health and quality of life in comparison with school children without FHL. Thus, the aim of this project was to evaluate the quality of life in school-aged individuals with and without FHL using the FHSQ.

2. Material and Methods

2.1 Participants

A case control study was carried out in multiple schools from different places in Catalonia (Spain) and was developed between January 2022 and February 2023. The sampling method was consecutive to recruit 116 children aged between 6 and 12 years with a mean ± SD (9.55 ± 1.54) years. This study was performed consecutively and conveniently.

This case control study followed all the criteria of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (8) assessed FHSQ results in school-aged children with and without functional hallux limitus.

For this project, all subjects met the inclusion criteria to be part of the study and did not show any of the exclusion criteria.

The following inclusion criteria for both groups of participants were met: 1) age between 6 and 12 years; 2) absence of musculoskeletal disorders or significant general conditions; 3) absence of previous surgical treatment or trauma to the lower extremities; 4) having flexible feet; 5) participants with and without FHL; 6) parents and children who agreed to complete the FHSQ, 7) legal guardians who agreed to sign the written informed consent, and 8) subjects interested in participating and completing all phases of the study. The exclusion criteria were: 1) age not between 6 and 12 years; 2) patients under treatment with any medication that could affect the final results; 3) presence of musculoskeletal disorders or neurological disease; 4) hypermobility syndrome; 5) participants with a IMTPJ angular value of less than 10º with knee extension and with an ankle angular value of less than 10º with the knee extended; and 6) subjects who refused to comply with the guidelines for participating in the study.

The research was approved by the Human Ethics Committee of the Universitat de Barcelona, Barcelona, Spain (Ethics Code: IRB 00003099). All actions complied with all current regulations on human experimentation, as well as the Declaration of Helsinki and Organic Law 3/2018, of December 5, on protection of personal data and guarantee of digital rights (9).

2.2 Procedure

The study was performed by an expert podiatrist with more than 10 years' experience in biomechanical evaluation.

The legal documentation and FHSQ were given to the volunteers' legal guardians interested in participating in the study, to be read and completed calmly at home.

The FHSQ is a foot health status questionnaire and has been recognized as a validated tool (10). Section 1 is associated with specific foot health and consists of 13 questions reflecting four foot health-related domains: pain, function, footwear, and general foot health. For each section, different questions are answered with specific words ("none", "very mild", "mild", "moderate", "severe"). The first section has demonstrated a high degree of content, criterion, and construct validity (Cronbach α= 0.89–0.95) and high retest reliability (intraclass correlation coefficient = 0.74–0.92). The section 2 is linked with general well-being and includes questions that reflect four general health-related domains: general health, physical activity, social capacity and vigour. The domains and questions in this section are largely adapted from the Medical Outcomes Study 36-Item Short-Form Health Survey, which has been validated for use in the Spanish population (11).

The day of sample collection, participants came to the designated location, carrying the necessary documentation described in the inclusion criteria. Subsequently, they removed their shoes and socks. They were then measured and weighed by the clinician to ensure that the anthropometric measurements were current. Once these data were obtained, the body mass index (BMI) was calculated, and the participating subjects were checked to ensure that they did not meet any exclusion criteria.

Next, the clinician checked the range of motion of the IMTPJ and ankle DF to discard hallux rigidus (HR) and ankle equinus. To assess this, the patient was in a seated position and the subtalar joint was in a neutral position, then maximum DF of the ankle was performed with the knee extended. To verify that the DF of the IMTPJ was greater than 10º, it was measured with an arm goniometer (12).

After selecting the participants who met all the study inclusion criteria, they completed the FHL test described by H. Dananberg and scientifically validated (13), and were classified into the corresponding group according to the presence or absence of FHL. To perform the FHL test, the subject is placed in a seated position, barefoot and without socks so that the clinician can perform the test. The test consists of holding the foot with one hand and placing the thumb under the first metatarsal head. Then, with the contralateral hand, pressure is exerted on the proximal phalanx of the first toe to perform DF of the IMTPJ . If both forces are similar, the result for the FHL test is negative (FHL-), whereas if the force for IMTPJ DF is greater than that exerted under the first metatarsal head, it is considered a positive result (FHL+).

Data acquisition from the FHSQ was performed by entering the score for each individual and for each specific question into the software (The Foot Health Status Questionnaire, Version 1.03), which transforms the raw scores and sums them into sections. Scores range from 0-100, with 0 being the worst value and 100 the best value. In addition, the software provides graphical illustrations of the results (10,14). To facilitate the response and adapt it to the subjects participating in this study, the FHSQ was translated into Spanish (15).

The outcome measurements for subjects diagnosed with functional hallux limitus and healthy matched-paired controls included foot pain, foot function, footwear, general foot health, overall health, physical function, social capacity, and vigor.

To calculate the sample size for this study, the specific levels of confidence, power and equal size groups were applied using the Epidat software version 4.2 created by public organizations and aimed at epidemiologists and other health professionals that analyze tabulated data (16). To achieve statistical confidence, a statistical power of 80% with a β error of 20%, an α error of 0.05 and a two-tailed test were established. A total sample of 116 school-aged children aged between six and twelve years were included in the study and divided into two groups of 58 subjects each. One group had FHL and the other did not.

