UNIVERSIDAD DE CASTILLA-LA MANCHA

FACULTAD DE CIENCIAS DEL DEPORTE (TOLEDO)

DEPARTAMENTO DE ACTIVIDAD FÍSICA Y CIENCIAS DEL DEPORTE

PROGRAMA DE DOCTORADO EN
INVESTIGACIÓN SOCIOSANITARIA Y DE LA ACTIVIDAD FÍSICA

COMPOSICIÓN CORPORAL Y SU RELACIÓN CON LA PRÁCTICA DEPORTIVA, LA SUPERFICIE DE JUEGO Y LA CONDICIÓN FÍSICA EN EDAD PEDIÁTRICA

[BODY COMPOSITION AND ITS ASSOCIATION WITH SPORTS, SPORT SURFACE AND FITNESS IN PAEDIATRIC AGE]

Tesis Doctoral Internacional desarrollada por: Esther Ubago Guisado

Dirigida por: Dra. Dª. Leonor Gallardo Guerrero/Dr. D. Javier Sánchez Sánchez

TOLEDO, 2017

A MIS PADRES Y A MI HERMANO

Con trabajo y esfuerzo se pueden conseguir muchas cosas,

pero tener el amor incondicional de tus seres queridos hace que todo sea más fácil.

Dra. Dª. Leonor Gallardo Guerrero,
Profesora Titular de la Universidad de Castilla-La Mancha
en la Facultad de Ciencias del Deporte de Toledo,

Certifica:

Que el trabajo de Tesis Doctoral Internacional desarrollado por la Graduada Esther Ubago Guisado, titulado **COMPOSICIÓN CORPORAL Y SU RELACIÓN CON LA PRÁCTICA DEPORTIVA, LA SUPERFICIE DE JUEGO Y LA CONDICIÓN FÍSICA EN EDAD PEDIÁTRICA**, ha sido realizado bajo mi dirección. En mi opinión, reúne los requisitos para proceder a iniciar los trámites pertinentes para la Comisión de Doctorado de la Universidad de Castilla-La Mancha y su posterior defensa ante tribunal.

Y para que conste, expido la presente certificación en Toledo, a 19 de Diciembre de 2016.

Fdo. Dra. Dª. Leonor Gallardo Guerrero

Dr. D. Javier Sánchez Sánchez,
Profesor Adjunto de la Universidad Europea
en la Facultad de Ciencias del Deporte de Madrid,

Certifica:

Que el trabajo de Tesis Doctoral Internacional desarrollado por la Graduada Esther Ubago Guisado, titulado **COMPOSICIÓN CORPORAL Y SU RELACIÓN CON LA PRÁCTICA DEPORTIVA, LA SUPERFICIE DE JUEGO Y LA CONDICIÓN FÍSICA EN EDAD PEDIÁTRICA**, ha sido realizado bajo mi dirección. En mi opinión, reúne los requisitos para proceder a iniciar los trámites pertinentes para la Comisión de Doctorado de la Universidad de Castilla-La Mancha y su posterior defensa ante tribunal.

Y para que conste, expido la presente certificación en Toledo, a 19 de Diciembre de 2016.

Fdo. Dr. D. Javier Sánchez Sánchez

AGRADECIMIENTOS [ACKNOWLEDGEMENTS]

Me gustaría que estas líneas sirvieran para expresar mi más profundo y sincero agradecimiento, a todas aquellas personas que con su ayuda han colaborado en la realización de este trabajo. En especial, quiero darle las gracias a la Dra. Dª. Leonor Gallardo Guerrero, por darme la oportunidad de formar parte de este estupendo grupo de investigación, por su orientación, seguimiento y supervisión continua, pero sobre todo, por la motivación y el apoyo recibido a lo largo de estos años. Es un orgullo que haya confiado en mí como persona y como profesional. Para mí, es un gran ejemplo de esfuerzo, superación, trabajo y buen hacer.

A mi compañeros del Grupo IGOID, en especial a mi co-director el Dr. D. Javier Sánchez Sánchez por su gran ayuda a lo largo de todo este trabajo, sin esperar nada a cambio. Gracias a él mi motivación ha sido continua durante todos estos años. También al Dr. D. Jorge García Unanue, por el interés mostrado en mi evolución y porque con él siempre aprendo cosas nuevas.

Quisiera hacer extensiva mi gratitud al resto de compañeros que se encuentran trabajando fuera, puesto que siempre he tenido su apoyo y tomado en cuenta todas sus sugerencias; y a los que entraron en el grupo un poco más tarde, porque su compañía en el día a día hace que a uno le resulten las horas de trabajo más amenas. También quiero hacer una mención especial al Grupo GENUD de la Universidad de Castilla-La Mancha, especialmente al Dr. Ignacio Ara, al Dr. Luis Alegre y a la Dra. María Martín por su inestimable ayuda estos años.

Y por último, de manera muy especial a mis padres y a mi hermano, por su apoyo incondicional ya que han sido un gran ejemplo de sacrificio y esfuerzo para mí, ayudándome a ser mejor cada día.

A todos ellos, muchas gracias.

LISTA DE PUBLICACIONES [LIST OF PUBLICATIONS]

La presente Tesis Doctoral es un compendio de trabajos científicos previamente publicados, aceptados para publicación o sometidos a revisión. Las referencias de cada uno de los artículos que componen este documento se detallan a continuación:

I. **Ubago-Guisado, E.**, Mata, E., Sánchez-Sánchez, J., Plaza-Carmona, M., Martín-García, M., & Gallardo, L. (2015). Influence of different sports on fat mass and lean mass in growing girls (in press). ***Journal of Sport and Health Science***.
DOI: 10.1016/j.jshs.2015.06.001

II. **Ubago-Guisado, E.**, Gómez-Cabello, A., Sánchez-Sánchez, J., García-Unanue, J., & Gallardo, L. (2015). Influence of different sports on bone mass in growing girls. ***Journal of Sports Sciences***, *33*(16), 1710-1718.

III. **Ubago-Guisado, E.**, Martínez-Rodríguez, A., Gallardo, L., & Sánchez-Sánchez, J. (2016). Bone mass in girls according to their BMI, VO_{2max}, hours and years of practice. ***European Journal of Sport Science***, *16*(8), 1176-1186.

IV. **Ubago-Guisado, E.**, Vlachopoulos, D., de Moraes A. C., Torres-Costoso, A., Wilkinson, K., Metcalf, B., Sánchez-Sánchez, J., Gallardo, L., Gracia-Marco, L. Fitness, bone mineral density and hip geometry in young males: The PRO-BONE study. ***European Journal of Sport Science***. (Submitted).

V. **Ubago-Guisado, E.**, García-Unanue, J., López-Fernández, J., Sánchez-Sánchez, J., & Gallardo, L. (2016). Association of different types of playing surfaces with bone mass in growing girls. ***Journal of Sports Sciences***.
DOI: 10.1080/02640414.2016.1223328

BECAS Y CONTRATOS [SCHOLARSHIPS AND CONTRACTS]

Es importante destacar que durante el periodo de formación doctoral, Esther Ubago Guisado ha sido beneficiaria de un *Contrato predoctoral para la formación de personal investigador en el marco del Plan Propio de I+D+i de la Universidad de Castilla-La Mancha, cofinanciados en el marco del Programa Operativo FSE para Castilla-La Mancha 2014-2020 por el Fondo Social Europeo [2014/10340].*

Diario Oficial de Castilla-La Mancha
AÑO XXXIII Núm. 162 25 de agosto de 2014 27366

III.- OTRAS DISPOSICIONES Y ACTOS

Universidad de Castilla-La Mancha

Resolución de 31/07/2014, de la Universidad de Castilla-La Mancha, por la que se establecen las bases reguladoras y la convocatoria de contratos predoctorales para la formación de personal investigador en el marco del Plan Propio de I+D+i, cofinanciados por el Fondo Social Europeo. [2014/10340]

La Universidad de Castilla-La Mancha (en adelante UCLM) como mayor organismo de Investigación de la Región, tiene encomendada la formación en investigación del personal titulado universitario y, por ello, fomenta la realización de tesis doctorales, haciendo pública la presente convocatoria para selección de beneficiarios de contratos para la formación de personal investigador.

Como recoge la Ley 14/2011, de 1 de junio, de la Ciencia, la Tecnología y la Innovación, en la sociedad actual los doctores son imprescindibles en el tejido productivo y social. La Universidad debe formar doctores y debe hacer el esfuerzo de adecuar esa formación a una sociedad que avanza en el conocimiento y la innovación, integrando en ella el saber de mujeres y hombres y la igualdad de derechos, responsabilidades y oportunidades de unas y otros. Los estudios de doctorado son un proceso de formación de la persona que le permiten adquirir y generar conocimientos y métodos de trabajo que serán imprescindibles tanto para su desarrollo personal como para realizar una contribución al tejido productivo y social. Además, la Universidad debe formar personal investigador y ha de hacerlo atendiendo tanto a las necesidades de una sociedad que demanda conocimiento e innovación para una mejora de su bienestar, como para la preparación de futuros líderes y emprendedores.

Los Estatutos de la UCLM establecen en su artículo 14 la necesidad de coordinar los estudios de doctorado entre las distintas estructuras específicas que tienen encomendadas la organización de tales estudios. La resolución de 18/12/2013, de la Universidad de Castilla-La Mancha, por la que se delegan competencias en diferentes materias y órganos de la UCLM, atribuye al Vicerrectorado de Investigación y Política Científica el fomento y la coordinación de la investigación, la promoción y fomento de la actividad investigadora, y las competencias en materia de doctorado. Al amparo de dichas competencias y de la planificación de los objetivos perseguidos por esta Universidad, se establecen las bases reguladoras para la selección de beneficiarios de contratos para la selección de personal investigador.

Esta convocatoria forma parte de las medidas incluidas en el Plan de Fortalecimiento Institucional 2014-2015 de la UCLM, aprobado por el Consejo Social en su reunión plenaria de 30 julio de 2014 a propuesta del Consejo de Gobierno en su reunión ordinaria de 22 de julio de 2014. Las actuaciones previstas en la presente Resolución serán objeto de cofinanciación a través del programa Operativo Fondo Europeo de Desarrollo Regional 2014-2020 Castilla-La Mancha en aquellos casos en que se incorporen como actuación en dicho programa y cumplan con los criterios de selección aprobados en el Comité de Seguimiento.

Los contratos regulados en la presente resolución estarán cofinanciados en el marco del Programa Operativo FSE para Castilla-La Mancha 2014-2020 por el Fondo Social Europeo, cuya misión es mejorar el empleo y las oportunidades de trabajo, impulsando la empleabilidad, el espíritu de empresa, la adaptabilidad, la igualdad de oportunidades y la inversión en recursos humanos.

Por consiguiente, es necesario convocar procedimiento, en régimen de concurrencia competitiva, para la selección de beneficiarios de contratos para la formación de personal investigador en el marco del Plan Propio de Investigación de la UCLM, de acuerdo a las siguientes bases.

Albacete, 31 de julio de 2014

El Rector
P.D. (Resolución de 18/12/2013, DOCM de 02/01/2014)
El Vicerrector de Investigación y Política Científica
JOSÉ JULIÁN GARDE LÓPEZ-BREA

Además, desde el día 01 de Abril de 2016 hasta el 30 de Junio de 2016 disfrutó de una Estancia Pre-Doctoral en la Universidad de Exeter en Reino Unido, puesto que le fue concedida una *Ayuda para estancias en otras universidades y centros de investigación para el año 2016, cofinanciadas por el Fondo Europeo de Desarrollo Regional [2015/13630]*. Dicha estancia se realizó dentro del grupo de investigación CHERC (Children's Health and Exercise Research Centre) bajo la dirección del Professor Craig Williams.

UNIVERSITY OF EXETER

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Re. Esther Ubago Guisado (PhD student); Research stay at CHERC (Children's Health and Exercise Research Centre), University of Exeter, United Kingdom.

Professor Craig Williams certifies that Miss Esther Ubago Guisado visited CHERC (Children's Health and Exercise Research Centre) from 01st April 2016 to 30th June 2016 (three months). Esther has worked on four different manuscripts in relation to body composition, physical fitness and physical activity that will be published in JCR journals.

Esther has also acquired a variety of new skills analysing biochemical markers of bone metabolism (PINP, CTX, 25OHD and calcium) and using new equipment and software, such as the 'Achilles bone ultrasonometer', 'Air Displacement Plethysmography' and 'Trabecular Bone Score iNsight to enhance identification of fracture risk'. Moreover, Esther attended the internal meetings organised within CHERC.

Esther has been very productive during these three months and she has developed her skills in statistical analysis, scientific writing and use of scientific equipment.

Sincerely,

Professor Craig A. Williams
Director of CHERC
30/06/2016

RESUMEN

En los últimos años, ha aumentado el interés por la salud de los niños y por los diversos beneficios que se derivan de la práctica deportiva. Además, se ha producido un incremento alarmante del sobrepeso y la obesidad entre los jóvenes, y un aumento de la osteoporosis en la edad adulta. La obesidad en la infancia está estrechamente relacionada con la obesidad del adulto, hasta el punto de que estos niños tienen el doble de riesgo de desarrollar esta enfermedad en la edad adulta, que los que no son obesos.

Por otro lado, la osteoporosis se considera un problema de salud pública, debido al aumento de la población que la padece y las repercusiones socioeconómicas que se generan a causa de su tratamiento y rehabilitación. Este problema aún es más preocupante, debido a que ha aumentado el envejecimiento de la población. Asimismo, los efectos derivados de la actividad física durante la infancia, parecen provocar un efecto positivo en la acumulación de masa ósea, persistiendo éste en la edad adulta. Esos efectos pueden verse influenciados por diversos factores, entre los que encontramos el tipo de práctica deportiva, la condición física o el tipo de superficie deportiva sobre el que se realiza dicha práctica.

En la presente Tesis Doctoral, se han llevado a cabo cinco estudios diferentes que analizan la composición corporal y su relación con la práctica deportiva, la superficie de juego y la condición física en edad pediátrica. Los objetivos de estos estudios fueron: **1)** Analizar el efecto de la práctica deportiva en la masa grasa y masa muscular en niñas; **2)** Comparar las diferencias en masa ósea en niñas en función del tipo de deporte practicado; **3)** Estudiar la influencia de la masa grasa, la masa muscular, el consumo máximo de oxígeno, las horas de entrenamiento semanales y los años de práctica deportiva sobre la masa ósea en niñas; **4)** Examinar la asociación entre la condición física muscular y cardiorrespiratoria con la densidad mineral ósea y la geometría de cadera en niños; **5)** Comparar las diferencias en la masa ósea en niñas en función del pavimento utilizado durante su práctica deportiva.

En los **estudios 1 y 2**, la muestra estaba compuesta por 200 niñas prepúberes y púberes con edades comprendidas entre los 9 y 13 años (10.6 ± 1.5 años; Tanner I–III). Estas se

dividieron en cuatro grupos en función del deporte practicado fuera de la escuela: 40 futbolistas, 40 jugadoras de baloncesto, 40 jugadoras de balonmano y 40 nadadoras. También formaban la muestra un total de 40 niñas pertenecientes al grupo control. En el **estudio 3** no se incluyeron el grupo de nadadoras ni el grupo control, contando con un total de 120 participantes. La masa grasa, la masa muscular y la masa ósea se midieron usando absorciometría fotónica dual de rayos X (DXA). El grado de desarrollo sexual se determinó mediante el Test de Tanner, el $VO_{2máx}$ se calculó de forma indirecta a través del Test Course Navette y los hábitos de actividad física se registraron mediante un cuestionario diseñado *ad hoc* para esta investigación (anexo 1).

En el **estudio 4** participaron 121 niños de entre 12 y 14 años (13.1 ± 0.1 años; Tanner I-V) divididos en tres grupos en función del deporte practicado: 41 nadadores, 37 futbolistas y 29 ciclistas. También formaban la muestra un total de 14 niños pertenecientes al grupo control. La densidad mineral ósea y los parámetros de la estructura y geometría de la cadera fueron medidos usando DXA. Los test físicos realizados fueron el salto vertical y el salto de longitud para la valoración de la fuerza muscular de las extremidades inferiores y el Test Course Navette para la valoración de la capacidad cardiorrespiratoria. Además, se utilizaron dispositivos de acelerometría para la valoración objetiva de la actividad física vigorosa.

Por último, en el **estudio 5**, además de las 120 participantes y las pruebas anteriormente citadas del estudio 3, también se incluyeron seis superficies deportivas diferentes (fútbol-tierra, fútbol-césped artificial, baloncesto-sintético, baloncesto-parquet, balonmano-sintético y balonmano-hormigón liso). Las propiedades mecánicas de las superficies deportivas se evaluaron *in situ* bajo la norma UNE-EN 15330-1: 2014 para césped artificial y UNE-EN 14904: 2007 para las superficies interiores. A través del Triple A (Atleta Artificial Avanzado) se midieron la absorción de impactos (%), la deformación vertical (mm) y la energía de restitución (%) de cada superficie.

Las principales conclusiones de estos estudios fueron: **1)** Las niñas que practican deporte regular de alto impacto (fútbol, baloncesto y balonmano) y de bajo impacto (natación) tienen menor masa grasa y mayor masa muscular, en comparación con aquellas que no practican deporte durante la etapa prepuberal y puberal; **2)** Las niñas que practican deportes de alto impacto (fútbol, baloncesto y balonmano) tienen una mayor masa ósea, frente a niñas que practican deportes de bajo impacto (natación) o la falta de actividad física en la pubertad; **3)** Durante la pubertad, la masa ósea de las niñas está relacionada con la masa muscular, la condición física cardiorrespiratoria y las horas semanales de práctica deportiva; **4)** La actividad física vigorosa no parece explicar la asociación entre la condición física (cardiorrespiratoria y muscular) y los parámetros óseos (densidad mineral ósea y geometría de cadera), mientras que la masa muscular juega un papel clave en dicha asociación en jóvenes varones; **5)** Una superficie de juego dura, con menos deformación vertical y absorción de impactos, y una mayor energía de restitución, se asocia con niveles más altos de masa ósea en niñas, independientemente del deporte que practiquen.

ABSTRACT

Over the last years the benefits deriving from sport participation have gained interest, especially in paediatric population. In addition, there has been an alarming increase in overweight and obesity among young people and an increase in osteoporosis in adulthood. Obesity in childhood is closely related with adult obesity to the extent that obese children have twice the risk to develop this disease in adulthood than those who are not obese.

Osteoporosis is considered a public health problem due to the increasing number of people suffering it and the socioeconomic repercussions that are generated by its treatment and rehabilitation. This problem is even more worrying because life expectancy continuously increases as so it does the number of people suffering osteoporosis. During childhood, being physically active seems to have a positive effect on the accumulation of bone mass, which persists into adulthood. Besides, these effects can be influenced by several factors, such as the type of sport or playing surface.

The present Doctoral Thesis includes five different studies that analyse the body composition and its relationship with sports, playing surface and physical fitness in paediatric age. The objectives of these studies were: **1)** To analyse differences on fat mass and lean mass in girls playing different sports; **2)** To compare the differences on bone mass in girls according to the type of sport practiced; **3)** To study the influence of fat mass, lean mass, maximum oxygen consumption, weekly training hours and years of sports practice on bone mass on girls; **4)** To examine the association between muscular and cardiorespiratory fitness with bone mineral density and hip geometry in boys; and **5)** To compare the differences on bone mass in girls playing on different surfaces.

In **studies 1 and 2**, the sample was composed of 200 prepubertal and pubertal girls aged 9 to 13 years old (10.6 ± 1.5 years old; Tanner I-III), divided in four groups according to the sport practiced: 40 footballers, 40 basketball players, 40 handball players and 40 swimmers. In addition, 40 inactive girls were recruited as control group. In **study 3**, 120 participants were measured after removing swimmers and controls. Fat mass, lean mass

and bone mass were measured using dual-energy X-ray absorptiometry (DXA). Sexual maturation was determined by the Tanner method; VO_{2max} was calculated indirectly through the Course Navette Test; and physical activity habits were recorded using a questionnaire designed ad hoc for these studies (annex 1).

In **study 4**, 121 young males aged 12 to 14 years old (13.1 ± 0.1 years old; Tanner I-V) were divided in three groups according to the sport practiced: 41 swimmers, 37 footballers and 29 cyclists. In addition, 14 boys not participating in these sports regularly were recruited as control group. Bone mineral density and hip structure and geometry parameters were measured using DXA. Lower limbs muscular fitness was measured by means of the vertical jump and standing long jump tests while cardiorespiratory fitness was measured by means of the Course Navette Test. In addition, tri-axial accelerometers were used for the objective assessment of vigorous physical activity.

Finally, **study 5** includes the same participants and tests than those described in study 3 according to six different playing surfaces (soccer-ground, soccer-artificial turf, basketball-synthetic, basketball-parquet, handball-synthetic and handball-smooth concrete). The mechanical properties of playing surfaces were evaluated in situ according to regulations UNE-EN 15330-1: 2014 for artificial turf and UNE-EN 14904: 2007 for indoor surfaces. Force reduction (%), vertical deformation (mm) and energy return (%) for each surface was measured by the Triple A (Advanced Artificial Athlete).

The main conclusions of these studies were: **1)** Girls who practice regular high impact sports (football, basketball and handball) and low impact (swimming) have lower fat mass and higher lean mass compared to the controls at prepubescence and puberty; **2)** Girls who practice high impact sports (football, basketball and handball) have higher bone mass compared to girls who practice low impact sports (swimming) and controls at puberty; **3)** During puberty, bone mass in girls is related to lean mass, cardiorespiratory fitness and weekly hours of sports practice; **4)** Vigorous physical activity does not seem to explain the association between fitness (cardiorespiratory and muscular) and bone parameters (bone mineral density and hip geometry), while lean mass plays a key role in this association in young males; and **5)** A hard playing surface, with less vertical deformation and force reduction; and higher energy return, is associated with higher levels of bone mass in girls, regardless of the sport they practice.

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ÍNDICE DE ABREVIATURAS [LIST OF ABBREVIATIONS]

AFM: Actividad física moderada.

AFV: Actividad física vigorosa.

ANCOVA: Análisis de la covarianza.

ANOVA: Análisis de la varianza.

CMO: Contenido mineral óseo.

DE: Desviación estándar.

DMO: Densidad mineral ósea.

DXA: Absorciometría fotónica dual de rayos X.

ES: Tamaño del efecto

HSA: Análisis estructural de cadera.

IC: Intervalos de confianza.

SPSS: Paquete estadístico para ciencias sociales.

* Abbreviations in English language are shown in the scientific papers included in the present Doctoral Thesis.

Capítulo 1

INTRODUCCIÓN [INTRODUCTION]

1.1. EL DESARROLLO DE LA COMPOSICIÓN CORPORAL DURANTE EL CRECIMIENTO

1.1.1. Masa ósea: estructura, composición y remodelado óseo

Estructura y composición

La función principal del tejido óseo es proteger nuestro organismo y dar soporte estructural (Merí, 2005). La rigidez de dicho tejido viene determinada por su estructura y su composición (Seeman, 2008). Los huesos se dividen según su morfología en huesos largos, huesos cortos y huesos planos (Latarjet & Ruiz-Liard, 2004). Estos se componen de una estructura hueca cilíndrica llamada diáfisis y dos extremos más anchos recubiertos de cartílago llamados epífisis. Entre la diáfisis y la epífisis se encuentra una porción de hueso que recibe el nombre de metáfisis, donde se encuentra el cartílago de crecimiento (Young, O'Dowd, & Woodford, 2014). Cuando termina el crecimiento óseo longitudinal, el cartílago de crecimiento es sustituido por tejido óseo esponjoso, fusionándose la diáfisis y la epífisis (Young et al., 2014). Las propiedades elásticas del hueso le permiten absorber energía por deformación cuando sufre una carga mecánica (Currey, 2002).

Además, el hueso está formado por dos tipos diferentes de tejidos. Por un lado, el tejido óseo compacto (hueso cortical), se encuentra en la capa más externa de los huesos y en la diáfisis de los huesos largos, aportando resistencia a las fuerzas de compresión y a las tensiones musculares producidas durante la contracción (Merí, 2005). Por otro lado, el tejido óseo esponjoso (hueso trabecular), se encuentra en el interior de los huesos y en la epífisis de los huesos largos, está muy vascularizado y contiene la médula ósea roja, donde tiene lugar la producción de células sanguíneas. El hueso se compone principalmente de matriz ósea y elementos celulares específicos, entre los que destacamos los siguientes (Hernández et al., 2003):

- **Osteoblastos**: son los responsables de la formación de la matriz extracelular del hueso y de su mineralización.

- **Osteoclastos**: son los agentes principales del recambio óseo y responsables de la reabsorción de la matriz ósea. Por ello, juegan un papel muy importante en la mayoría de las enfermedades del esqueleto, como por ejemplo, la osteoporosis (exceso de actividad osteoclástica).

- **Osteocitos**: son células óseas maduras procedentes de los osteoblastos que constituyen el 90% del tejido óseo.

Remodelado óseo

El hueso es un órgano formado por tejido óseo que se encuentra en constante cambio durante el desarrollo del ser humano, a través de una serie de procesos de modelado, remodelado y reparación (López-Chicharro & López-Mojares, 2008). El **modelado** es la etapa asociada al crecimiento en la infancia y adolescencia, donde el hueso adquiere y mantiene su forma; el **remodelado** es un proceso de formación y destrucción del hueso (Figura 1); y la **reparación** se produce como respuesta ante una fractura (López-Chicharro & López-Mojares, 2008).

En el remodelado intervienen las células óseas llamadas osteoclastos, que son las responsables de la reabsorción ósea en la superficie del hueso, y los osteoblastos que son los encargados de la formación (Hernández et al., 2003). En 1987, Frost sentó las bases conceptuales de la remodelación ósea, describiéndolo como un fenómeno dinámico mediante el cual, el tejido óseo es activamente reabsorbido y reemplazado por tejido nuevo (Frost, 1987; Parfitt et al., 1987). Este es un proceso continuo que existe toda la vida, pero sólo hasta la tercera década el balance es positivo (Ross & Pawlina, 2009).

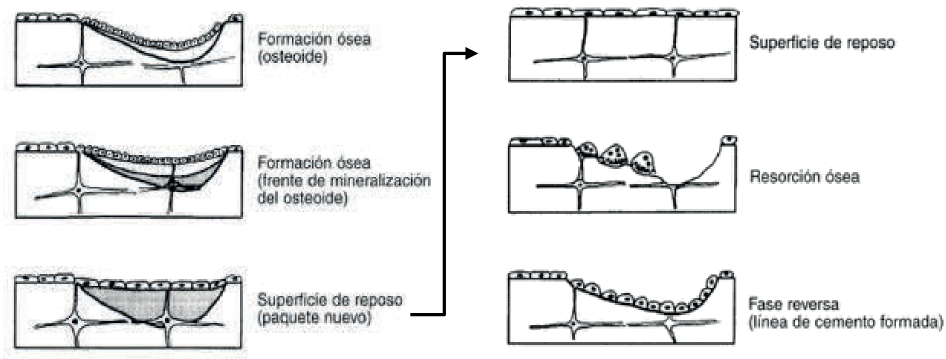


Figura 1. Proceso de remodelado óseo (Zanchetta & Talbot, 2001).

Son numerosos los factores que afectan a la acumulación y pérdida de masa ósea, siendo los más importantes los de tipo genético, mecánico, nutricional y hormonal, entre otros. Se ha estimado que entre el 60% y el 80% en la variación en el pico de masa ósea está genéticamente determinada (Cheng et al., 2009). Por ello, la predisposición a padecer osteoporosis es más alta en hijas con madres que la sufren (Pocock et al., 1987). Por otro lado, aproximadamente el 20% de la variación del pico de masa ósea se explica a través de estilo de vida (Ferrari, 2005). De hecho, la actividad física es imprescindible para el correcto desarrollo del hueso (Branca & Valtuena, 2001) y por el contrario, la falta de actividad, el reposo o la ingravidez tienen un efecto negativo sobre el hueso, acelerando la reabsorción (Morey & Baylink, 1978).

Además, la ingesta de calcio (Vicente-Rodriguez et al., 2008) y los hábitos tóxicos como la cafeína, el alcohol y el exceso de sal constituyen factores de riesgo para la aparición de la osteoporosis (Fernández-Tresguerres, Alobera-Gracía, Del Canto-Pingarrón, & Blanco-Jerez, 2006). Por último, el desarrollo normal del esqueleto está condicionado por el correcto funcionamiento del sistema endocrino, fundamentalmente de la hormona del crecimiento y las hormonas calcitrópicas (parathormona, calcitonina y metabolitos de la vitamina D) (Fernández-Tresguerres et al., 2006).

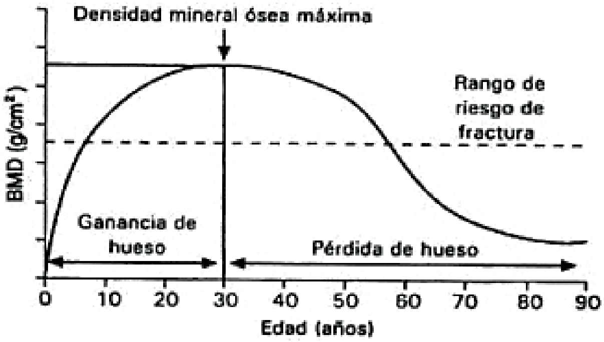


Figura 2. Desarrollo de la DMO (Mahan, Escott-Strump, & Raymond, 2012).

Adquirir una elevada masa ósea durante la infancia y adolescencia determina en gran medida la salud ósea adulta (Rizzoli, Bianchi, Garabédian, McKay, & Moreno, 2010). Durante la infancia y la adolescencia se produce el mayor crecimiento y maduración del esqueleto (Figura 2), junto con una mineralización ósea que se consolida al final de la pubertad (Maïmoun & Sultan, 2011), pudiendo alcanzarse el 51% del pico de masa ósea en este periodo (MacKelvie, Khan, & McKay, 2002).

Las mayores ganancias en la masa ósea se aprecian entre los 11 y 14 años en las chicas y entre los 14 y 16 años en chicos (Bailey, McKay, Mirwald, Crocker, & Faulkner, 1999). La acumulación de masa ósea se conserva durante la adolescencia y a partir de los 30 años, la cantidad de hueso que se reabsorbe comienza a superar a la que se renueva (Ljunggren, 2006). Por ello, la calidad del hueso obtenida durante la infancia resulta fundamental para prevenir riesgos posteriores, puesto que se mantiene durante la etapa adulta y va disminuyendo en la vejez.

1.1.2. Tejidos blandos: masa muscular y masa grasa

Antes de la pubertad, los niños y niñas tienen un porcentaje de grasa corporal similar, sin embargo, durante la pubertad los chicos pierden grasa corporal mientras que las chicas la ganan (McKeag, 1991). Durante el crecimiento, la composición corporal se modifica de forma significativa, debido a la influencia de los estrógenos y de la testosterona (López-Chicharro, Lucía-Mulas, Pérez-Ruíz, & López-Mojares, 2002). Al comienzo de la edad adulta, según la SEEDO (Sociedad Española para el Estudio de la Obesidad), los hombres tienen en torno a un 18% de grasa corporal y las mujeres un

22%, debido a la mayor cantidad de estrógenos que generan las mujeres (López-Chicharro et al., 2002).

En cuanto a la masa muscular, desde el nacimiento hasta la adolescencia se produce un aumento de la misma, alcanzándose los valores máximos entre los 16 a 20 años en mujeres y entre los 18 a 25 años en los hombres (López-Chicharro et al., 2002). Este aumento es debido a un mayor tamaño de las fibras musculares (hipertrofia), y no a un incremento del número de fibras musculares (hiperplasia) (López-Chicharro & Fernández-Vaquero, 2006). La masa muscular aumenta de forma progresiva hasta los 15 años en las chicas y hasta los 17-18 años en los chicos (Andrade-Ramiro, Previnaire, & Sturbois, 1990). Esto hace que durante la adolescencia aumenten las diferencias entre sexos, mientras que durante la etapa preadolescente son menores. La asociación entre los tejidos blandos y la masa ósea ha sido objeto de estudio en los últimos años y se presenta a continuación.

1.2. ASOCIACIÓN ENTRE LOS TEJIDOS BLANDOS Y LA MASA ÓSEA

Las fuerzas musculares actúan sobre el hueso, surgiendo una relación intrínseca entre ambos. Esta relación se describe a través de la teoría del mecanostato propuesta por Frost (1987). Existe un mecanismo que regula el crecimiento y la pérdida de hueso, en función de los estímulos mecánicos que deforman localmente el mismo (fuerza, presión y torsión) (Frost, 1987). Según este modelo, el incremento de la fuerza muscular máxima durante el crecimiento o en respuesta al incremento de la carga, afectará a la masa ósea, al tamaño y a la resistencia del hueso, produciéndose un efecto directo en la ganancia de masa ósea, a través del incremento de la masa muscular (Daly, Saxon, Turner, Robling, & Bass, 2004; Vicente-Rodriguez, Ara, Perez-Gomez, Dorado, & Calbet, 2005).

Por ello, el desarrollo del sistema muscular y esquelético no debe considerarse por separado, ya que los cambios en la fuerza muscular afectan a la resistencia ósea (Schoenau & Frost, 2002). Este concepto de una unidad músculo-hueso, subraya que la resistencia ósea está estrechamente relacionada con la fuerza muscular (Vivanco-Muñoz et al., 2012).

Esta relación ha sido demostrada en la literatura científica a lo largo de los últimos años (Figura 3) (Gracia-Marco, 2016). Diversos estudios transversales han señalado una asociación positiva entre el contenido mineral óseo (CMO) y la fuerza muscular del antebrazo en niños y niñas (Schoenau, Neu, Beck, Manz, & Rauch, 2002; Schoenau, Neu, Mokov, Wassmer, & Manz, 2000). Del mismo modo, se encontró que la actividad de levantamiento de peso contribuye a la mejora de la resistencia ósea de las extremidades inferiores (Duncan et al., 2002; Greene et al., 2005).

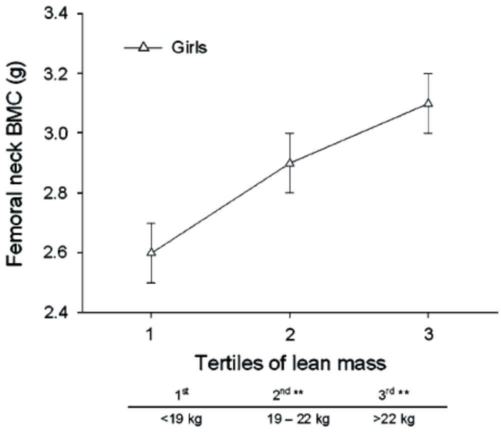


Figura 3. El CMO del cuello femoral está positivamente relacionado con la masa muscular total en niñas (Baptista et al., 2012).

Hay pocos datos sobre los cambios longitudinales en la relación entre el músculo y el hueso durante el crecimiento en los niños. La mayoría de los estudios longitudinales han investigado la fuerza muscular, en relación con la velocidad del crecimiento óseo en el radio o la tibia (Jackowski et al., 2009; Rauch, Bailey, Baxter-Jones, Mirwald, & Faulkner, 2004; Xu, Nicholson, Wang, Alén, & Cheng, 2009). Estos estudios muestran que los cambios en el tamaño o la fuerza muscular, preceden a los cambios en la masa ósea. Por lo tanto, el conocimiento de la relación músculo-hueso, va a mejorar nuestra comprensión de la fisiología y la fisiopatología del desarrollo óseo en niños y adolescentes.

Así como el papel de la masa muscular en el desarrollo de la masa ósea es evidente, la asociación entre la masa grasa y la masa ósea genera cierto debate. Diversos estudios transversales (El Hage, Jacob, et al., 2009; Pietrobelli et al., 2002) y longitudinales (Sayers & Tobias, 2010; Young et al., 2001) en chicas, demuestran que la masa grasa está relacionada positivamente con la masa ósea. No obstante, otros estudios apoyan la idea de que la masa grasa está negativamente relacionada con la densidad mineral ósea (DMO) en chicos (El Hage, Courteix, Benhamou, Jacob, & Jaffré, 2009; El Hage, Moussa, El Hage, Theunynck, & Jacob, 2011). Otras investigaciones señalan que tener sobrepeso y obesidad en la niñez y adolescencia está asociado a menores niveles de CMO y DMO (Goulding, Taylor, Jones, Manning, & Williams, 2002; Rocher, Chappard, Jaffre, Benhamou, & Courteix, 2008), mientras que otros autores demuestran lo contrario (Cobayashi, Lopes, & Taddei, 2005; Ellis, Shypailo, Wong, & Abrams, 2003; Leonard, Shults, Wilson, Tershakovec, & Zemel, 2004; Reid, 2002).

Sin embargo, la mayoría de estas investigaciones no han valorado la presencia de variables de confusión, como pueden ser la actividad física valorada de forma objetiva y la masa muscular, entre otras. Estudios recientes han mostrado que la posible asociación entre la masa grasa y la masa ósea, queda anulada completamente una vez que el efecto de la masa muscular se controla (Gracia-Marco et al., 2012). Estos hallazgos sugieren, que la razón por la cual los adolescentes con sobrepeso y obesidad tienen mayor masa ósea, es debido a que desarrollan una mayor masa muscular y no debido a la mayor masa grasa.

1.3. LA ACTIVIDAD FÍSICA Y LA COMPOSICIÓN CORPORAL

La actividad física se define como cualquier movimiento del cuerpo, producido por los músculos esqueléticos que genera gasto energético (Caspersen, Powell, & Christenson, 1985). Actualmente, las recomendaciones actuales de actividad física para niños y adolescentes con edades comprendidas entre los 5 a 17 años son, acumular como mínimo, 60 minutos diarios de actividad física de al menos moderada intensidad (World Health Organization, 2010).

Durante la adolescencia, la práctica regular de actividad física produce diversos beneficios no sólo a nivel físico, disminuyendo el riesgo de enfermedades cardiovasculares (Boreham et al., 2002), o el riesgo de diferentes tipos de cáncer (Okasha, McCarron, Gunnell, & Smith, 2003), sino también a nivel social (Slattery, Edwards, Ma, Friedman, & Potter, 1997) y mental, combatiendo la depresión y la ansiedad (Lavie, Milani, O'Keefe, & Lavie, 2011). También previene de otras enfermedades como la diabetes tipo 2 (Steanovv, Vekova, Kurktschiev, & Temelkova-

Kurktschiev, 2011) y la obesidad (Blair, 1993). A pesar de ello, en los últimos años ha habido una tendencia negativa en los niveles de práctica de actividad física de los más jóvenes (Brodersen, Steptoe, Boniface, & Wardle, 2007; Gracia-Marco et al., 2010; Roman, Serra-Majem, Ribas-Barba, Perez-Rodrigo, & Aranceta, 2008).

A continuación, se describen los conceptos utilizados en la descripción de los niveles de actividad física recomendados (World Health Organization, 2010):

- **Actividad física moderada (AFM):** actividad física realizada con un nivel de intensidad de entre 3.0 a 5.9 METS.

- **Actividad física vigorosa (AFV):** actividad física realizada a un nivel de intensidad de 6.0 METS o superior.

El MET es la unidad de medida del índice metabólico y corresponde a 3,5 ml O_2/kg/min, que es el consumo mínimo de oxígeno que el organismo necesita para mantener sus constantes vitales.

Dentro de la literatura científica, existen diversos métodos para cuantificar la actividad física y el gasto energético en niños y adolescentes (Sirard & Pate, 2001). Estos se dividen en tres grandes grupos:

- Las **técnicas de referencia**, como pueden ser el agua doblemente marcada (Armstrong & Welsman, 2006) y la calorimetría indirecta (Gracia-Marco, Vicente-Rodríguez, Rey-López, España-Romero, & Moreno, 2009), para la obtención del gasto energético. Destacan por su fiabilidad, aunque debido a su coste económico no son muy utilizados en el ámbito epidemiológico.