Statistical analyses were carried out with the Statistical Package for the Social Sciences (SPSS software, version 19.0). Parametric data were described as normal mean, standard deviation (SD) and range (minimum-maximum values). Normality was tested with the Kolmogorov-Smirnov test for the variables studied ($p > 0.05$) in the data on FHSQ results. Independent t-tests were used for outcome variables that were normally distributed. The non-parametric Mann-Whitney "U" test was performed to consider contrasts between the two groups with or without FHL.

In all analyses, a statistically significant result was considered when $p < 0.05$ (with 95% confidence interval).

3. Results

Out of the 116 participants recruited for this study, a total of 58 were diagnosed with FHL and the other 58 were healthy. The total sample consisted of 54 boys and 62 girls, and no significant results were observed between the two groups based on quantitative sociodemographic and descriptive data (Table 1).

Table 1. Quantitative sociodemographic and descriptive data for patients diagnosed with functional hallux limitus, healthy controls and total sample.

Quantitative Descriptive Data	Total Group (n=116) Mean ± SD (Range)	FHL (n=58) Mean ± SD (Range)	Healthy (n=58) Mean ± SD (Range)	p-Value
Age (years)	9.55 ± 1.54 (6.00 - 12.00)	9.72 ± 1.36 (7.00- 12.00)	9.38 ± 1.69 (6.00 – 12.00)	0.302†
Weight (Kg)	36.73 ± 11.40 (17.95 - 90.00)	36.72 ± 9.53 (20.00 - 66.00)	36.74 ± 13.09 (17.95 - 90.00)	0.515†
Height (cm)	140.64 ± 11.03 (113.00– 176.00)	140.90 ± 9.78 (120.00 – 167.00)	140.40 ± 12.22 (113.00 – 176.00)	0.730†
BMI (kg/m^2)	18.29 ± 4.01 (11.00 - 40.00)	18.21 ± 3.26 (14.00 - 30.00)	18.38 ± 4.67 (11.00 - 40.00)	0.764†
Sex (male/female)	54/62 (46.60/53.40)	24/34 (41.40/58.60)	30/28 (51.70/48.30)	0.264‡
Foot Size	35.86 ± 3.35 (15.00 - 43.0)	36.22 ± 2.34 (30.00 - 43.00)	35.50 ± 4.11 (15.00 - 42.00)	0.418†

Abbreviations: Kg, Kilogram; Cm, Centimeter; m^2, Square Meter; % Percentage; SD, Standard Deviation; N, Number. † Mann-Whitney U test was used. ‡ Fisher exact test was used. In all the analyses, $P < 0.05$ (with a 95% confidence interval) was considered statistically significant.

The values obtained were not significant to determine differences between the study groups. This indicates that there was no relationship between the presence or absence of FHL and weight, height, BMI, sex, or foot size among the study sample aged 6 to 12 years used for this project.

Table 2 shows the relationship between the population samples studied and the FHSQ results obtained for each domain. Section 1 is associated with specific foot health outcomes: foot pain, foot function, general foot health, and footwear showing significant differences ($P < 0.05$) for general foot health. They showed a worse QoL related to foot health for FHL, with the FHL group having lower scores than children without FHL, but not significant differences for foot pain, foot function and footwear ($P > 0.05$). The section 2 is linked with general well-being assesses four domains without showing significant differences ($P < 0.05$) for overall health, physical function, social capacity, and vigor.

Table 2. The relation between positive and negative FHL patients and FHSQ scores.

	Total Group (n=116) Mean ± SD (Range)	FHL (n=58) Mean ± SD (Range)	Healthy (n=58) Mean ± SD (Range)	p-Value
1. Specific Foot Health				
Foot Pain	90.26 ± 16.15 (10.00 -100)	88.15 ± 17.99 (10.00 -100)	92.37 ± 13.90 (10.00 -100)	0.285†
Foot function	94.02 ± 12.62 (43.75 -100)	92.56 ± 14.22 (43.75 -100)	95.47 ± 10.72 (43.75 -100)	0.098†
Footwear	60.42 ± 17.68 (8.33 -75)	58.48 ± 18.37 (16.67 -75.00)	62.36 ± 16.90 (8.33 -75)	0.285†
General foot health	78.45 ± 21.07 (25 -100)	73.14 ± 23.87 (25-100)	83.75 ± 16.43 (25 -100)	**0.024†**
2. General well-being				
Overall health	84.91 ± 18.90 (30-100)	84.31 ± 17.58 (30-100)	85.52 ± 20.28 (30-100)	0.255†
Physical function	94.88 ± 11.88 (22.22 -100)	94.44 ± 10.96 (55.56 -100)	95.31 ± 12.82 (22.22 -100)	0.254†
Social capacity	93.32 ± 14.03 (25 -100)	94.61 ± 13.87 (25 -100)	92.03 ± 14.18 (37.50 -100)	0.186†
Vigor	78.40 ± 17.30 (25 -100)	79.53 ± 16.79 (25 -100)	77.26 ± 17.86 (37.50 -100)	0.515†

Abbreviations: SD, Standard Deviation; N, Number. † Mann-Whitney U test was used. ‡ Fisher exact test was used. In all the analyses, $P < 0.05$ (with a 95% confidence interval) was considered statistically significant.