- Las **técnicas subjetivas** tienen el inconveniente de que infra y/o sobrestiman los niveles de actividad física (Bassett, 2000; Hagstromer et al., 2008; Westerterp, 2009). A pesar de ello, numerosos estudios utilizan los cuestionarios y entrevistas para valorarla (Branca & Valtuena, 2001; Burrows, Díaz, & Muzzo, 2004; Delvaux et al., 2001; Kemper et al., 2000; Kriemler et al., 2008; McVeigh, Norris, Cameron, & Pettifor, 2004; Sundberg et al., 2002; Tobias, Steer, Mattocks, Riddoch, & Ness, 2007)

- Las **técnicas objetivas** como los acelerómetros, los monitores de frecuencia cardíaca y los podómetros, se han utilizado con mayor frecuencia en los últimos 20 años. En este sentido, los acelerómetros son los más exitosos, ya que además de obtener información relativa a la intensidad, duración y frecuencia de actividad física, también pueden monitorizar la frecuencia cardiaca y el número de pasos. En función del número de ejes en los que registran el movimiento, los acelerómetros se clasifican en: uniaxiales (eje longitudinal), biaxiales (ejes longitudinal y transversal) y triaxiales (ejes longitudinal, transversal y antero-posterior). Estudios previos han analizado la asociación entre la actividad física valorada mediante acelerometría y la masa ósea (Kriemler et al., 2008; Tobias et al., 2007), siendo la mejor opción debido a su reducido coste, facilidad de uso y precisión.

1.3.1. La actividad física y su relación con los tejidos blandos

El incremento de la actividad física se asocia a una mejora de los índices de salud (Hallal, Victora, Azevedo, & Wells, 2006). La actividad física influye sobre la masa muscular como resultado del incremento del gasto energético, y ayuda a mantener la masa muscular, la DMO y el peso corporal (Hallal et al., 2006). La práctica de actividad física desde edades tempranas no sólo mejora la salud general, sino también la salud ósea (Bielemann, Martinez-Mesa, & Gigante, 2013; Gunter, Almstedt, & Janz, 2012). Asimismo, se ha observado su efecto beneficioso en la prevención de enfermedades crónicas y degenerativas, gracias a la reducción de la obesidad y a la mejora en la composición corporal (Yeung, Yuan, Hui, & Feresu, 2016). Además, es importante destacar que los beneficios para la salud derivados de la actividad física en la infancia, se transmiten a la vida adulta (Aznar, Webster, & López- Chicharro, 2005).

Como forma de actividad física, el deporte tiene influencia sobre el desarrollo de los tejidos blandos. En este sentido, el tipo de deporte condiciona el somatotipo del que lo practica (Andrade-Ramiro et al., 1990). Cada deporte, debido a sus características y requerimientos se asocia con distintos perfiles de jugadores (Bahamondes-Avila, Cifuentes-Cea, Lara-Padilla, & Berral-De La Rosa, 2012). Varios estudios muestran que los jugadores de baloncesto muestran mayor masa muscular que los futbolistas (Gil-Gómez & Juan, 2011; Pérez-Guisado, 2009), puesto que al tratarse de un deporte más explosivo produce un mayor desarrollo de la misma, especialmente en las piernas (Koley, Singh, & Kaur, 2011).

Por otro lado, en el estudio de Milanese, Piscitelli, Lampis y Zancanaro (2011), existe una clara tendencia de las jugadores de balonmano femenino de élite a acumular más masa muscular en el tren superior, frente a jugadoras de categorías inferiores, resaltando el papel de la práctica deportiva regular. En otra línea, Grijota, Muñoz, Crespo, Robles y Maynar (2012) mostraron que el porcentaje de masa grasa en nadadores, era superior al de otros deportistas (balonmano y karate) en categorías infantiles.

1.3.2. La actividad física y su relación con la masa ósea

En 1870, Wolff afirmó que la arquitectura ósea está determinada por el espesor y el número de trabéculas, es decir, la distribución de la masa ósea corresponde a la distribución de las cargas mecánicas por estrés, mediante compresión o tensión (Wolff, 1870). Esta teoría se consideró la base de nuestros conceptos actuales de adaptación ósea y, a partir de esta base, están surgiendo nuevos conceptos. En 1987, Frost explicó que no sólo era la tensión mecánica el principal impulsor de la adaptación ósea, sino que también es necesario un umbral de tensión mínimo, para que se produzca la adaptación del hueso (Figura 4) (Frost, 1987). Además, ese aumento de la formación ósea se produce mediante estrés dinámico y no estático (Hert, Liskova, & Landa, 1971), convirtiéndose en el principal estímulo de adaptación ósea. Así pues, la actividad física es un claro ejemplo de estrés dinámico.

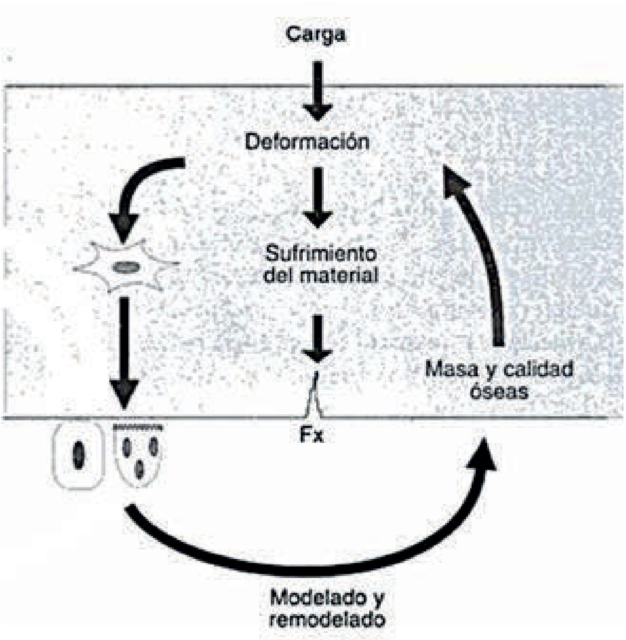


Figura 4. La teoría del mecanostato de Frost (Zanchetta & Talbot, 2001).

Por lo tanto, existe una fuerte evidencia de que la actividad física se relacionada con la salud ósea en edades pediátricas, debido a la mayor sensibilidad del esqueleto para adaptarse a la tensión mecánica (Hallal et al., 2006). Estudios previos han demostrado que la acumulación de masa ósea en edades tempranas y su persistencia en la edad adulta, se ve favorecida por la práctica deportiva o actividad física entre los 8 y los 15 años (Baxter-Jones, Eisenmann, Mirwald, Faulkner, & Bailey, 2008; Baxter-Jones, Kontulainen, Faulkner, & Bailey, 2008).

Por otra parte, los beneficios del ejercicio parecen ser mayores cuando se practica antes de la pubertad (Vicente-Rodriguez et al., 2003). Este no sólo produce un aumento de la masa ósea, sino también cambios estructurales que pueden persistir de por vida (Gustavsson, Thorsen, & Nordström, 2003). De hecho, estudios anteriores concluyen que existe una relación directa, entre la cantidad de actividad física y la masa ósea (Burrows, Baxter-Jones, Mirwald, Macdonald, & McKay, 2009; Delvaux et al., 2001; Kemper et al., 2000; McVeigh et al., 2004; Sundberg et al., 2002), también confirmada mediante estudios longitudinales (Delvaux et al., 2001; Rauch et al., 2004; Vicente-Rodriguez, Ara, et al., 2004).

En cuanto a la intensidad, se ha demostrado que periodos de AFV de al menos 28 minutos diarios, están asociados con una DMO óptima (+2 desviaciones estándar) en el cuello femoral (Gracia-Marco, Moreno, et al., 2011). Además, estudios en chicos preadolescentes han mostrado que el CMO y los valores de geometría de cadera, están positivamente relacionados con la AFV (Sayers et al., 2011; Tobias et al., 2007). Por otro lado, se ha sugerido en niños que son necesarios 25 minutos de AFV por día, para aumentar la masa ósea y los valores de geometría de cadera (Sardinha, Baptista, & Ekelund, 2008).

No obstante, investigaciones previas han sugerido que la asociación entre los resultados de AFV y de hueso, está mediada por otros factores como la masa muscular. El estudio realizado por Janz et al. (2004) en niños, mostró que la AFV explicaba el 6,9% de la variabilidad en variables relacionadas con la geometría de cadera, tales como el área transversal y la sección modular. Sin embargo, la asociación se debilitó (al 3,7%) al controlar en los análisis de regresión la masa muscular. Otro estudio realizado en niños y niñas de 8 a 15 años, observó que la asociación entre la actividad física y la resistencia ósea del cuello femoral desapareció, después de ajustar por la masa muscular (Forwood et al., 2006).

Por otro lado, en los últimos años ha aumentado el interés por los diversos efectos osteogénicos que producen diferentes disciplinas deportivas (Agostinete et al., 2016; Weidauer, 2012). Los ejercicios de alta intensidad, de impactos y en los que el sujeto soporta el propio peso corporal son sugeridos para mejorar la DMO. En este sentido, ejercicios pliométricos y de carreras con cambios de dirección, aceleraciones y frenadas bruscas son altamente recomendados (Vicente-Rodríguez, 2006). Por esa razón, los deportes como el fútbol (Vicente-Rodriguez et al., 2003; Vlachopoulos et al., 2016; Zouch et al., 2015), el baloncesto (Agostinete et al., 2016) o el balonmano (Missawi et al., 2016; Vicente-Rodriguez, Dorado, Perez-Gomez, Gonzalez-Henriquez, & Calbet, 2004) producen grandes estímulos en los huesos, debido a las fuerzas de reacción aplicadas durante el desarrollo de las diferentes acciones del juego, siendo beneficiosos para la deposición de calcio y remodelación ósea en la infancia y adolescencia.

Sin embargo, en relación con los deportes de bajo impacto, como puede ser la natación o el ciclismo, se ha observado que tanto ciclistas como nadadores tienen un hueso más débil que los atletas de deportes de alto impacto (Ferry et al., 2011; Gómez-Bruton, Gónzalez-Agüero, Gómez-Cabello, Casajús, & Vicente-Rodríguez, 2013; Olmedillas, Gonzalez-Aguero, Moreno, Casajus, & Vicente-Rodriguez, 2011; Vlachopoulos et al., 2016). Por lo tanto, durante la pubertad se ha demostrado que deportes de alto impacto donde se soporta el propio peso corporal, producen un mayor efecto positivo sobre el hueso, frente a deportes de bajo impacto donde no se soporta el propio peso corporal, como la natación y el ciclismo.

1.4. CONDICIÓN FÍSICA Y MASA ÓSEA

La condición física se define como *un conjunto de atributos relacionados con la habilidad de un sujeto, para desarrollar actividades físicas que requieren condición aeróbica, resistencia, fuerza o flexibilidad, y que está determinada por una combinación entre actividad regular y habilidad adquirida genéticamente* (Caspersen et al., 1985). Una buena condición física implica llevar a cabo las tareas diarias, sin fatiga excesiva y con la energía suficiente para disfrutar de actividades de tiempo libre (Siscovick, Laporte, & Newman, 1985). Por otra parte, los componentes que conforman la condición física se dividen en dos grupos (Caspersen et al., 1985):

- **Relacionado con la salud:** la resistencia cardiorrespiratoria, la resistencia muscular, la fuerza muscular, la composición corporal y la flexibilidad.

- **Relacionado con las habilidades referentes a la capacidad atlética:** la agilidad, el equilibrio, la coordinación, la velocidad, la potencia y el tiempo de reacción.

En los últimos años, la condición física se ha consolidado como un importante marcador de salud (Ortega, Ruiz, Castillo, & Sjöström, 2008), y por ello, se han publicado valores de referencia de condición física tanto en niños (De Miguel-Etayo et al., 2014), como en adolescentes (Ortega et al., 2011). No sólo se puede medir la salud en general (Przeweda & Dobosz, 2003), sino también la salud cardiovascular (Ortega et al., 2005; Ortega et al., 2008), muscular (Vicente-Rodriguez, Ara, et al., 2004) y ósea (Fonseca, De Franca, & Van Praagh, 2008; Vicente-Rodriguez, Dorado, et al., 2004; Vicente-Rodriguez et al., 2003; Vicente-Rodriguez et al., 2008; Wang et al., 2007). Además, la condición física también se ha relacionado con la masa ósea y su geometría (Daly, Stenevi-Lundgren, Linden, & Karlsson, 2008).

A la hora de relacionar la condición física y la masa ósea existe cierta controversia, ya que hay que tener en cuenta que esta relación puede verse influenciada por diversos factores, tanto intrínsecos como extrínsecos. En pruebas de condición física muscular en adolescentes, como el salto de longitud o la prueba de presión manual, después de ajustar por sexo, altura, masa magra, ingesta de calcio y desarrollo puberal, se observó una relación positiva con el CMO en todo el cuerpo y en las extremidades inferiores (Gracia-Marco, Vicente-Rodríguez, et al., 2011). Otro estudio encontró una relación entre el CMO y la condición física muscular en los adolescentes, independientemente del estado de maduración y la masa magra (Vicente-Rodriguez et al., 2008).

En relación a la capacidad cardiorrespiratoria, un estudio longitudinal en adolescentes encontró que está directamente relacionada con la formación y la reabsorción de la masa ósea (Schneider et al., 2007). En una investigación realizada por Gracia-Marco, Vicente-Rodríguez, et al. (2011), el bajo rendimiento en el Test Course Navette se relacionó con un menor CMO en todo el cuerpo en adolescentes activos, ajustando por sexo, altura, masa magra, ingesta de calcio y desarrollo puberal. Por el contrario, en un estudio longitudinal de 15 años en adolescentes, las asociaciones encontradas entre la aptitud cardiorrespiratoria (medido directamente como $VO_{2máx}$) y la DMO de la columna lumbar y de la cadera, desaparecieron después de controlar por sexo, estatura, peso, pliegues cutáneos, edad biológica e ingesta de calcio (Kemper et al., 2000).

1.5. VALORACIÓN DE LA COMPOSICIÓN CORPORAL: DXA

Existe una gran variedad de métodos validados para la valoración de la composición corporal (Wells & Fewtrell, 2006). Comúnmente, se clasifican en **métodos de campo y de laboratorio**. Algunos de los **métodos de campo** más utilizados para la valoración de la grasa corporal son: los pliegues cutáneos (Brook, 1971; Wendel et al., 2016) o el análisis de impedancia bioeléctrica (Kushner, 1992; Kyle, Earthman, Pichard, & Coss-Bu, 2015), entre otros. Por otro lado, entre los **métodos de laboratorio** más utilizados para la valoración de la composición corporal, encontramos:

- La hidrodensitometría (Fuller, Jebb, Laskey, Coward, & Elia, 1992) y la pletismografía por desplazamiento de aire (conocido como Bod Pod) (Fields, Goran, & McCrory, 2002), para la medición de la densidad corporal y posterior estimación del porcentaje de grasa.

- El DXA (Lifshitz et al., 2016), para la valoración de la masa ósea y los tejidos blandos.

A pesar de que el **Bod Pod** es considerado un método de referencia en población pediátrica, para la valoración de los tejidos blandos como la masa grasa y la masa libre de grasa (Michels et al., 2013), el **DXA** ofrece una visión más completa y detallada (a nivel de cuerpo entero y regional), tanto de la masa grasa (Henche, Torres, & Pellico, 2008), la masa libre de grasa (Freedman et al., 2005), la masa muscular (Jeddi et al., 2015) y la masa ósea (Bachrach & Gordon, 2016). En este sentido, la valoración de la DMO y el CMO a través del DXA, es considerado el método de referencia para el diagnóstico no invasivo de la osteoporosis (Crabtree et al., 2014).

Esta técnica es el resultado de la evolución de la absorción de fotón de energía única y de dos energías (Sirvent-Belando et al., 2009). Es una prueba fácil de realizar, segura y clínicamente aceptada en niños y adultos (Lim, 2010). Actualmente, el DXA ha sido utilizado globalmente en numerosos estudios en niños y adolescentes, no sólo para la evaluación de la masa ósea (Agostinete et al., 2016; Binkovitz, 2007; Heidemann et al., 2013; Vlachopoulos et al., 2015), sino también para los tejidos blandos (Jespersen et al., 2014; McCormack, Meendering, Specker, & Binkley, 2016; Toschke et al., 2007). Por lo tanto, su uso en edad pediátrica está muy aceptado, tanto en el campo clínico como en el de la investigación.

La técnica consiste en hacer pasar radiación de baja intensidad por todo el cuerpo, para medir la atenuación diferencial de haces de rayos X de dos energías diferentes, cuando estas atraviesan el organismo (Binkovitz, 2007). Consta de una unidad de exploración y una consola de control (Figura 5). La unidad de exploración es una camilla sobre la que se coloca el participante en decúbito supino, donde se encuentra la fuente emisora de radiación.

Las mediciones se pueden hacer del cuerpo entero y a nivel regional, como por ejemplo, la cadera y la columna lumbar. En el apartado clínico, a la hora de interpretar los resultados en niños surgen algunos conflictos. Sin embargo, en investigación el DXA se puede usar para medir los efectos del ejercicio entre diferentes grupos, siempre especificando la versión del software, la marca y el modelo de la máquina, para permitir la comparación con otros datos publicados (Fewtrell, 2003).

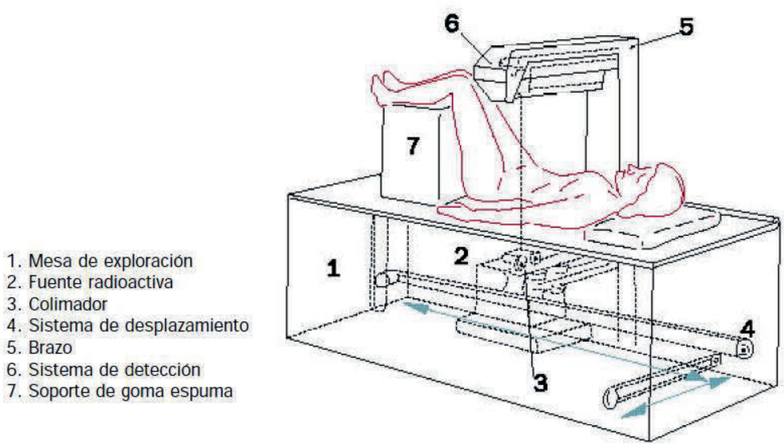


Figura 5. Componentes de la unidad de exploración del DXA (Dolors-Estrada et al., 1999).

1.6. LAS SUPERFICIES DEPORTIVAS Y SU RELACIÓN CON LA MASA ÓSEA

El estudio de las superficies deportivas es un tema importante, que abarca aspectos de diseño, materiales, construcción, rendimiento y durabilidad (Fleming, 2011). Las funciones principales de una superficie deportiva son: proporcionar condiciones de seguridad en la interacción del jugador y la interacción con la pelota, a un buen nivel de rendimiento (Fleming, 2011). Hay diferentes tipos de superficies en las que las personas practican deportes, pero, en general, las más investigadas son el césped natural y el césped artificial (Akkaya, 2011; Fuller, Dick, Corlette, & Schmalz, 2007; Soligard, Bahr, & Andersen, 2012; Steffen, Andersen, & Bohr, 2007; Stiles, James, Dixon, & Guisasola, 2009).

El césped artificial está bajo el punto de mira sobre su influencia en los riesgos de lesión del jugador (Dragoo, Braun, & Harris, 2013; Hägglund, Walden, & Atroshi, 2009; Knowles, 2010), y sobre el rendimiento del jugador en el terreno de juego (Fleming, 2011). Sin embargo, también es importante estudiar la relación que existe entre el jugador y la superficie, no sólo para el rendimiento, sino también para la salud del mismo, en superficies tanto de exterior como de interior.

Dentro del análisis de las propiedades mecánicas de las superficies deportivas, podemos distinguir dos interacciones: superficie-jugador y superficie-balón. Estas interacciones pueden estar influenciadas tanto por factores externos como por factores internos. La interacción resultante de la superficie con el jugador es la que está más relacionada con la seguridad y la salud del deportista (Rosa, Sanchís, Alcántara, & Zamora, 2008). A continuación, se detallan las propiedades mecánicas que se analizan en relación a dicha interacción:

- **Absorción de impactos:** es la capacidad de un material de disminuir el efecto de las fuerzas de impacto, a través de la absorción y la disipación de energía (Rosa et al., 2008). Está directamente relacionada con la capacidad de protección del usuario frente a impactos, tales como la carrera, los saltos y las caídas. Una superficie con poca absorción de impactos podría causar lesiones en el jugador, sin embargo, una absorción de impactos alta reducirá el rendimiento deportivo (Burillo et al., 2010).

- **Deformación vertical:** se refiere a cuánto se deforma el pavimento tras un impacto, es decir, la disipación de energía de un impacto sobre el mismo, provocando pérdidas de equilibrio laterales en los deportistas, debido sobre todo, a un comportamiento inesperado. Por tanto, una deformación de la superficie deportiva alta ayuda a amortiguar, pero puede llegar a producir inestabilidades, provocando movimientos articulares inesperados y pudiendo resultar en posibles lesiones, como esguinces de tobillo (Burillo et al., 2010).

- **Retorno de energía o energía de restitución:** relaciona la energía que se le aplica a la superficie, con la energía devuelta y con la dureza de la superficie (absorción de impactos y deformación vertical) (Burillo et al., 2010).

- **Tracción rotacional y tracción lineal:** se relacionan con el deslizamiento del calzado sobre la superficie deportiva (Burillo et al., 2010). Durante el juego, el deportista necesita un mínimo agarre para no caerse y poder realizar giros, cambios de dirección, etc. Sin embargo, este agarre no puede ser excesivo ya que un bloqueo del pie puede desembocar en lesiones. Con el ensayo de tracción rotacional, la máquina simula la acción de un deportista realizando un cambio de dirección con un giro, y la resistencia del pavimento ante esa acción (Burillo et al., 2010). Por otro lado, el ensayo de tracción lineal simula cuando un jugador hace un cambio de sentido, y la fuerza horizontal que se crea sobre la superficie es muy elevada, llevando a un momento de desequilibrio del jugador (Burillo et al., 2010).

- **Abrasión de la piel:** con esta prueba se analiza el nivel de abrasión y, por lo tanto, el riesgo de producirse una quemadura al deslizarse sobre la superficie deportiva (Burillo et al., 2010). Es un tema muy evaluado, sobre todo, en los campos de césped artificial, ya que este es uno de los grandes problemas en comparación con el césped natural.

Las fuerzas ejercidas por la superficie de juego durante la actividad física, es un factor importante a la hora de valorar la masa ósea de los niños que juegan sobre diferentes superficies (Plaza-Carmona et al., 2014). La práctica deportiva produce tensiones mecánicas sobre los huesos de las extremidades inferiores, debido a las fuerzas de reacción que ejerce el suelo hacia el jugador (Freychat, Belli, Carret, & Lacour, 1996). Estas fuerzas dependen de la absorción de impactos, la deformación vertical y la energía de restitución del pavimento.

Sin embargo, hay que tener en cuenta el riesgo de lesión implícito al amortiguar. La superficie deportiva debe estar en un rango óptimo de absorción y deformación, es decir, ni muy alto que empeore el rendimiento, ni muy bajo que produzca riesgos para la salud del deportista. Respecto a la energía de restitución, suele estar inversamente relacionado con la absorción y la deformación, es decir, a mayor absorción de impactos y deformación vertical, menor energía de restitución, y viceversa (Burillo et al., 2010).

Para la valoración de la superficie de juego, el método empleado para evaluar la absorción de impactos, la deformación vertical y la energía de restitución del pavimento deportivo es el Triple A (Atleta Artificial Avanzado) (Figura 6). Este simula el impacto del talón de un deportista sobre la superficie durante la práctica deportiva. Para ello, se deja caer desde una altura conocida una masa determinada de 20 Kg (± 0,1 kg), usando un muelle con una rigidez controlada que simula el efecto amortiguador de las articulaciones inferiores, tal y como indica la norma UNE-EN 14808:2006. Cuando esta masa impacta sobre la superficie deportiva, se registra la fuerza máxima aplicada a través de una célula de carga. A raíz de ese valor se calcula el retorno de energía, tomando como referencia de fuerza máxima la obtenida en un pavimento de hormigón.

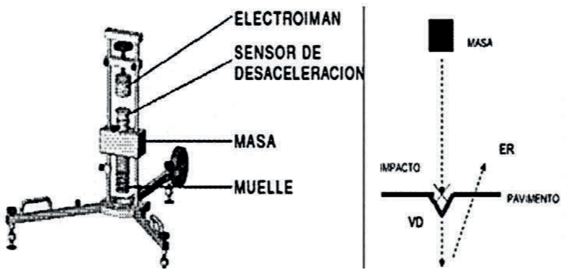


Figura 6. Esquema de impactos del Triple A (Burillo et al., 2010)

Capítulo 2

JUSTIFICACIÓN [JUSTIFICATION]

En los últimos años, se ha producido un aumento alarmante de la obesidad y el sobrepeso entre los más jóvenes (Ogden, Carroll, Kit, & Flegal, 2012), debido, entre otros factores, a los bajos niveles de actividad física (Strong et al., 2005). La obesidad en la infancia está estrechamente relacionada con la obesidad en la edad adulta (Alvero-Cruz et al., 2009), hasta el punto de que un niño obeso tienen el doble de riesgo de desarrollar obesidad en la edad adulta, que el que no lo es (Serdula et al., 1993). Investigaciones como la de Boreham et al. (2002), muestran que la actividad física durante la infancia previene la obesidad en la edad adulta. Por ello, la prevención de la obesidad en edad pediátrica es una prioridad, dado el impacto que tiene sobre las enfermedades crónicas, la salud general y el correcto desarrollo (Waters et al., 2014).

Se sabe que la actividad física y el deporte en general regulan la masa grasa y muscular de los niños (Abbott & Davies, 2004; Eimarieskandari, Zilaeibouri, Zilaeibouri, & Ahangarpour, 2012; Yildiz, Karakaş, Güneş, & KÖse, 2009). Estudios como el de Ara et al. (2004), demuestran que los niños prepúberes que practican actividad física regular al menos 3 horas por semana, en comparación con un grupo control, tienen menor porcentaje de masa grasa total. Además, el ejercicio físico también influye en la masa muscular. Una investigación realizada en niños tenistas prepúberes, muestra que los niveles de masa muscular en el brazo dominante, son entre un 10% y un 15% más elevados que en el no dominante (Sanchis-Moysi, Dorado, Olmedillas, Serrano-Sanchez, & Calbet, 2010).

Por otra parte, el tipo de modalidad deportiva practicada tiene influencia sobre el desarrollo de la composición corporal. Cada deporte, debido a sus características y requerimientos, se asocia con distintos perfiles de jugadores (Bahamondes-Avila et al., 2012). La mayoría de los estudios que comparan entre modalidades deportivas, se centran en el análisis del alto rendimiento (Bayios, Bergeles, Apostolidis, Noutsos, & Koskolou, 2006) o de un deporte específico (Almagiá-Flores, Rodríguez-Rodríguez, Barrraza-Gómez, Lizana-Arce, & Jorquera-Aguilera, 2008; Milanese, 2012; Pérez, Prado, Aréchiga, & Arroyo, 2007). Por lo tanto, los beneficios del deporte en población infantil requieren de más investigaciones. Así pues, **el estudio 1** fue planteado para contribuir con la literatura científica, respecto al efecto de la práctica deportiva en la masa grasa y masa muscular en niñas.

Asimismo, el interés por la salud ósea durante la infancia ha crecido de manera significativa, como resultado del aumento de los casos de osteoporosis en adultos (Bailey et al., 1999; Bellew & Gehrig, 2006; De Henauw et al., 2007; Moreno et al., 2008). El 60% de los casos de osteoporosis en la edad adulta están relacionados con el CMO adquirido durante la adolescencia (Baroncelli, Bertelloni, Sodini, & Saggese, 2005). La osteoporosis se considera un problema de salud pública, debido al aumento del número de personas que la sufren, y las repercusiones económicas que se generan durante el tratamiento y la rehabilitación (Cruz et al., 2009). De hecho, los costes derivados de la fractura ósea como consecuencia de esta enfermedad, son más altos que los producidos por el cáncer de mama y el cáncer de próstata (Clark, Carlos, & Vázquez-Martínez, 2010). En la actualidad, hay más de 200 millones de personas que sufren esta enfermedad en todo el mundo (Schurman et al., 2013). Las previsiones actuales estiman que en 2050 se producirán unas 6 millones de fracturas de cadera relacionadas con la osteoporosis (Gullberg, Johnell, & Kanis, 1997). Desde un punto de vista de la salud pública, y debido al bajo éxito de los tratamientos para combatir la osteoporosis, existe cierto consenso a la hora de considerar la prevención como el mejor de los tratamientos (International Osteoporosis Foundation, 2014).

Un incremento en el nivel de actividad física en los niños, se traduce en una mayor acumulación de masa ósea y una disminución del riesgo de fracturas de hueso en la edad adulta (Karlsson, Nordqvist, & Karlsson, 2008). Investigaciones llevadas a cabo con deportes de alto impacto por Vicente-Rodriguez, Dorado, et al. (2004) y Vicente-Rodriguez et al. (2003), demostraron que la práctica de fútbol en niños y de balonmano en niñas, aumenta los valores de masa ósea en comparación con grupos controles. Sin embargo, mediante la práctica de deportes de bajo impacto como la natación (Gómez-Bruton et al., 2015) y el ciclismo (Vlachopoulos et al., 2016), los huesos no reciben tantos estímulos por lo que los valores de DMO son más bajos.

La mayoría de estudios al respecto, se han centrado en comparar entre un deporte en concreto y la falta de práctica deportiva en niños (Ackerman, Skrinar, Medvedova, Misra, & Miller, 2012; Andreoli et al., 2001; Calbet, Dorado, Diaz-Herrera, & Rodriguez-Rodriguez, 2001; Chaari, 2012; Zouch et al., 2008) y en niñas (Bass et al., 1998; Bellew & Gehrig, 2006; Długołęcka, 2011), o en analizar diferencias en masa ósea entre deportes (Courteix et al., 1998; Maïmoun et al., 2013). Es necesario seguir estudiando en niñas debido a su mayor riesgo de padecer osteoporosis en la etapa adulta, ya que las mujeres a partir de los 30 años van perdiendo una media de un 10% de masa ósea por década (López-Chicharro et al., 2002). Por ello, los resultados del **estudio 2** se centran en esta temática, y analizan las diferencias en masa ósea en niñas que realizan diferentes disciplinas deportivas comúnmente practicadas.

Por otro lado, la masa muscular es reconocida como un importante factor predictivo del aumento de la masa ósea durante la pubertad (Courteix et al., 1998; Gracia-Marco et al., 2012; Vicente-Rodriguez et al., 2005). Así como el papel de la masa muscular en el desarrollo de la masa ósea es evidente, la asociación entre la masa grasa y la masa ósea genera cierto debate. Numerosos estudios en chicas demuestran que la masa grasa está relacionada positivamente con la masa ósea (El Hage, Courteix, et al., 2009; Pietrobelli et al., 2002), confirmado también de forma longitudinal (Sayers & Tobias, 2010; Young et al., 2001). No obstante, otros estudios apoyan la idea de que la masa grasa está negativamente relacionada con la DMO en chicos (El Hage, Courteix, et al., 2009; El Hage et al., 2011).

Numerosas investigaciones han mostrado que los niños y adolescentes con sobrepeso y obesidad tienen mayores niveles de CMO y DMO (Cobayashi et al., 2005; Ellis et al., 2003; Gracia-Marco et al., 2012; Leonard et al., 2004; Reid, 2002), mientras que otros estudios muestran lo contrario (Goulding et al., 2002; Rocher et al., 2008). Muchos de estos estudios no han tenido en cuenta en sus análisis la presencia de algunas variables de confusión, como puede ser la actividad física y la masa muscular, entre otras. Wey, Binkley, Beare, Wey y Specker (2011) observaron que el nivel de actividad física influía en la relación entre el músculo y el desarrollo de los huesos, lo que pone de relieve la importancia de controlar las variables de confusión, cuando se examina la unidad músculo-hueso durante el crecimiento. Gracia-Marco et al. (2012) concluyeron que el motivo por el cual, adolescentes con sobrepeso y obesidad tenían mayor CMO y DMO que aquellos con normopeso, era debido a sus mayores niveles de masa muscular, independientemente de la actividad física y la masa grasa. En este sentido, el **estudio 3 y 4** abordan el tema teniendo en cuenta un conjunto de variables de confusión: en el estudio 3 son la masa muscular y la masa grasa; y en el estudio 4 son la masa muscular y la AFV, los cuáles han demostrado ser importantes predictores del desarrollo de la masa ósea durante el crecimiento.

Finalmente, también debemos tener en cuenta factores extrínsecos como la superficie de juego. La afinidad entre el jugador y el pavimento deportivo es importante para el rendimiento y la salud del jugador. La mayoría de las investigaciones se han centrado en el estudio de la influencia en la incidencia de lesiones (Hershman et al., 2012; Iacovelli et al., 2013), o el rendimiento (Hughes et al., 2013; Sánchez-Sánchez et al., 2014). A fecha de hoy, tan solo un estudio transversal en niños realizado por Plaza-Carmona et al. (2014) ha abordado el tema en superficies de exterior. En esa investigación no se mostraron diferencias significativas en la masa ósea en las regiones de las extremidades, la pelvis y la cadera, entre practicar fútbol en superficie de tierra y sobre césped artificial. Por ello, existe un vacío en la literatura científica sobre las superficies deportivas, no sólo de exterior sino también de interior, y su posible asociación con la masa ósea. Así pues, en el **estudio 5** proporcionamos información acerca de la asociación entre la práctica deportiva en distintas superficies (interior y exterior), y la masa ósea en niñas prepúberes y púberes.

Capítulo 3

Hipótesis y Objetivos [Hypotheses and objectives]

3.1. HIPÓTESIS

La infancia es una etapa con multitud de cambios, entre los cuáles se encuentran los relacionados con la composición corporal. Estos cambios pueden tener una gran influencia en etapas posteriores de la vida. El incremento alarmante del sobrepeso y la obesidad entre los jóvenes y el aumento de la osteoporosis en la edad adulta, se suman a los bajos niveles de actividad física, creando una situación preocupante. Mediante la práctica deportiva regular y de alto impacto durante la etapa de desarrollo en niños y niñas, se pueden adquirir cambios saludables en la masa ósea, la masa grasa y la masa muscular. Además, el tipo de superficie deportiva sobre la que se practica el ejercicio, puede jugar un papel importante en la adquisición de masa ósea. Por ello, las hipótesis que se plantean en la Tesis Doctoral son:

- Las niñas que practican actividad física fuera del horario escolar obtienen niveles mayores en masa muscular y menores en masa grasa, frente a niñas que no practican actividad física fuera de la escuela.

- Practicar fútbol, baloncesto y balonmano (deportes de alto impacto) en edades en crecimiento, produce una mejora en los niveles de DMO y CMO en comparación con la práctica de natación (deporte de bajo impacto) y la innactividad en niñas.

- La masa muscular, la masa grasa, la condicion física cardiorrespiratoria, las horas semanales de entrenamiento y los años de práctica deportiva, están asociados positivamente con la masa ósea en niñas.

- Existe asociación positiva entre la condición física muscular y cardiorrespiratoria con la densidad mineral ósea y la geometría de cadera en niños, influenciada principalmente por la masa muscular.

- La práctica de actividad física sobre una superficie dura produce mayores ganancias de DMO y CMO, respecto a la misma práctica en superficies blandas en niñas.

3.1. HYPOTHESES

Childhood and adolescence are periods associated with many body composition changes that can track into adulthood. The alarming increase in overweight and obesity in young people and the increase in osteoporosis in adulthood, in addition to the low levels of physical activity, leads to a worrying situation. Regular and high-impact sports during the developmental stages in boys and girls may be related to healthy changes in bone mass, fat mass and lean mass. In addition, the type of playing surface can also play an important role in the acquisition of bone mass. Therefore, the hypotheses that led to the present Doctoral Thesis were:

- Girls engaged in extra-curricular physical activity have higher lean mass and lower fat mass, compared to girls who do not practice extra-curricular physical activity.

- The practice of football, basketball and handball (high impact sports) at growing ages, produces an improvement on bone mineral density and bone mineral content compared to swimming (low-impact sport) and the inactive group in girls.

- Lean mass, fat mass, cardiorespiratory fitness, weekly training hours and years of sport practice are positively associated with bone mass in girls.

- There is a positive association between muscular and cardiorespiratory fitness with bone mineral density and hip geometry in boys, mainly influenced by lean mass.

- Girls training on a hard surface will present higher gains of bone mineral density and bone mineral content than those training on soft surfaces.

3.2. OBJETIVOS

El objetivo general de la presente Tesis Doctoral fue analizar la composición corporal y su relación con la práctica deportiva, la superficie de juego y la condición física en edad pediátrica.

Los objetivos específicos de los cinco estudios que componen esta Tesis Doctoral en niños/as prepúberes y púberes son los siguientes:

Estudio 1. Analizar el efecto de la práctica deportiva en la masa grasa y masa muscular en niñas.

Estudio 2. Comparar las diferencias en masa ósea en niñas en función del tipo de deporte practicado.

Estudio 3. Estudiar la influencia de la masa grasa, la masa muscular, el consumo máximo de oxígeno, las horas de entrenamiento semanales y los años de práctica deportiva sobre la masa ósea en niñas.

Estudio 4. Examinar la asociación entre la condición física muscular y cardiorrespiratoria con la DMO y la geometría de cadera en niños.

Estudio 5. Comparar las diferencias en la masa ósea en niñas en función del pavimento utilizado durante su práctica deportiva.

3.2. OBJECTIVES

The general objective of this Doctoral Thesis was to analyse body composition and its relationship with sports, playing surface and physical fitness in paediatric age.

The specific objectives of the five studies that compose this Doctoral Thesis in prepubertal and pubertal children are the following:

Study 1. To analyse differences on fat mass and lean mass in girls playing different sports.

Study 2. To compare the differences on bone mass in girls according to the type of sport practiced.

Study 3. To study the influence of fat mass, lean mass, maximum oxygen consumption, weekly training hours and years of sports practice on bone mass in girls.

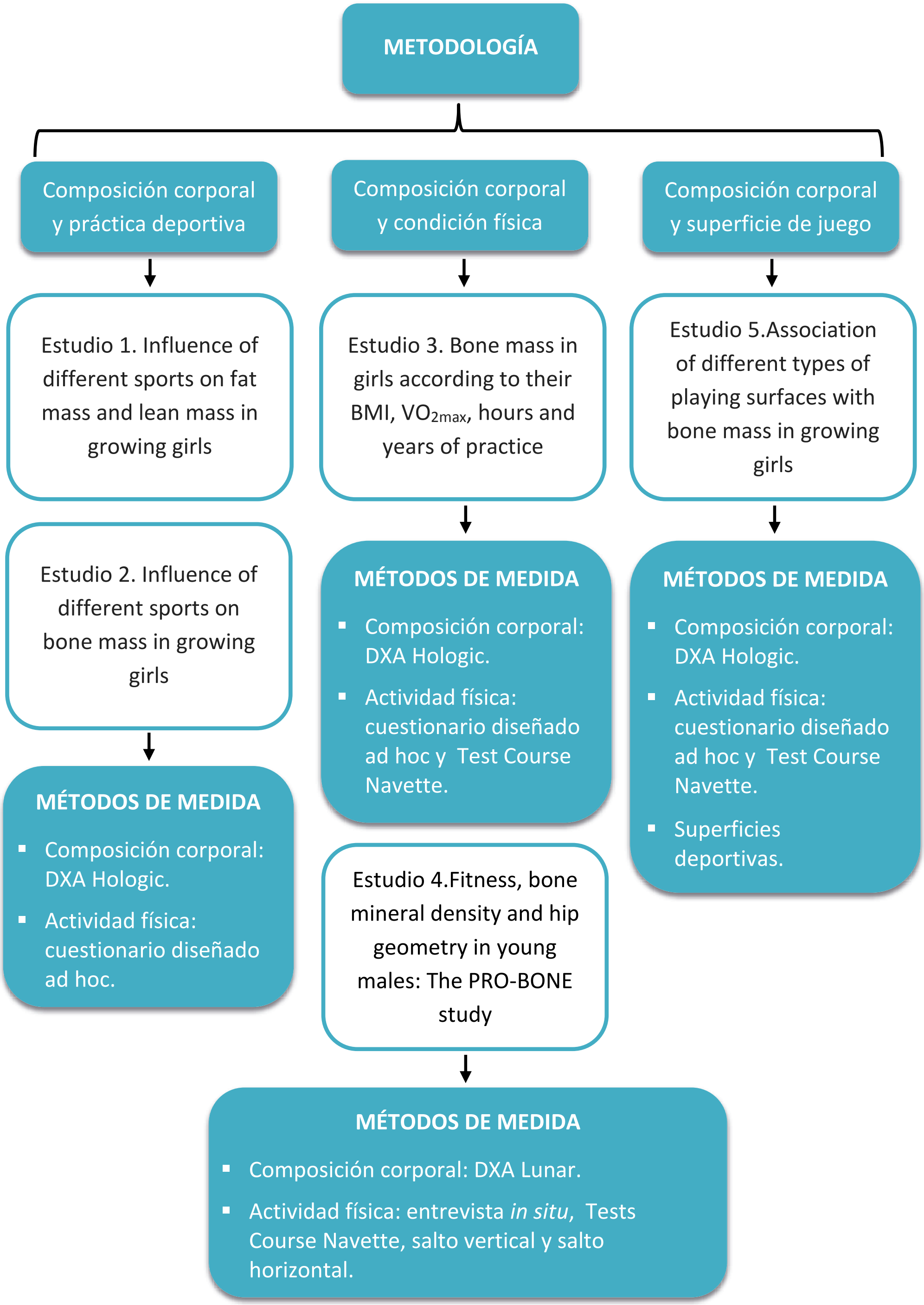
Study 4. To examine the association between muscular and cardiorespiratory fitness with bone mineral density and hip geometry in boys.