4. Discussion

This study contributes to a greater understanding of the influence of FHL on the quality of life of the school-age population by comparing self-reported FHSQ scores of a sample of 116 school-aged individuals. A decrease in the general score of the FHSQ would mean that FHL is certainly affecting foot health at this early stage. Utilising research for health professionals to advance in their practice will ensure appropriate knowledge and will provide high-quality advice and care to this target population in the future. However, to the best of the authors' knowledge, the lack of epidemiological studies addressing FHL makes it challenging to accurately assess the impact of this condition on school children.

A comparison of the mean scores obtained in the FHSQ between both groups revealed a relationship between the perception of general foot health and the presence of FHL. This lower perception of general foot health seems to be related to the lower scores obtained for foot pain and the footwear domain. Similar observations were addressed in the study performed by López_López et al. (17) in school-aged children to determine whether arch height has an effect on the health-related quality of life. The study reported that the children experience foot pain, restrictions in terms of footwear and, in general, a worse state of foot health. Nevertheless, they couldn't establish a relationship between these findings and the height arch which differs from this study where the score of the general foot health domain was directly related to the presence of FHL.

The outcomes of this investigation are aligned with findings shown in populations experiencing foot problems associated with the first MTPJ, particularly in more advanced stages, characterized by progressive subluxation and osteoarthritis. Lazarides et al. (18) and López et al. (19) have suggested that disorders involving the first MTPJ, such as hallux valgus or hallux rigidus may have an adverse impact on the perception of general foot health during adulthood and among older individuals when compared to the earlier stages such as in FHL dysfunction. Consequently, effective management of alterations in the first MPTJ during the initial stages can potentially embrace a positive influence on the status and perception of general foot health in the later life stages which is aligned with the current study perspectives. Similarly, the presence of hallux valgus has been correlated with a lower quality of life, increased foot pain, disability, and functional limitations, as demonstrated in a study performed by Gonzalez-Martin et al. (20) involving a random population sample of 1837 individuals in Spain. Furthermore, Gilheany et al. (3) examined foot health among adult patients with hallux valgus and hallux rigidus, who were candidates for surgery to address these conditions. The Foot Health Status Questionnaire (FHSQ) was administered both pre- and post-surgery. The hallux valgus group exhibited consistently low scores in areas of pain, foot function, shoe fit, and overall foot health. Notably, individuals with hallux rigidus scored even lower, indicating that as the motion of the first metatarsophalangeal joint becomes severely limited, general foot health markedly deteriorates. In contrast to the outcomes of this study, it is evident that hallux valgus and hallux rigidus conditions affect in depth of the first metatarsophalangeal joint (MTPJ), leading to tissue degeneration and a decline in overall quality of life.

To mitigate potential significant biases in this study, the participants presenting generalized ligamentous laxity were excluded so this condition was adopted as an exclusion criterion. This condition is common within the school-age population and is characterized by excessive joint mobility associated, among others, with foot pain and several foot disorders. The resolution of exclusion was based on the results of the study conducted by Palomo-López et al. (21) after analysing a sample of 100 participants from 18 to 35 years old with and without general ligamentous laxity and the correlation of this condition with FHSQ domains. The results suggested that general ligamentous laxity is related to more foot pain, greater restrictions in terms of footwear and a worse state of foot health thus, it was considered as an uncontrolled condition that could affect the interpretation of the results of the current study. The present study had some limitations such as including a larger and a diverse sample of individuals from various countries or even different country regions. Including different ethnicities would make a worthwhile contribution to the strength of this research and may help to identify if there is a cultural difference related to FHL disease in terms of pain, footwear, foot health perception and well-being thus, future research would be beneficial for improving the knowledge in this field and target population once addressing these limitations.

5. Conclusions

The perception of the quality of general foot health was poorer in the school-aged group with FHL. Variables such as foot pain and footwear are likely contributors influencing the perception of foot health quality. The school-aged population with FHL faces a decline in the quality of foot life. Ensuring adequate foot control in children and implementing future foot programs for this population are imperative for enhancing school children's perception of foot health and managing the development of pain and footwear-related issues.

Declarations

Ethics approval

Human Ethics Committee of the Universitat de Barcelona, Barcelona, Spain (Ethics Code: IRB 00003099).

Consent to participate

Written informed consent was obtained from the parent(s) of each child participant.

Competing interests

The authors declare no competing interests.

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Funding

The sponsors played no part in the design, methods, subject recruitment, data collections, analysis and preparation of the paper or have any personal relationships with other people or organizations that could inappropriately influence (bias) their work.

Availability of data and materials

The dataset supporting the conclusions of this article is available in the claudia.cuevas@udc.es in the Research, Health and Podiatry Group. Department of Health Sciences. Faculty of Nursing and Podiatry. Industrial Campus of Ferrol, Universidade da Coruña, Spain.

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