Study 5. To compare the differences on bone mass in girls playing on different surfaces.

Capítulo 4

Metodología [Methodology]

A continuación, se explica la metodología de la presente Tesis Doctoral. La descripción detallada y concreta se encuentra en el Capítulo 5 de Resultados y Discusión [Results and Discussion], donde aparecen cada uno de los artículos publicados.



4.1. PARTICIPANTES DE LOS ESTUDIOS

Se midieron un total de 321 niños/as (121 niños y 200 niñas) españoles e ingleses con edades comprendidas entre los 9 y 14 años. Los participantes no podían padecer enfermedades o tomar medicamentos que afectasen al metabolismo óseo, no presentar lesiones y debían pertenecer a la etnia caucásica blanca. Estos fueron evaluados individualmente para determinar su grado de madurez sexual, por medio de la herramienta Test de Tanner diseñada por Marshall y Tanner (1969, 1970). A través de unos dibujos que representan el grado de desarrollo de los senos y la pilosidad púbica con cinco escalas diferentes, los niños/as escogen aquella que más les representa (Figura 7). Es un método con reconocida validez (Duke, Litt, & Gross, 1980) y fiabilidad (r =0.97) (Morris & Udry, 1980).

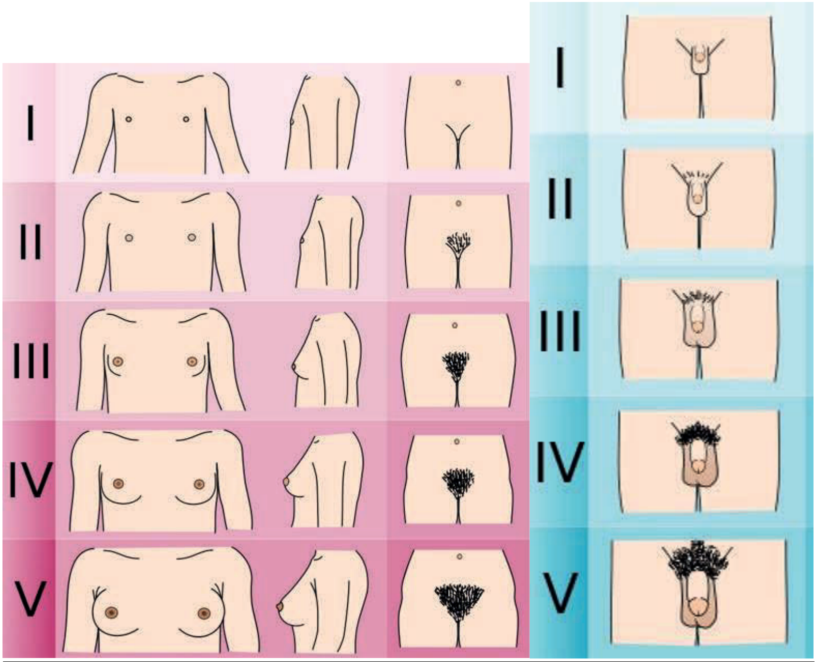


Figura 7. Imágenes Test de Tanner para niñas y niños diseñada por Marshall y Tanner (1969, 1970).

Estudios 1, 2 y 3

Las participantes fueron un total de 200 niñas con edades comprendidas entre los 9 y los 13 años (10.6 ± 1.5 años de edad) y con el grado del Test de Tanner entre I–III, procedentes de las provincias de Madrid, Toledo y Ciudad Real. Estas se dividieron en 4 grupos en función del deporte practicado fuera del horario escolar: 40 futbolistas, 40 jugadoras de baloncesto, 40 jugadoras de balonmano y 40 nadadoras. También formaban la muestra un total de 40 niñas inactivas pertenecientes al grupo control. Los datos fueron recogidos entre otoño e invierno de 2013. En el estudio 3 no se incluyeron el grupo de nadadoras ni el grupo control, ya que por las características del estudio, la muestra se redujo con el fin de analizar solamente a aquellas que hacían deporte osteogénico, contando finalmente con un total de 120 participantes: 40 futbolistas, 40 jugadoras de baloncesto y 40 jugadoras de balonmano.

Los criterios de inclusión de esta muestra fueron:

- Las niñas pertenecientes al grupo control no participaban en ningún tipo de deporte fuera del horario escolar.

- Las niñas pertenecientes a cada grupo deportivo, debían practicar sólo ese deporte específico al menos durante 3 horas por semana (Ara et al., 2004), durante al menos los últimos 8 meses (Ferry, Lespessailles, Rochcongar, Duclos, & Courteix, 2013).

En la tabla 1 que se muestra a continuación, se detallan las características descriptivas de los participantes de los estudios 1, 2 y 3.

Tabla 1. Características descriptivas de las niñas de los estudios 1, 2 y 3.

NIÑAS PREPÚBERES (Escala Tanner I)	Natación* (n=20)	Fútbol (n=20)	Baloncesto (n=20)	Balonmano (n=20)	Control* (n=20)
Edad (años)	9.2 ± 0.7	9.6 ± 1.0	10.4 ± 0.5	9.9 ± 0.6	10.0 ± 0.5
Talla (cm)	135.0 ± 6.2	141.2 ± 9.8	151.2 ± 10.7	142.0 ± 8.2	141.2 ± 6.3
Masa corporal (kg)	29.0 ± 4.4	35.7 ± 8.7	43.0 ± 9.3	37.5 ± 8.7	38.4 ± 8.8
IMC (kg/m^2)	15.9 ± 1.7	17.7 ± 2.6	18.7 ± 3.0	18.5 ± 3.9	19.1 ± 3.4
Historial de entrenamiento (años)	4.7 ± 2.0	3.9 ± 1.8	3.4 ± 1.5	3.4 ± 1.4	0
Entrenamiento semanal (horas)	3.8 ± 1.9	3.0 ± 0.0	2.9 ± 0.4	3.1 ± 0.2	0
CMO total (g)	973.68 ± 115.32	1171.74 ± 186.41	1302.71 ± 286.73	1133.46 ± 183.35	1122.66 ± 151.6
DMO total (g/cm^2)	0.78 ± 0.06	0.86 ± 0.07	0.87 ± 0.09	0.84 ± 0.06	0.82 ±0.06
NIÑAS PÚBERES (Escala Tanner II y III)	Natación* (n=20)	Fútbol (n=20)	Baloncesto (n=20)	Balonmano (n=20)	Control* (n=20)
Edad (años)	12.2 ± 0.6	12.3 ± 0.6	13.1 ± 0.3	12.7 ± 0.9	12.1 ± 0.7
Talla (cm)	154.6 ± 8.4	153.9 ± 6.3	163.1 ± 8.3	160.0 ± 8.1	155.8 ± 8.3
Masa corporal (kg)	49.1 ± 11.2	45.6 ± 10.0	56.9 ± 13.2	52.7 ± 11.2	46.4 ± 11.3
IMC (kg/m^2)	20.3 ± 3.1	19.1 ± 3.4	21.1 ± 3.5	20.4 ± 2.7	18.9 ± 3.2
Historial de entrenamiento (años)	4.1 ± 2.4	4.5 ± 1.7	4.4 ± 1.4	3.9 ± 1.8	0
Entrenamiento semanal (horas)	4.4 ± 2.7	3.6 ± 0.8	3.1 ± 0.2	4.2 ± 2.8	0
CMO total (g)	1458.32 ± 271.96	1488.10 ± 233.64	1761.62 ± 409.35	1784.40 ± 410.98	1207.70 ± 131.84
DMO total (g/cm^2)	0.93 ± 0.08	0.95 ± 0.08	1.00 ± 0.13	1.01 ± 0.12	0.83 ± 0.04

Los valores se presentan como media ± desviación estándar.

IMC: Índice de Masa Corporal; CMO: Contenido Mineral Óseo; DMO: Densidad Mineral Ósea.

* No se incluyeron en el estudio 3.

Estudio 4

En el estudio 4 participaron un total de 121 niños con edades comprendidas entre los 12 y los 14 años (13.1 ± 0.1 años de edad). Se trata de un análisis transversal con los datos del estudio PRO-BONE, cuya finalidad y metodología completa ya ha sido previamente publicada en detalle (Vlachopoulos et al., 2015), y la cual se detalla en los siguiente apartados. Los datos fueron recogidos entre el otoño y el invierno de 2014/15. Los participantes se dividieron en 3 grupos dependiendo del deporte practicado fuera del horario escolar: natación (n=41), fútbol (n=37) y ciclismo (n=29). Además, también participaron 14 niños que pertenecían al grupo control.

A modo general, los criterios de inclusión de la muestra de este estudio fueron:

- Los niños que formaban el grupo control no podían practicar en los últimos 3 años, más de 3 horas de natación, fútbol y ciclismo.

- Los niños que pertenecían a los grupos de natación, fútbol o ciclismo, tenían que practicar ese deporte específico durante al menos 3 horas por semana y durante al menos los últimos 3 años.

En la tabla 2, se muestran las características descriptivas de los participantes del estudio 4.

Tabla 2. Características descriptivas de los niños del estudio 4.

	Natación (n=41)	Fútbol (n=37)	Ciclismo (n=29)	Control (n=14)
Edad (años)	13.4 ± 1.0	12.8 ± 0.9	13.2 ± 1.0	12.3 ± 0.5
Escala Tanner (I/II/III/IV/V) (%)	15/25/13/45/2	24/35/24/16/0	14/28/28/27/3	29/21/21/29/0
Talla (cm)	165.5 ± 9.7	155.2 ± 9.3	160.8 ± 9.9	154.5 ± 9.9
Masa corporal (kg)	52.4 ± 9.0	44.3 ± 7.6	49.5 ± 12.3	48.3 ± 13.0
IMC (kg/m^2)	19.0 ± 1.7	18.3 ± 1.4	18.9 ± 3.3	20.0 ± 3.4
Masa muscular (kg)	41.6 ± 9.1	35.4 ± 7.2	37.7 ± 7.5	31.7 ± 5.5
DMO total menos cabeza (g/cm^2)	0.92 ± 0.07	0.93 ± 0.07	0.90 ± 0.09	0.83 ± 0.07
AFMV (min/day)	85.9 ± 30.4	119.8 ± 29.7	107.2 ± 33.3	83.2 ± 26.8
AFV (min/day)	11.9 ± 7.3	22.5 ± 9.0	18.5 ± 12.8	8.9± 4.0

Los valores se presentan como media ± desviación estándar.

IMC: Índice de Masa Corporal; DMO: Densidad Mineral Ósea; AFMV: Actividad Física Moderada-Vigorosa; AFV: Actividad Física Vigorosa.

Estudio 5

Las participantes del estudio 5 pertenecen a la misma muestra de 120 niñas del estudio 3, es decir, 40 futbolistas, 40 jugadoras de baloncesto y 40 jugadoras de balonmano. Además, se incluyeron 6 superficies deportivas diferentes donde las niñas practicaban deporte, formando los siguientes grupos de estudio: fútbol-tierra (n=22), fútbol-césped artificial (n=18), baloncesto-sintético (n=21), baloncesto-parquet (n=19), balonmano-sintético (n=20) y balonmano-hormigón liso (n=20).

Los criterios de inclusión del estudio 5 fueron los siguientes:

- Las niñas pertenecientes a cada grupo deportivo debían practicar sólo ese deporte específico, al menos durante 3 horas por semana (Ara et al., 2004), durante al menos los últimos 8 meses (Ferry et al., 2013).

- Además, tenían que realizar el entrenamiento en el mismo tipo de superficie durante al menos esos últimos 8 meses.

4.2. COMITÉS DE ÉTICA: ESPAÑA Y REINO UNIDO

Todos los participantes formaron parte de los estudios de forma voluntaria. Los padres/madres o tutores de los niños fueron informados sobre el objetivo de la investigación y su procedimiento, así como de su posible riesgo. Los niños dieron su consentimiento verbal y sus padres/madres o tutores firmaron un consentimiento informado por escrito.

Estudio 1, 2, 3 y 5 (España)

El protocolo de estos estudios se desarrolló según la normativa española y siguiendo las consignas éticas establecidas en la Declaración de Helsinki en 1975 (revisada en Hong Kong en 1989 y Edimburgo en 2000). Dicho protocolo fue aprobado por el Comité de Ética de Investigación Clínica del Hospital Universitario de Albacete, perteneciente a la Universidad de Castilla-La Mancha (CEIC 13/10) y por el Comité Ético de Investigación Clínica del Área Sanitaria de Toledo (anexo 2).

Estudio 4 (Reino Unido)

Los métodos y procedimientos del estudio 4 fueron aprobados por: 1) the Ethics Review Sector of Directorate-General of Research (European Commission, ref. number 618496); 2) the Sport and Health Sciences Ethics Committee (University of Exeter, ref. number 2014/766) y 3) the National Research Ethics Service Committee (NRES Committee South 89 West – Cornwall & Plymouth, ref. number 14/SW/0060) (anexo 3).

4.3. MÉTODOS DE MEDIDA

4.3.1. Composición corporal

Talla, masa corporal e índice de masa corporal

En los estudios 1, 2, 3 y 5, la talla (cm) y la masa corporal (kg) se midieron por medio de la báscula electrónica y el tallímetro SECA (modelo 711; Seca & Co, KG, Hamburgo, Alemania; precisión de 100 g y 0,1 cm; rango 0-220 kg y 85-200 cm), sin zapatos y en ropa interior. La talla se midió en bipedestación con los talones, los glúteos, la espalda y la región occipital en contacto con el plano del tallímetro.

En el estudio 4, la talla (cm) y la masa corporal (kg) se midieron utilizando un tallímetro (Harpenden, Holtain Ltd, Crymych, Reino Unido; precisión de 0,1 cm, rango 60-210 cm) y una báscula electrónica (877 Seca, Seca Ltd, Birmingham, Reino Unido; precisión de 100 g; rango 2-200 kg), respectivamente.

El índice de masa corporal (IMC) se calculó utilizando la fórmula: IMC (kg/m^2) = masa corporal (kg)/talla $(m)^2$.

Absorciometría fotónica dual de rayos X (DXA)

En los estudios 1, 2, 3 y 5, la masa ósea (CMO en g, y DMO en g/cm^2), la masa grasa (g) y la masa muscular (g) se calcularon mediante el DXA (Hologic Series Discovery QDR, Software Physician's Viewer, APEX System Software Version 3.1.2. Bedford, MA, USA). El DXA se calibró antes de cada día de pruebas usando un fantoma de la columna lumbar y siguiendo las directrices marcadas por el fabricante. Los participantes fueron escaneados en posición supina, con su cuerpo y las extremidades completamente extendidos, y dentro de los límites establecidos por las líneas de exploración de la camilla.

Se realizó un escáner el cuál proporcionó datos de CMO, DMO, masa grasa y masa muscular, tanto a nivel del cuerpo entero como a nivel regional (extremidades superiores, extremidades inferiores, tronco y pelvis) (Figura 8). Además, se realizó un escáner específico en la zona de la cadera, el cuál proporcionó datos a nivel de cadera total, cuello femoral, trocánter, zona intertrocantérea y triángulo de Ward's (Figura 8). Este último escáner más específico, se realizó debido a la relevancia clínica de la cadera en el diagnóstico de osteoporosis. Los errores de precisión de laboratorio para el análisis de la exploración corporal, definida por el coeficiente de variación para medidas repetidas estimados en voluntarios jóvenes, fueron los siguientes: CMO <3,5%, DMO <4% y masa muscular <3,3%.

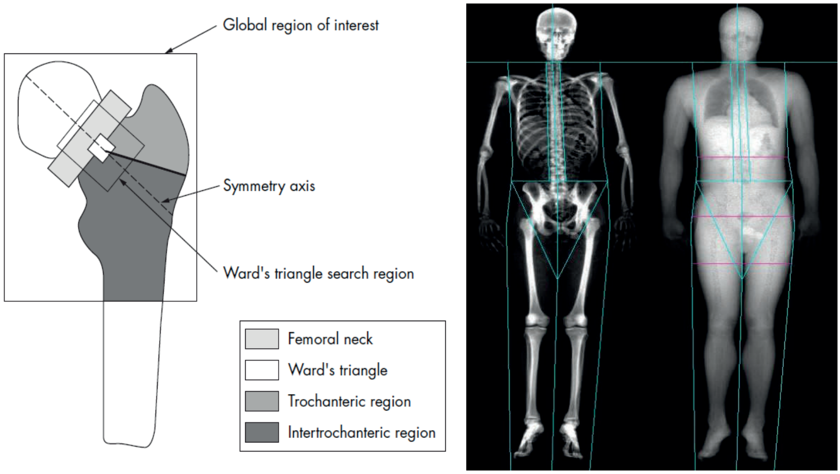


Figura 8. Subregiones analizadas en la prueba de cadera (Vicente-Rodriguez et al., 2005) y de cuerpo entero (Lorente-Ramos et al., 2012).

En el estudio 4, se utilizó un DXA fabricado por GE Lunar (GE Lunar Healthcare Corp., Madison, WI, EE.UU.) para obtener datos relativos a la DMO (g/cm^2) y la masa muscular (kg). Se realizaron cuatro exploraciones diferentes para obtener datos del cuerpo entero (menos la cabeza), la columna lumbar (media de L1-L4) (Figura 9), la cadera derecha y la cadera izquierda (utilizando valores medios de cuello femoral, el trocánter y la cadera total). Todos los exámenes del DXA y los posteriores análisis en el software fueron completados por el mismo investigador, con el software Encore GE (2006, versión 14.10.022). El equipo se calibró antes de cada día de pruebas mediante el uso de un fantoma de la columna lumbar siguiendo las recomendaciones del fabricante.

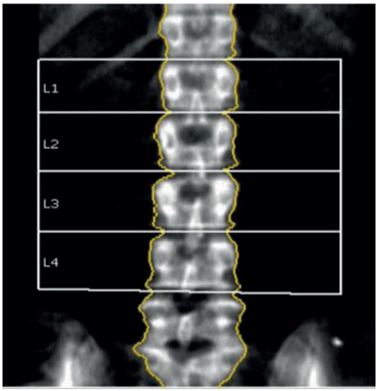


Figura 9. Subregiones analizadas en la prueba de columna lumbar (Lorente-Ramos et al., 2012).

Además, en **el estudio 4** se realizó un análisis estructural de la cadera, a través del software HSA (Hip Structural Analyses, GE Lunar Healthcare Corp., Madison, WI, EE.UU.). Los análisis se realizaron en la región estrecha del cuello del fémur. El software HSA utiliza la distribución de la masa mineral ósea en la línea de píxeles a través del eje del hueso, para medir las dimensiones estructurales de las secciones transversales de los huesos. Las propiedades geométricas del hueso que se utilizaron como variables fueron (Figura 10): 1) *narrow neck width* (en mm), es la zona más estrecha del cuello femoral; 2) *cross-sectional moment of inertia* (CSMI, en mm^4), es un índice de la rigidez estructural y refleja la distribución de la masa en el centro de un elemento estructural; 3) *section modulus* (Z, en mm^3), es un indicador de la fuerza máxima de flexión en una sección transversal; y 4) *cross sectional area* (CSA, en mm^2), es el área total de la superficie del hueso con exclusión de la zona del tejido blando y el trabecular.

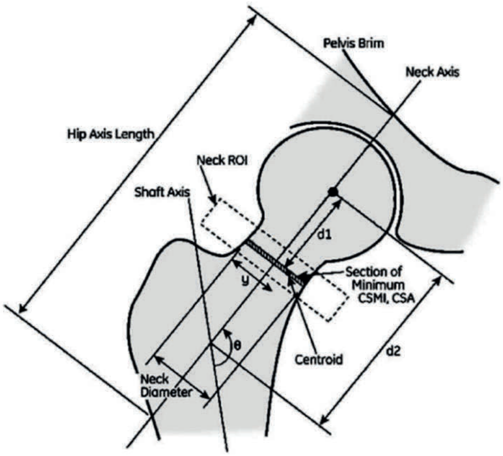


Figura 10. Variables obtenidas a partir del HSA con un DXA de la marca GE Lunar (Faulkner et al., 2006).

4.3.2. Actividad física

Cuestionario y entrevista

En **los estudio 1, 2, 3 y 5** se creó un cuestionario diseñado ad hoc (anexo 1) y en **el estudio 4** se realizó una entrevista in situ, para conocer los hábitos de práctica deportiva y salud, que incluían información sobre el tipo y años de práctica deportiva, el número de horas de actividad deportiva semanales e historial médico.

Acelerometría

En **el estudio 4**, la actividad física se midió objetivamente durante siete días consecutivos utilizando acelerómetros de muñeca (GENEActiv, GENEA, Reino Unido). Los participantes fueron instruidos para colocar el acelerómetro en su muñeca no dominante y se recogieron los datos a 100 Hz. Los datos se analizaron en intervalos de 1 s para establecer diferentes intensidades. La AFV se calculó utilizando un punto de corte de ≥3600 counts por minuto y la AFMV usando un punto de corte de ≥1140 counts por minuto (Phillips, Parfitt, & Rowlands, 2013). La validez y fiabilidad del acelerómetro se ha establecido previamente en niños y adolescentes (Phillips et al., 2013).

Condición física

El Test Course Navette (estudios 3 y 4): la condición física cardiorrespiratoria (capacidad aeróbica), se calculó mediante el Test Course Navete, el cual es un test de esfuerzo máximo que ha demostrado ser fiable y válido en niños y adolescentes (Castro-Piñero et al., 2010). Los participantes fueron evaluados después de un calentamiento estandarizado. Para la realización del test, los participantes tuvieron que correr entre dos líneas separadas por 20 m entre sí, siguiendo el ritmo marcado por unas señales de audio audibles, por ejemplo, a través de un reproductor de CD (Figura 11). El test comienza con una velocidad inicial de 8,5 km/h que se incrementa en 0,5 km/h cada minuto. Se animó a los participantes a continuar la prueba hasta que llegasen a un esfuerzo máximo. La prueba termina cuando el participante no es capaz de llegar a la línea dos veces consecutivas. El último periodo completado indicó la puntuación de la prueba. Además, en el **estudio 3**, se estimó el $VO_{2máx}$ en milímetros por kilogramo de peso corporal y por minuto (ml/kg/min). Para ello, se usó la siguiente fórmula sugerida para jóvenes con edades comprendidas entre 8 y 18 años de edad (Leger, Mercier, Gadoury, & Lambert, 1988):

$$Y = 31.025 + 3.238X1 - 3.248X2 + 0.1536X1X2$$

Dónde: Y= $VO_{2máx}$ (ml/kg/min); X1 = máxima velocidad alcanzada (km/h); X2 = edad (años). El valor X1 se calculaba de la siguiente forma: X1 = 8 + (0,5*B2); donde B2 era el periodo máximo alcanzado.

A pesar de tratarse de una estimación del $VO_{2máx}$, diversos estudios científicos lo han utilizado en niños (Plaza-Carmona et al., 2014; Vicente-Rodriguez, Dorado, et al., 2004; Vicente-Rodriguez et al., 2003).

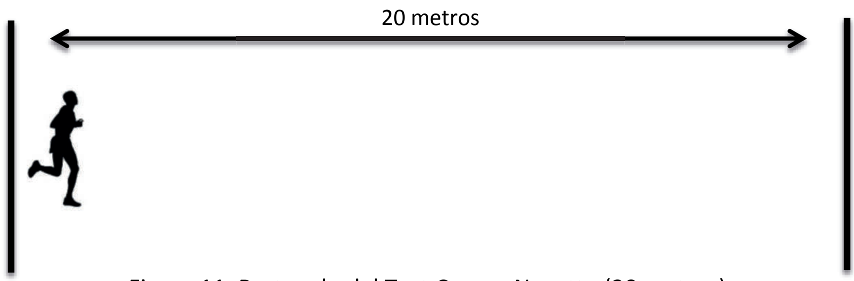


Figura 11. Protocolo del Test Course Navette (20 metros).

El salto vertical (cm) y el salto de longitud (cm) (estudio 4): estos tests fueron utilizados con el fin de valorar la condición física muscular de las extremidades inferiores. La prueba de salto de longitud se realizó en el laboratorio sobre un suelo duro no resbaladizo. La posición de inicio de la prueba fue en bipedestación, justo detrás de una línea marcada en el suelo, con los pies colocados a la anchura de los hombros (Figura 12). Los participantes fueron informados de que se les permitía balancear sus brazos y eran animados para saltar lo más lejos posible pero sin perder el equilibrio al caer. Esta se midió desde la línea de salida, hasta la parte posterior del talón más retrasado tras el salto. La prueba de salto vertical (CounterMovement Jump, CMJ) se realizó utilizando una plataforma de salto (Probotics Inc., Huntsville, EE.UU.) que calcula la altura del salto en base al tiempo de vuelo. Se dieron instrucciones antes de la prueba indicando que se permitía balancear los brazos y que los pies tenían que estar separados a la altura de los hombros. También se les animó verbalmente para saltar lo máximo posible. La posición de partida fue de pie, a continuación flexionaban las rodillas hasta 90º y saltaban (Figura 12). Se realizó una demostración de ambos tests de saltos y se les permitió saltar una vez para practicar. Cada participante realizó tres saltos máximos y la mejor marca fue la que se utilizó para el análisis.

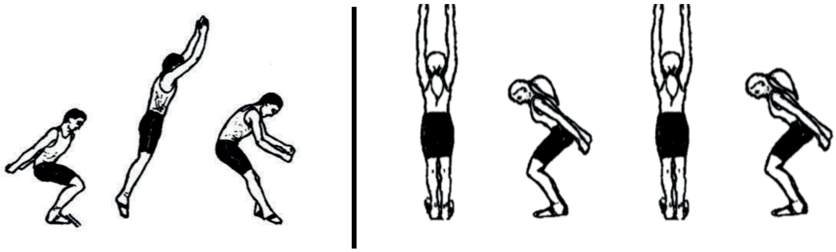


Figura 12. Protocolo del salto de longitud y el salto vertical (CMJ), respectivamente (Martínez-López, 2002).

4.3.3. Superficies deportivas

Las propiedades mecánicas de las superficies deportivas seleccionadas en **el estudio 5** se evaluaron *in situ*, para estimar la interacción del jugador con la superficie de juego. Estas pruebas se realizaron bajo las normas UNE-EN 15330-1: 2014 para césped artificial y UNE-EN 14904: 2007 para las superficies de interior. Las variables analizadas fueron la absorción de impactos (%), deformación vertical (mm) y energía de restitución (%). Las fórmulas utilizadas para calcular estas variables fueron:

Para absorción de impactos:

$$SA = [1 - F_{máx}/F_{ref}] \times 100$$

Dónde: SA, es la absorción de impactos (%); $F_{máx}$, es la fuerza máxima medida en la superficie deportiva (Newtons, N); F_{ref}, es la fuerza de referencia fijada a 6760 N (valor teórico calculado para un pavimento de hormigón).

Para la deformación vertical:

$$D = \boldsymbol{D}_{mass} - \boldsymbol{D}_{spring}$$

Dónde: $\boldsymbol{D}_{mass} = \iint_{T1}^{T2} g\, dt$, con $\boldsymbol{D}_{mass} = 0$ mm en $T1$; $\boldsymbol{D}_{spring} = (m \times g \times G_{máx})/C_{spring}$; $G_{máx}$ es la aceleración máxima durante el impacto (g); g es la aceleración mediante la gravedad (9.81 m/s²); m es la masa que cae, incluyendo el muelle, la placa base y el acelerómetro (kg); C_{spring} es la constante del muelle (dada por el certificado de calibración).

Para la energía de restitución:

$$ER = [E_2/E_1] \times 100$$

Dónde: E_1 es la energía antes del impacto. $E_1 = 0.5 \times mV^2_{máx}$; E2 es la energía después del impacto. $E_2 = 0.5 \times mV^2_{min}$; $V_{máx}$ es la velocidad antes del impacto en m/s (T1); V_{min} es la velocidad después del impacto en m/s (T2); m, es la masa que cae incluyendo el muelle, la placa base y el acelerómetro (kg); T1 es el tiempo en el que la masa hace contacto inicial con la superficie (corresponde al valor máximo absoluto de la velocidad de la masa que cae $V_{máx}$); T2 es el tiempo de la velocidad absoluta máxima de la masa durante sus rebotes después del impacto sobre la superficie (determinado por V_{min}).

Estas variables nos dan información sobre la respuesta de las superficies a un impacto. Se midieron utilizando un Triple A (Advanced Artificial Athlete; Deltec Metal, Duiven, Holanda), bajo los procedimientos estipulados por la norma UNE-EN 14808:2005 y UNE-EN 14809:2005. Para la valoración de las propiedades mecánica, se deja caer una masa determinada (20 ± 0,1 kg) desde una altura conocida, utilizando un muelle de rigidez controlado para simular el efecto amortiguador de las articulaciones de la rodilla y el tobillo. Al impactar esta masa en el pavimento, queda registrada la fuerza máxima aplicada mediante la señal de una célula de carga. La recogida de datos se hace en un ordenador portátil con un software de informática (G-Force v.3.03, DeltecMetaal, Duiven, Holanda).

Este procedimiento se realiza tres veces en intervalos de 60 ± 10 s. En el caso de las superficies de interior el test se realizó en cuatro zonas específicas (Figura 13) y en el césped artificial y en el campo de tierra en cinco zonas específicas (Figura 14). Para valorar las propiedades mecánicas, se registró el valor medio entre el segundo y el tercer impacto. Dentro cada una de estas zonas, la prueba se repite en tres posiciones diferentes separadas por más de 100 mm. Las pruebas se llevaron a cabo bajo condiciones climáticas de entre 18 - 22.5 ºC de temperatura y 20 - 35% de humedad.

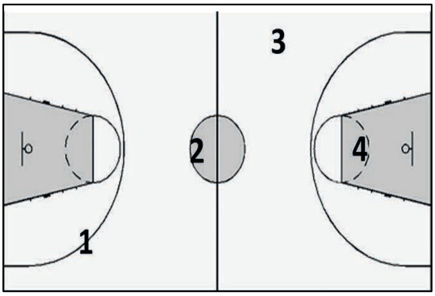


Figura 13. Áreas de medición de superficies de interior según la normativa UNE-EN 14904:2007.

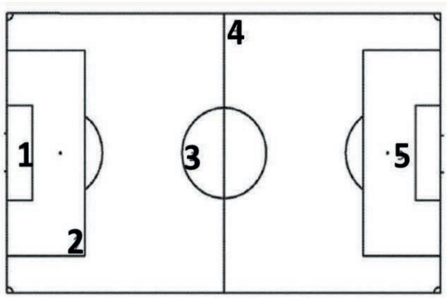


Figura 14. Áreas de medición de campos de fútbol de césped artificial según la normativa UNE-EN 15330-1:2014.

4.4. ANÁLISIS ESTADÍSTICOS

Estudio 1, 2 y 3

La distribución de las variables se comprobó y verificó mediante la prueba de Kolmogorov-Smirnov. Las características descriptivas de los participantes se calcularon utilizando análisis de varianza (ANOVA) y se presentan como media y desviación estándar (DE). Las diferencias entre grupos se determinaron usando análisis de covarianza (ANCOVA) con el Post hoc de Bonferroni incluyendo como covariables la altura en el estudio 1 (Crabtree et al., 2004; Milanese, 2014); la altura y la masa muscular en el estudio 2 (Courteix et al., 1998); y la masa muscular, la masa grasa total y el porcentaje de masa grasa en el estudio 3 (Crabtree et al., 2004; Milanese, 2014).

Para identificar la magnitud de los cambios, se calcularon los intervalos de confianza (IC 95%) y el tamaño del efecto de las diferencias (ES; d de Cohen). ES se evaluó mediante los siguientes criterios: 0-0.2 = trivial, 0.2-0.5 = pequeño, 0.5-0.8 = moderado y >0.8 = grande (Cohen, 1992). En todos los casos, se repitió el análisis para el grupo prepuberal y puberal de forma independiente, ya que son diferentes grados madurativos y por lo tanto, es necesario distinguir entre ellos para obtener una correcta validez y fiabilidad (Bailey et al., 1999; Vicente-Rodriguez, Dorado, et al., 2004). En estos tres estudios se utilizó el programa estadístico SPSS (paquete estadístico para ciencias sociales) versión 19.0 para Windows (Inc. Chicago, IL, USA), y se aplicó un nivel de significación de $p < 0.05$.

Estudio 4

La distribución de las variables se comprobó y verificó por medio del test Shapiro-Wilk's, valores de asimetría y curtosis, verificación visual de los histogramas, gráfico Q-Q y diagramas de cajas. Los datos descriptivos se presentan como la media ± DE a menos que se indique lo contrario. Las diferencias entre grupos (descriptivas) se determinaron utilizando ANOVA o test de Chi-cuadrado para variables categóricas.

Las correlaciones bivariadas de Pearson se realizaron para examinar la asociación entre variables predictoras y dependientes. Se analizaron las relaciones de las pruebas de condición física (salto de longitud, salto vertical y el Test Course Navette) con los resultados de hueso (geometría de la cadera y DMO), usando tres modelos de ajuste en el análisis de regresión lineal múltiple: Modelo 1: edad y estatura; Modelo 2: modelo 1 + AFV; Modelo 3: modelo 2 + masa muscular. Los análisis estadísticos se realizaron utilizando el programa SPSS IBM (versión 22.0 para Windows, Chicago, IL, EUA). El ajuste de Bonferroni se aplicó para contrarrestar el problema de múltiples ensayos, considerándose como el método más conservador para controlar el *familywise error rate*. Por ello, el nivel de significación se fijó en 0,006 (0,05/9).

Estudio 5

Inicialmente, se realizó una prueba de Kolmogorov-Smirnov y la prueba de Levene para comprobar y verificar la normalidad y la homogeneidad de las varianzas. Los datos descriptivos se presentan como la media ± DE a menos que se indique lo contrario. Las diferencias entre grupos (descriptivas) se determinaron utilizando análisis de t para muestras independientes. En todos los casos, se repitió el análisis para el grupo prepuberal y puberal de forma independiente, ya que son diferentes grados madurativos y por lo tanto, es necesario distinguir entre ellos para obtener una correcta validez y fiabilidad (Bailey et al., 1999; Vicente-Rodriguez, Dorado, et al., 2004).

La comparación entre las variables de masa ósea y las superficies en cada uno de los deportes (tierra en comparación con césped artificial en el fútbol, sintético en comparación con parquet en el baloncesto y sintética en comparación con hormigón liso en el balonmano) fue llevada a cabo mediante ANCOVA de 2 vías (superficie × deporte). La altura y la masa muscular se utilizaron como covariables debido a su correlación con la masa ósea (Bielemann et al., 2013). Por último, se realizó un análisis de regresión lineal utilizando las propiedades mecánicas de las superficies de juego como variables independientes (absorción de impactos, deformación vertical y energía de restitución), mientras que las variables de masa ósea fueron las variables dependientes.

Los datos se analizaron por medio del SPSS versión 19.0 para Windows (SPSS Inc., Chicago, IL, EE.UU.). El nivel de significación se fijó en $p < 0{,}05$. Además, se calcularon los IC 95% para identificar la magnitud de los cambios y el ES. Este último se evaluó siguiendo los siguientes criterios (Cohen, 1992): 0-0.2 = trivial, 0.2-0.5 = pequeño, 0.5-0.8 = moderado y >0.8 = grande.

Capítulo 5

Resultados y Discusión [Results and Discussion]

5.1. RESULTADOS

Los resultados de la presente Tesis Doctoral se muestran en forma de artículos científicos. A continuación aparecen anexados en el formato en que han sido publicados.

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Original article

Influence of different sports on fat mass and lean mass in growing girls

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Abstract

Purpose: The aim of this study was to analyze and compare the effects of different sports (swimming, football, basketball, and handball) on fat mass and lean mass in prepubertal and pubertal girls.
Methods: Two hundred girls (10.6 ± 1.5 years old, Tanner stages I–III) participated in the study and were divided into five groups: 40 swimmers, 40 football players, 40 basketball players, 40 handball players, and 40 controls. Fat and lean masses at whole body, arms, trunk, and legs were measured using dual-energy X-ray absorptiometry (DXA). Pubertal status was determined using Tanner test. Effects of different sports on fat and lean masses were assessed through analysis of covariance with height as covariates. Analyses were performed separately in two groups depending on the Tanner stage (prepubertal and pubertal).
Results: The girls of the control group had less lean mass and more fat mass compared to the girls who play sports ($p < 0.05$). There were differences in body fat between sports. The swimmers and football players had less body fat ($p < 0.05$). On the other hand, handball players showed the highest values in lean mass ($p < 0.05$).
Conclusion: Impact sports (football, basketball, and handball) and low-impact sports (swimming) provide an appropriate development of lean mass in growing girls. We can conclude that people practicing sports at early ages ensure a lower fat mass and higher lean mass compared to those who do not practice. These results may be useful as a preventive method of adult obesity.

Keywords: Body composition; DXA; Female players; Physical activity; Sports

1. Introduction

In the last few years, there has been an alarming increase in overweight and obesity among young people.[1] Among other reasons, this is because of low levels of habitual physical activity and associated negative health outcomes among young people, especially females.[2] Physical inactivity is a risk factor for many diseases such as type 2 diabetes, cardiovascular diseases, high blood lipid, arthritis, asthma, and cancer.[3] Obesity in childhood is closely related to adult obesity,[4] because these children have twice the risk of developing obesity in later life than those who are not obese.[5] Studies such as Boreham et al.[6] show that physical activity during childhood prevents obesity in later life. For these reasons, the prevention of obesity in childhood is an international priority given the impact it has on chronic diseases, general health, development, and well-being.[7]

The direct relationship between physical activity and body composition results in sport having a positive effect on body composition.[8] Physical activity has an influence on muscle mass as a result of increased energy expenditure and helps maintain lean mass, bone mineral density, and body weight.[9] It is known that sport is an important factor that regulates body mass of children, which is associated with lower obesity.[8] Exercise practiced continuously and regularly produces changes in body composition.[3] Physically active people have a lower percentage of fat than people who do not exercise.[10]

For these reasons, health institutions are increasing their interest in assessing body composition of schoolchildren.[4] During the study of body composition, health problems can be identified in relation to body fat, lean mass (excluding bone mass), or muscle mass and changes associated with different types of exercise can be compared.[11] This measurement of body

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composition can be performed through indirect techniques, such as the dual-energy X-ray (DXA). This has become an important tool for evaluating and monitoring obesity and related diseases.[12] It is recognized as an accurate and precise method to measure body composition[13] and it is useful to quantify fat mass and fat-free mass in separate segments or total body.[14] Several reviews claim its theoretical and empirical validity to estimate fat mass and fat-free mass.[15,16]

Moreover, the type of sport has some influence on the development of body composition. Each sport has a different player profile, as each sport has different physical requirements.[17] Most studies are focused on the analysis of high-performance[18] or a particular sport.[19–21] Therefore, studies focused on children's health and proper growth through sport and its various forms are needed. The present study was planned to fill the gap in the literature.

All the sports of this research have their own special features. Football is considered as a resistance sport that generates different levels of intermittent activity at variable intensities,[22] which involves mainly the lower body. On the other hand, the movements that basketball players perform during the games are multiple and differ in terms of intensity, distance, and duration.[23] Movements such as consecutive jumps, changes of direction, several sorts of accelerations and quick counterattacks (short runs) are usually very powerful.[24] However, swimming allows an improvement of the aerobic capacity, flexibility, strength, coordination, and muscle tone of the whole body.[25] Finally, handball is a dynamic sport, with a high aerobic demand, characterized by runs, jumps, throws, passes, and blocks.[26] According to Hatzimanouil and Oxizoglou,[27] handball is a sport that requires certain skills such as speed, agility, reaction speed, speed strength, resistance, strength, and coordination. During game tasks such as pushes and blocks, a great power and strength are required for the limbs and the trunk.[28,29]

To study the body composition of child athletes is important not only to detect young talent but also to track their optimal development.[30] This can be helpful to reconsider teaching and training programs in different contexts (school, training, and performance). Thus, the objective of the study is to analyze and compare the effects of different sports (swimming, football, basketball, and handball) on fat and lean masses in prepubertal and pubertal girls. The hypothesis, in which this research is based on, was that sport practice reduces girls' fat mass and improves their lean mass. The results of the study will show the influence that a particular sport has on the body composition development of growing girls.

2. Materials and methods

2.1. Participants

Healthy prepubertal (Tanner stage I) and pubertal (Tanner stages II–III) female children from different schools and football clubs of Toledo, Ciudad Real, and Madrid (Spain) were recruited for the study. In total, 200 girls aged 9–13 years (10.6 ± 1.5 years) were divided into five groups (swimming, football, basketball, handball, and control group) according to their sport activity patterns. The characteristics of each group and descriptive statistics are presented in Table 1. Once the sample was recruited, the participants underwent a series of tests to assess the degree of sexual development and body composition (fat mass and lean mass).

All the girls practicing sport were recruited from sport clubs, whereas all the control group participants were recruited from schools. According to the answers given during a personal

Table 1
Descriptive characteristics of five groups of prepubertal and pubertal girls.

	Swimming	Football	Basketball	Handball	Control
Prepubertal					
n	20	20	20	20	20
Age (year)	9.16 ± 0.69	9.63 ± 0.98	10.36 ± 0.51[a,b]	9.86 ± 0.64	10.01 ± 0.52[a]
Height (cm)	135.03 ± 6.19	141.20 ± 9.84	151.18 ± 10.74[a,b,d,e]	142.04 ± 8.24	141.15 ± 6.32
Body mass (kg)	29.01 ± 4.38	35.73 ± 8.74	43.04 ± 9.34[a]	37.50 ± 8.69[a]	38.44 ± 8.79[a]
BMI (kg/m^2)	15.85 ± 1.66	17.67 ± 2.60	18.74 ± 2.98[a]	18.52 ± 3.86	19.12 ± 3.38[a]
Years of training	4.68 ± 2.00	3.85 ± 1.81	3.37 ± 1.52	3.35 ± 1.35	0
Weekly training hours	3.83 ± 1.89	3.00 ± 0.00	2.88 ± 0.39	3.05 ± 0.22	0
Total BMC (g)	973.68 ± 115.32	1171.74 ± 186.41[a]	1302.71 ± 286.73[a,e]	1133.46 ± 183.35	1122.66 ± 151.6
Total BMD (g/cm^2)	0.78 ± 0.06	0.86 ± 0.07[a]	0.87 ± 0.09[a]	0.84 ± 0.06	0.82 ± 0.06
Pubertal					
n	20	20	20	20	20
Age (year)	12.20 ± 0.62	12.31 ± 0.60	13.05 ± 0.34[a,b,e]	12.69 ± 0.86	12.10 ± 0.72
Height (cm)	154.55 ± 8.41	153.85 ± 6.25	163.12 ± 8.27[a,b,e]	159.96 ± 8.14	155.76 ± 8.32
Body mass (kg)	49.06 ± 11.24	45.61 ± 9.95	56.85 ± 13.20[b,e]	52.66 ± 11.21	46.39 ± 11.27
BMI (kg/m^2)	20.34 ± 3.13	19.13 ± 3.40	21.11 ± 3.51	20.35 ± 2.73	18.91 ± 3.24
Years of training	4.08 ± 2.36	4.45 ± 1.70	4.35 ± 1.42	3.90 ± 1.77	0
Weekly training hours	4.44 ± 2.71	3.55 ± 0.76	3.09 ± 0.19	4.20 ± 2.78	0
Total BMC (g)	1458.32 ± 271.96	1488.10 ± 233.64[e]	1761.62 ± 409.35[a,e]	1784.40 ± 410.98[a,b,e]	1207.70 ± 131.84
Total BMD (g/cm^2)	0.93 ± 0.08[e]	0.95 ± 0.08[e]	1.00 ± 0.13[e]	1.01 ± 0.12[e]	0.83 ± 0.04

Notes: Data adjusted by height. Differences concerning the mentioned group at [a]swimming, [b]football, [c]basketball, [d]handball, [e]control, $p < 0.05$.
Abbreviations: BMI = body mass index; BMC = bone mineral content; BMD = bone mineral density.

interview, the girls in the control group did not participate in any kind of sport outside school (2 weekly sessions of 45 min each). The general questions about health and sport activity habits, which included information regarding type and years of sport practice, number of hours of sport activity, bone diseases, any other known disease, injuries, other sport practice and medication, were asked at the beginning of the study. Thus, these questions were used as selection criteria for the sample in order to homogenize its characteristics. Other inclusion requirements were that they had to practice their sports at least 3 h per week[31] and had been practicing their sports for a minimum of 8 months.[32]

Both parents and children were informed about the aims and procedures of the study, as well as the possible risks and benefits prior to the start of the study. Children gave their verbal assent, and a written informed consent was signed by their parents. The study was approved by the Ethical Committee of Clinical Research, according to the Declaration of Helsinki regarding the ethical principles for medical research involving human subjects.

2.2. Anthropometry and body composition

Weight (kg) and height (cm) were measured using a SECA scale (model 711; SECA GmbH & Co. KG, Hamburg, Germany). Body mass index (BMI) was calculated as weight (kg)/height (m)^2. Fat mass (g) and lean mass (g) (body mass − (fat mass + bone mass)) were measured using a DXA absorptiometry (Hologic Serie Discovery QDR., Software Physician's Viewer, APEX System Software, Version 3.1.2., Bedford, MA, USA). DXAs were performed for the whole body (arms, trunk, and legs). Lean mass of the limbs was assumed to be equivalent to the muscle mass. The DXA was calibrated using a lumbar spine phantom as recommended by the manufacturer. Participants were placed in supine position with the body and limbs fully extended and within the limits set by the scan lines. Whole body scanning time was about 7 min. The total X-ray irradiation absorbed by a subject was about 10% of standard chest X-ray film. All scanning and analyses were performed by the same operator to ensure consistency.

2.3. Pubertal stage

Maturity assessment is necessary for studies on growing children because the maturation range between individuals of the same chronological age is wide, especially during the pubertal years.[33] Pubertal status was determined by self-assessment using photographs of the Tanner stages,[34] a tool designed by Marshall and Tanner.[35] Pubertal status was classified as prepubertal (Tanner stage I) and pubertal (Tanner stages II–III).

2.4. Data analysis

All data were analyzed statistically by means of the SPSS for Windows (V19.0; SPSS Inc., Chicago, IL, USA) with a significance level of $p < 0.05$. The Kolmogórov–Smirnov test resulted in a normal distribution of the variables. The characteristics of the study groups (mean and SEM) were determined through basic descriptive tests. The differences between groups were determined using a covariance analyses (ANCOVA), including height as covariate. This covariate was used because of the scientific evidence about its influence on body composition.[36,37] A preliminary analysis indicated that the fat and lean masses differed for prepubertal and pubertal. Therefore, because of the interactions between Tanner groups and the bone mass variables, every analysis was performed independently for the prepubertal and pubertal group.

To identify meaningful changes, 95% confidence intervals (95%CI) and effect sizes (ES; Cohen's *d*) were calculated. ES was assessed using the following criteria: 0–0.2 = trivial, 0.2–0.5 = small, 0.5–0.8 = moderate, and >0.8 = large.[38]

3. Results

Table 2 presents the data related to fat and lean masses from both the prepubertal and pubertal groups of girls.

3.1. Fat mass

Firstly, results for fat mass for the five groups of prepubertal girls are described. The control group has significantly higher values of percentage for body fat (5.73%; 95%CI: −0.01% to 11.49%; ES = 0.89), total fat mass (3982.46 g; 95%CI: 344.56–7620.36 g; ES = 1.31), and arms fat mass (284.13 g; 95%CI: 54.58–513.68 g; ES = 1.27) than swimmers ($p < 0.05$). The control group also has higher values for legs fat mass than swimmers and handball players ($p < 0.01$). The football players show significantly lower values for arms fat mass (−190.06 g; 95%CI: −429.31 to 49.19 g; ES = 1.11) and trunk fat mass (−1148.03 g; 95%CI: −3320.18 to 1024.12 g; ES = 0.82) compared to the basketball group.

In a different way, the pubertal girls did not obtain significant differences either in trunk or in arms fat mass for any of the sports. The swimmers show significantly lower values for legs fat mass (−90.04 g; 95%CI: −838.28 to 658.19 g; ES = 0.45) than the control group ($p < 0.05$) and lower body fat percentage when compared to footballers ($p < 0.05$) and control group girls ($p < 0.01$). Finally, the basketball players have higher total body fat (2379.61 g; 95%CI: −1867.43 to 6626.65 g; ES = 0.91) than the control group ($p < 0.05$).

3.2. Lean mass

Secondly, the lean mass differences between prepubertal girls are shown. The handball players have significantly higher values for total lean mass (2619.34 g; 95%CI: −5.63 to 5244.31 g; ES = 1.53) than swimmers. Likewise, the handball players also show significantly higher trunk lean mass ($p < 0.01$) when compared to swimmers, footballers, and control group girls. Finally, the handball players obtained significantly higher legs muscle mass results (−561.96 g; 95%CI: −979.07 to −144.85 g; ES = 0.60) than the control group. Trunk lean mass (−726.46 g; 95%CI: −2329.01 to 876.09 g; ES = 1.06) and arms muscle mass (−25.67 g; 95%CI: −163.14 to 111.81 g; ES = 0.95) were lower in the control group in comparison with the basketball players ($p < 0.05$). The football

Table 2
Fat mass and lean mass in the five groups of prepubertal and pubertal girls.

	Swimming	Football	Basketball	Handball	Control
Prepubertal					
Percent body fat (%)	26.86 ± 6.79	26.99 ± 5.55	28.94 ± 5.62	27.81 ± 6.90	32.38 ± 5.65[a]
Total fat mass (g)	7779.80 ± 2807.73	9388.80 ± 3114.85	12430.72 ± 4608.84	10588.96 ± 4754.89	12648.63 ± 4599.68[a]
Fat mass arms (g)	451.88 ± 198.67	471.56 ± 189.50	719.47 ± 255.71[b]	606.35 ± 276.95	771.53 ± 305.87[a]
Fat mass trunk (g)	2887.40 ± 1139.96	3507.98 ± 1416.40	5187.54 ± 2692.31[b]	5052.47 ± 2264.05	5099.30 ± 3159.16
Fat mass legs (g)	1632.54 ± 681.82	2099.25 ± 677.85	2534.79 ± 837.76	1780.46 ± 570.79	2657.81 ± 906.24[a,d]
Total lean mass (g)	19632.44 ± 2460.38	23698.05 ± 4363.06	28182.20 ± 5280.04	25191.76 ± 4827.06[a]	23257.44 ± 5014.84
Muscle mass arms (g)	882.18 ± 129.85	1064.92 ± 191.93	1252.38 ± 253.07[e]	1109.14 ± 266.77	1033.79 ± 205.68
Lean mass trunk (g)	9405.51 ± 1316.65	11347.95 ± 2213.93	14127.28 ± 3123.16[e]	13204.71 ± 2731.77[a,b,e]	11347.60 ± 2136.99
Muscle mass legs (g)	3014.55 ± 460.98	3864.05 ± 865.34[e]	4374.80 ± 887.07	4012.07 ± 901.74[e]	3517.92 ± 747.72
Pubertal					
Percent body fat (%)	25.83 ± 6.23	27.43 ± 4.71[a]	29.32 ± 6.50	26.99 ± 4.90	27.74 ± 7.06[a]
Total fat mass (g)	12782.56 ± 5666.25	12247.14 ± 4580.89	16548.59 ± 6439.27[e]	14349.03 ± 5035.06	11375.02 ± 4930.07
Fat mass arms (g)	711.22 ± 333.15	615.00 ± 300.47	931.10 ± 376.64	803.07 ± 303.27	616.24 ± 336.12
Fat mass trunk (g)	5888.63 ± 2935.90	4796.38 ± 2252.87	7055.00 ± 3342.12	6311.68 ± 2567.08	4301.61 ± 2387.68
Fat mass legs (g)	2361.57 ± 1135.92	2680.50 ± 855.57	3429.01 ± 1232.18	2550.77 ± 983.54	2831.14 ± 969.02[a]
Total lean mass (g)	33711.83 ± 6493.51[b,e]	29708.51 ± 4898.89[e]	36161.50 ± 5945.94[e]	35565.89 ± 5887.83[b,e]	26919.27 ± 3960.52
Muscle mass arms (g)	1610.21 ± 347.71[b,e]	1490.67 ± 241.65	1631.51 ± 239.70[e]	1606.98 ± 287.07[b,e]	1234.88 ± 187.11
Lean mass trunk (g)	18160.29 ± 3789.42[b,e]	14555.66 ± 2663.12[e]	18176.47 ± 3721.08[e]	19127.48 ± 3435.61[b,e]	12579.14 ± 1963.78
Muscle mass legs (g)	4720.14 ± 1047.43	4985.56 ± 849.41[e]	5870.78 ± 980.56[e]	5125.49 ± 871.92	4341.65 ± 1271.40

Notes: Data adjusted by height. Differences concerning the mentioned group at [a]swimming, [b]football, [c]basketball, [d]handball, [e]control, $p < 0.05$.
Abbreviations: BMC: bone mineral content; BMD: bone mineral density.
Data adjusted by height.

players obtained significantly higher leg muscle mass results than the control group ($p < 0.01$).

Similarly, the pubertal girls of the control group show significantly lower total lean mass ($p < 0.01$) and trunk lean mass results in comparison with the rest of the sports groups (swimming, football, basketball, and handball). The controls present significantly lower arms muscle mass values than swimmers (−404.26 g; 95%CI: −575.53 to 233.00 g; ES = 1.40), basketball players (−220.86 g; 95%CI: −399.52 to −42.20 g; ES = 1.86), and handball players (−271.93 g; 95%CI: −445.49 to 98.37 g; ES = 1.57). The legs muscle mass of the control group was lower ($p < 0.01$) in relation to football and basketball players. Finally, the football players have significantly lower values ($p < 0.01$) for total lean mass, trunk lean mass, and arms muscle mass than handball players and swimmers.

4. Discussion

The main purpose of this study was to compare the fat and lean masses in prepubertal and pubertal girls practicing five different sports and as a consequence, determining the influence that a particular sport has on the development of growing girls' body composition. Most of the previous researches that investigated the influence of physical activity on children and adolescents' body composition focused only on talent identification,[39] adiposity,[40] or bone accumulation[41] in active and sedentary people. On the contrary, few researches have studied the influence of the physical activity on the muscle and fat masses of children and adolescents' practicing different sports from a health-related perspective.

After analyzing the results, the control group girls are observed to have greater fat mass than the girls who practice sports. In this manner, the results coincide with the studies of Andersen et al.[42] and Ferreira et al.,[43] who demonstrated that physical activity improves the body composition (decrease of fat mass and increase of muscle and bone mass) of children and adolescents. Moreover, Abbott and Davies[10] and Ball et al.[44] studied the relationship between physical activity and childhood obesity and obtained correlations between physical activity levels, BMI, and body fat mass. In the study by Ara et al.,[31] the children who had no physical activity had a higher percentage of fat mass, total body fat mass, and regional fat mass (trunk, arms, and legs) than those who had at least 3 h per week, which coincides with the results obtained in the present investigation. Regarding lean mass, the control group has less lean mass than physically active girls. Thus, physical activity increases the levels of muscle mass in male and female children[45] as well as during adolescence.[46]

According to the analysis between sports, the football players had lower arm and trunk fat masses at a prepubertal stage, which coincides with the studies of Gil-Gómez and Juan Verdoy[47] and Pérez-Guisado[48] that show the footballers' group to have less fat mass than the basketball group. The prepubertal basketball players had greater trunk and leg muscle mass than the control group. This could be because basketball being a more explosive sport produces greater muscle mass development, especially in the legs.[49] The study of Koley and Singh[50] with basketball players between the age 18 and 25 years, also shows how the basketball group had a higher percentage of lean mass than the control group. Likewise, the athletes who practice sports that require jumps and throws with the upper body are bigger, stronger, and heavier.[18,51,52] Withers et al.[53] investigated the anthropometric characteristics of basketball, football, and hockey players and concluded that basketball players were taller and heavier, having as a result greater muscle mass than other sports persons.

On the other hand, prepubertal and pubertal handball players have the highest total lean mass, as well as arm and trunk lean masses, which coincides with the study of Milanese et al.[54] where a clear tendency of female handball players to accumulate more lean mass, especially in the upper body, is shown. Handball as a sport requires strength in the trunk and explosive strength in the arms to throw.[55] In handball, the trunk is usually used to perform actions such as throwing[28,29] whereas in football, the lower body is predominantly used.[56] Bayios et al.[18] compared the body composition of handball and basketball players' and showed that basketball players are taller. Recent researches[57] suggest that handball players have greater muscle mass when compared to footballers, as in our study also. When talking about pubertal female swimmers, they have greater muscle mass and lower percentage of fat mass than football players. These results coincide with the ones obtained in the study of Grijota et al.,[58] in which swimmers had a higher fat mass percentage than other sportspersons (handball and karate) in infant categories.

More sports could have been included in this study to see the influence of different sports on body composition. Likewise, male participants could have been included to see if there are changes in body composition depending on the gender, as other studies did.[59] In future researches, it can be interesting to develop this study longitudinally to see if there is a cause–effect relationship. Finally, we agree with Ara et al.[31] who state that regular involvement in sport activities or competitions (at least 3 h per week) is associated with lower fat mass values in prepubertal children. Therefore, participation in sports during the development stage decreases obesity risks and risks related to the increased obesity.[31,60] Regarding the type of sport, team sports (football, basketball, and handball) provide growing girls with a good body composition development.

5. Conclusion

In short, it can be concluded that sport activity at early ages (independently of type of sport), unlike sport inactivity, ensures lower fat mass and greater lean mass. Therefore, our initial hypothesis is accepted. This becomes a good argument for coaches, teachers, and doctors to promote sports and recommend physical activity.

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Influence of different sports on bone mass in growing girls

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Abstract
The aim of this study was to analyse whether there are differences in bone mass in girls playing different sports. Two hundred girls (10.6 ± 1.5 years old, Tanner stages I–III) participated in the study and were divided into groups of 40 (swimmers, soccer players, basketball players, handball players and controls). Bone mineral content and bone mineral density (BMD) (whole body and hip) were measured using dual-energy X-ray absorptiometry. The degree of sexual development was determined using Tanner test, and physical activity habits were recorded through a questionnaire designed ad hoc for this research. Girls were divided by pubertal stage and the type of sport. In the prepubertal group, intertrochanteric BMD was significantly higher in both handball and soccer players compared with the control group ($P < 0.05$). Furthermore, in the pubertal group, total BMD, mean arms BMD, pelvis BMD, femoral neck BMD, intertrochanteric BMD and Ward's triangle BMD were significantly higher in soccer and handball players compared with the control group ($P < 0.05$), and the swimmers showed significantly higher values in the mean arms BMD compared with the control group ($P < 0.01$). Our data suggest that sport practice during puberty, especially in activities that support the body weight, may be an important factor in achieving a high peak bone mass and improving bone health in girls.

Keywords: *body composition, bone mass, DXA, female players, physical activity*

Introduction

In the past years, the interest in bone health in childhood has grown meaningfully as a result of the increase of osteoporosis cases in adults (Bailey, McKay, Mirwald, Crocker, & Faulkner, 1999; Bellew & Gehrig, 2006). Osteoporosis is considered a public health problem because of the increased number of people who are suffering from it and the economic repercussions, which are generated during treatment and rehabilitation (Cruz et al., 2009). In fact, the costs derived from bone fracture as a consequence of this disease are higher than those produced by breast cancer and prostate cancer (Clark, Carlos, & Vázquez-Martínez, 2010). Currently, there are more than 200 million people who are suffering from this illness around the world (Schurman et al., 2013). About 1.7 million of hip fractures related to osteoporosis took place in 1900 (Manzarbeitia, 2005). By 2050, that number will be about 6 million (Gullberg, Johnell, & Kanis, 1997).

The International Osteoporosis Foundation (2014), with the aim of avoiding this social and economic repercussion, proposed that prevention is the best method to fight against this disease. One of the best ways to improve bone health and, therefore, reduce the risk of suffering osteoporosis is through physical activity (Mesa-Ramos, 2010). An increment in the level of physical activity in children would result in higher bone mass accrual and a diminution of the risk of suffering bone fractures during adulthood (Karlsson, Nordqvist, & Karlsson, 2008). This increase can be achieved with 30 min of exercise impact, 3 days per week, gaining BMD in the greater trochanter by 1.4% over a period of 8 months (McKay et al., 2000). Indeed, approximately 20% of the variation of the peak bone mass is explained through lifestyle (Ferrari, 2005).

As a result of that situation, the interest in the diverse osteogenic effects of physical activity has grown to know which discipline produces the best bone development (Weidauer, Eilers, Binkley, Vukovich, & Specker, 2012). However, although there are many research studies that have investigated this aspect in other populations, for example, in the elderly and adults (Gómez-Cabello, Ara, González-Agüero,

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Casajús, & Vicente-Rodríguez, 2012; Verschueren et al., 2013), still, there are few studies that analyse the effect of exercise on bone growth in girls and its relation in the prevention of bone disease in adulthood, focusing most research only on children (Ackerman, Skrinar, Medvedova, Misra, & Miller, 2012; Andreoli et al., 2001; Plaza-Carmona et al., 2014; Zouch et al., 2008).

Previous studies have demonstrated that the accumulation of bone mass and its persistence in adulthood are favoured by doing sport or physical activity at early ages, between 8 and 15 years (Baxter-Jones, Eisenmann, Mirwald, Faulkner, & Bailey, 2008). Moreover, the effect of exercise is bigger when it is done before puberty (Vicente-Rodriguez et al., 2003). According to Bailey, Martin, McKay, Whiting, and Mirwald (2000), 25% of bone mineral content (BMC) is achieved between 11 and 13 years in girls and between 12 and 14 years in boys. The exercise produces not only an increase in the bone mass but also structural changes that can persist for life (Gustavsson, Thorsen, & Nordström, 2003). Sixty per cent of the osteoporosis cases in adulthood are related to a low BMC, which has been acquired during adolescence (Baroncelli, Bertelloni, Sodini, & Saggese, 2005). For that reason, the childhood is a key stage because the risk of suffering osteoporosis during adulthood can be reduced if the maximum peak of bone mass is increased during the growth (Rizzoli, Bianchi, Garabédian, McKay, & Moreno, 2010). Furthermore, immature bones are more sensible to mechanic tension (Vicente-Rodriguez et al., 2003).

The exercise suggested to improve the bone mineral density (BMD) is fundamentally the impact – ones which consist in applying plyometric exercises such as jumps and races (Asikainen, Kukkonen-Harjula, & Miilumpalo, 2004). For that reason, sports such as soccer, basketball or handball produce high stimulus in bones because of the reaction forces applied to the play surface during the development of the different game actions, being beneficial to calcium deposition and remodelling (González-Aramendi, 2003). In fact, research carried out by Vicente-Rodríguez et al. (2004), Vicente-Rodriguez, Dorado, Perez-Gomez, Gonzalez-Henriquez, and Calbet (2004) and Vicente-Rodriguez et al. (2003) showed that participation in football and handball in girls reduces the risk of skeletal fractures later in life.

Nevertheless, while practicing low-impact sports, as for example swimming, the bones do not get so many stimuli, so the bone density values are lower (Karlsson et al., 2008). In fact, in a review carried out by Gómez-Bruton, Gónzalez-Agüero, Gómez-Cabello, Casajús, and Vicente-Rodríguez review (2013), it is concluded that swimmers have a bone structure weaker than high-impact sports athletes and stronger when compared to sedentary control groups.

Although there are studies that analyse sports separately, to our knowledge, there is no research that examines the impact of different sports together in girls. Therefore, the objective of this study was to evaluate the influence of different sports with different grades of osteogenic impact in prepubertal and pubertal girls. The result of this study will dictate which sport discipline is best to guarantee the highest bone mass development in girls at early ages.

Materials and methods

Participants

The study sample is 200 Spanish girls from the province of Madrid, Toledo and Ciudad Real, and their age is from 9 to 13 years (10.6 ± 1.5 years old; Tanner stages I–III). All participants took part in the project voluntarily and were divided into five groups according to the sport type that they practice (swimming, soccer, basketball, handball and control group). The general characteristics of each group are described in Table I, divided per prepubertal girls (Tanner I) and pubertal (Tanner II–III). Once the sample was recruited, the participants realised a series of tests to assess their degree of sexual development and their body composition (bones mass, fat mass and muscle mass).

The sample was obtained by means of contacting with sport clubs and schools in the case of girls in the control group. According to the answer given by fathers in the personal interview, the control group participants did not participate in any kind of sport. The girls answered a medical general questionnaire and other questionnaires about their physical activity habits designed ad hoc for this research, collecting information such as years of practicing their sports, bone diseases, injuries, number of hours of training per week, practice of other sport type, medicines and illness known. Other inclusion requirements were that they had to practice their sport a minimum of 3 h per week (Vicente-Rodríguez et al., 2004) and have been practicing their sports at least 8 months (Ferry, Lespessailles, Rochcongar, Duclos, & Courteix, 2013).

Parents and girls were informed about the research goal and its procedure, as well as its possible risk. Girls gave their consent verbally and their parents signed the written informed consent. The study protocols were approved by the ethical committee from the University of Castilla–La Mancha (Toledo, Spain) on 15 December 2010 (no 4520), according to the Helsinki Declaration about ethic principles of medical research in humans. All measurements were taken in the same condition, following the same actuation protocol with each participant. All evaluations were done from October to December 2013.

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Influence of different sports on bone mass in growing girls

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The differences between groups were determined using a covariance analysis (ANCOVA) including height and lean mass as covariates. These covariates were used because of the scientific evidence of their influence in bone mass (Courteix et al., 1998). To identify meaningful changes, confidence intervals (CI 95%) and effect sizes (ES; Cohen's *d*) were calculated. ES was assessed using the following criteria: 0–0.2 = trivial, 0.2–0.5 = small, 0.5–0.8 = moderate and >0.8 = large (Cohen, 1992).

A preliminary analysis indicates that the BMC and BMD differed significantly between prepubertal and peripubertal girls. Therefore, because of the interactions between Tanner groups and the bone mass variables, every analysis was made independently between prepubertal and pubertal girls.

Results

In relation to the general results in Table I, we can observe the differences in descriptive characteristics of the participants. In the prepubertal group, the basketball players had higher age than the swimmers ($P < 0.01$) and soccer players ($P < 0.05$), higher height compared with the other groups ($P < 0.05$) and higher body mass ($P < 0.01$), BMI ($P < 0.05$) and fat mass ($P < 0.01$) than the swimmers. Moreover, the basketball players had data that are significantly higher than the swimmers ($P < 0.01$), soccer players ($P < 0.05$) and control group ($P < 0.01$) in the lean mass. The control group had higher age, body mass, BMI and fat mass than the swimmers ($P < 0.01$). The handball players showed higher values of body mass ($P < 0.05$) and lean mass ($P < 0.01$), compared to the swimmers.

In the pubertal group, the basketball players had data that are significantly higher ($P < 0.05$) than the swimmers, soccer players and control group in the age and weight. In terms of body mass and lean mass, the basketball players also showed higher values than the soccer players and the control group ($P < 0.05$). The swimmers showed higher values of lean mass ($P < 0.01$) than the control group. Finally, the handball group had higher lean mass ($P < 0.01$) compared to the soccer players and the control group.

Prepubertal

The results of bone densitometry (BMC and BMD) in the five groups of prepuberty are shown in Table II. According to the BMC, there are no significant differences between any of the groups in whole body, mean arms, mean legs and Ward's triangle. The control group had between 19% and 31% less BMC in the pelvis ($P < 0.05$) compared with soccer (−26.73 g; CI 95%: −42.60 to −7.48 g; ES = 1.17), basketball (−34.36 g; CI 95%: −38.38 to −0.68 g; ES = 1.47) and handball (−43.12 g; CI 95%: −52.84 to −17.16 g; ES = 1.87). Besides, the handball players had higher BMC ($P < 0.01$) in the hip than the swimmers (5.13 g; CI 95%: −0.05 to 5.66 g, ES = 1.61). The soccer group had data that

Table II. Bone mineral density and bone mineral content at different sites in the five groups of prepubertal girls.

	Swimming (a)	Soccer (b)	Basketball (c)	Handball (d)	Control (e)
BMC (g)					
Whole body	973.68 ± 115.32	1171.74 ± 186.41	1302.71 ± 286.73	1133.46 ± 183.35	1122.66 ± 151.6
Mean arms	60.11 ± 7.77	57.95 ± 10.89	73.34 ± 17.00	59.98 ± 12.69	59.61 ± 10.58
Mean legs	160.16 ± 27.19	216.50 ± 42.44	239.87 ± 61.09	198.32 ± 38.41	207.78 ± 39.26
Pelvis	99.39 ± 16.31	136.00 ± 29.70[e]	143.63 ± 49.87[e]	152.39 ± 29.91[a,e]	109.27 ± 16.10
Hip	20.34 ± 3.30	22.98 ± 3.07[a]	25.14 ± 1.86[a]	25.47 ± 3.07[a]	21.03 ± 2.95
Femoral neck	2.25 ± 0.52	3.08 ± 0.44[a,c]	3.01 ± 0.77	2.84 ± 0.66	2.73 ± 0.54
Trochanter	3.80 ± 0.71	5.30 ± 1.18[a,c,e]	5.25 ± 1.60	4.92 ± 1.16	4.17 ± 0.67
Intertrochanter	12.13 ± 3.61	13.95 ± 2.62	18.12 ± 6.14[e]	20.28 ± 4.18[a,b,e]	11.87 ± 2.01
Ward's triangle	0.85 ± 0.19	0.90 ± 0.14	0.83 ± 0.17	0.84 ± 0.13	0.82 ± 0.10
BMD ($g \cdot cm^{-2}$)					
Whole body	0.78 ± 0.06	0.86 ± 0.07	0.87 ± 0.09	0.84 ± 0.06	0.82 ± 0.06
Mean arms	0.48 ± 0.05	0.54 ± 0.07	0.58 ± 0.06	0.55 ± 0.06	0.53 ± 0.06
Mean legs	0.74 ± 0.06	0.86 ± 0.09	0.93 ± 0.13	0.89 ± 0.09[a]	0.85 ± 0.10
Pelvis	0.73 ± 0.10	0.86 ± 0.10	0.91 ± 0.14	0.86 ± 0.09	0.83 ± 0.09
Hip	0.78 ± 0.04	0.81 ± 0.05	0.80 ± 0.07	0.84 ± 0.06[e]	0.77 ± 0.08
Femoral neck	0.61 ± 0.10	0.73 ± 0.06[a]	0.71 ± 0.12	0.70 ± 0.09	0.68 ± 0.07
Trochanter	0.63 ± 0.06	0.70 ± 0.05	0.69 ± 0.10	0.72 ± 0.06[a]	0.70 ± 0.04
Intertrochanter	0.80 ± 0.11	0.91 ± 0.09[e]	0.93 ± 0.13	0.98 ± 0.10[a,c,e]	0.83 ± 0.07
Ward's triangle	0.71 ± 0.14	0.74 ± 0.16	0.69 ± 0.14	0.70 ± 0.10	0.68 ± 0.06

Notes: Differences concerning the mentioned group at a (swimming), b (soccer), c (basketball), d (handball), e (control) $P < 0.05$.
BMC: bone mineral content; BMD: bone mineral density.
Data adjusted by height and lean mass.

are significantly higher ($P < 0.05$) than swimmers and basketball players in the femur neck and trochanter. In the case of trochanter, soccer players had a 21.3% more BMC ($P < 0.05$) than the control group (1.13 g; CI 95%: 0.31 to 1.87 g; ES = 1.22). Handball players had 31% to 42% more BMC ($P < 0.01$) than the swimming, soccer and control groups in the intertrochanter. Also, basketball players had highest values ($P < 0.01$) in the intertrochanter (6.25 g; CI 95%: 0.96 to 7.38 g; ES = 1.53), compared with the control group. Finally, swimmers had values that are significantly lower in the hip ($P < 0.05$) compared with the rest of the participants in other sport types (soccer, basketball and handball).

Regarding BMD, there were no significant differences between any of the groups in the whole body, mean arms, pelvis and Ward's triangle. However, handball players had 12% to 17% more BMD than swimmers in the variables such as mean legs (0.15 g · cm^{-2}; CI 95%: 0.01 to 0.17 g · cm^{-2}; ES = 2.00) and trochanter (0.09 g · cm^{-2}; CI 95%: 0.01 to 0.12 g · cm^{-2}; ES = 1.50). Soccer players had the highest values (0.12 g · cm^{-2}; CI 95%: 0.01 to 0.16 g · cm^{-2}; ES = 1.50) in the femur neck compared with swimmers (all $P < 0.05$). In the intertrochanter, handball players had 5% to 19% more BMD ($P < 0.05$) than swimmers, basketball players and the control group, whereas soccer players had higher values than the control group. Finally, handball players had the highest significant differences in their hip ($P < 0.05$) with respect to the control group (0.07 g · cm^{-2}; CI 95%: 0.01 to 0.13 g · cm^{-2}; ES = 1.00).

Pubertal

The results obtained from the bone densitometry (BMC and BMD) from the five girls in pubertal groups are shown in Table III. Soccer players had 2% to 22% more BMC than swimmers and 9% to 26% more BMC than the control group in variables such as whole body, mean legs, hip, femur neck and trochanter ($P < 0.05$). Also, soccer players showed a higher level in the pelvis (50.75 g; CI 95%: 3.91 to 72.77 g; ES = 2.03) and Ward's triangle (0.19 g; CI 95%: 0.03 to 0.27 g; ES = 1.65), compared with the control group (all $P < 0.05$). On the other hand, handball players had 18% to 35% more BMC than swimmers and 32% to 51% more BMC than the control group in the variables whole body, mean legs, mean arms, hip, pelvis, femur neck, trochanter and intertrochanter ($P < 0.05$). Besides, handball players obtained the highest results in pelvis (60.78 g; CI 95%: 1.66 to 69.58 g; ES = 1.43) and intertrochanter (9.95 g; CI 95%: 2.85 to 11.10 g; ES = 2.59) in front of soccer players (all $P < 0.05$). The basketball group showed the highest significant values in variables such as mean arms (9.45 g; CI 95%: 0.34 to 18.56 g; ES = 2.47), hip (9.64 g; CI 95%: 0.82 to 10.11 g; ES = 3.46) and femur neck (1.41 g; CI 95%: 0.82 to 8.11 g; ES = 2.01) compared with the control group ($P < 0.05$) and in

Table III. Bone mineral density and bone mineral content at different sites in the five groups of pubertal girls.

	Swimming (a)	Soccer (b)	Basketball (c)	Handball (d)	Control (e)
BMC (g)					
Whole body	1458.32 ± 271.96	1488.10 ± 233.64^{a,e}	1761.62 ± 409.35	1784.40 ± 410.98^{a,e}	1207.70 ± 131.84
Mean arms	86.10 ± 2.11	89.10 ± 1.98	91.90 ± 2.04^{e}	93.87 ± 2.01^{e}	82.45 ± 2.00
Mean legs	256.69 ± 8.02	316.95 ± 7.53^{a,e}	297.00 ± 7.74^{a}	299.60 ± 7.63^{a}	275.03 ± 8.73
Pelvis	194.67 ± 57.15	180.39 ± 32.41^{e}	220.80 ± 68.08	241.17 ± 79.30^{a,b,e}	129.64 ± 17.68
Hip	26.87 ± 0.80	35.08 ± 0.85^{a}	37.16 ± 0.82^{a,e}	36.22 ± 0.80^{a}	27.52 ± 0.92
Femoral neck	3.28 ± 0.67	3.59 ± 0.51^{a,e}	4.07 ± 0.75^{e}	4.04 ± 0.99^{a,e}	2.66 ± 0.65
Trochanter	5.67 ± 1.29	7.26 ± 1.41^{a,e}	6.55 ± 1.64	7.34 ± 1.52^{a,b,e}	4.74 ± 0.87
Intertrochanter	17.36 ± 4.66	14.71 ± 2.97	19.41 ± 7.31	24.66 ± 4.70^{b,c,e}	14.49 ± 5.09
Ward's triangle	0.92 ± 0.16	0.93 ± 0.15^{e}	0.92 ± 0.16	1.00 ± 0.15	0.74 ± 0.08
BMD (g · cm^{-2})					
Whole body	0.92 ± 0.02	0.98 ± 0.02^{e}	0.95 ± 0.02	0.98 ± 0.02^{e}	0.90 ± 0.02
Mean arms	0.63 ± 0.01^{e}	0.64 ± 0.01^{e}	0.62 ± 0.01	0.64 ± 0.01^{e}	0.59 ± 0.01
Mean legs	0.99 ± 0.10	0.99 ± 0.08	1.09 ± 0.17	1.10 ± 0.14^{a}	0.88 ± 0.06
Pelvis	0.93 ± 0.02	1.06 ± 0.02^{a,e}	1.01 ± 0.02	1.06 ± 0.02^{a,e}	0.94 ± 0.03
Hip	0.93 ± 0.03	0.96 ± 0.07^{a,e}	1.01 ± 0.06^{e}	1.03 ± 0.07^{a,e}	0.88 ± 0.07
Femoral neck	0.75 ± 0.02	0.83 ± 0.02^{e}	0.78 ± 0.02	0.83 ± 0.02^{a,e}	0.70 ± 0.02
Trochanter	0.73 ± 0.06	0.73 ± 0.08	0.76 ± 0.09	0.81 ± 0.09	0.73 ± 0.14
Intertrochanter	0.99 ± 0.03	1.04 ± 0.02^{e}	0.99 ± 0.03	1.10 ± 0.02^{a,c,e}	0.92 ± 0.03
Ward's triangle	0.76 ± 0.10	0.78 ± 0.12^{e}	0.79 ± 0.14	0.85 ± 0.12^{e}	0.66 ± 0.09

Notes: Differences concerning the mentioned group at a (swimming), b (soccer), c (basketball), d (handball), e (control) $P < 0.05$.
BMC: bone mineral content; BMD: bone mineral density.
Data adjusted by height and lean mass.

variables such as mean legs (40.31 g; CI 95%: 7.94 to 72.66 g; ES = 1.11) and hip (10.29 g; CI 95%: 1.06 to 13.76 g; ES = 3.23) compared with swimmers ($P < 0.01$).

In BMD results, the only variable that did not show significant differences in any of the groups was the trochanter. Soccer players had 12% to 23% more BMD than the control group in variables such as whole body, mean arms, femur neck, intertrochanter and Ward's triangle and 5% to 17% more BMD in pelvis and hip compared with swimmers and the control group (all $P < 0.05$). On the other hand, handball players had 17% to 30% more BMD than the control group ($P < 0.05$) in whole body (0.08 g · cm^{-2}; CI 95%: 0.01 to 0.15 g · cm^{-2}; ES = 2.25), mean arms (0.05 g · cm^{-2}; CI 95%: 0.02 to 0.08 g · cm^{-2}; ES = 2.40), hip (0.15 g · cm^{-2}; CI 95%: 0.05 to 0.18 g · cm^{-2}; ES = 2.00), pelvis (0.12 g · cm^{-2}; CI 95%: 0.02 to 0.22 g · cm^{-2}; ES = 0.58), femoral neck (0.13 g · cm^{-2}; CI 95%: 0.04 to 0.23 g · cm^{-2}; ES = 2.08), intertrochanter (0.18 g · cm^{-2}; CI 95%: 0.07 to 0.29 g · cm^{-2}; ES = 2.30) and Ward's triangle (0.19 g · cm^{-2}; CI 95%: 0.01 to 0.21 g · cm^{-2}; ES = 1.81). The swimmers group also had 10% to 16% less BMD than the handball players ($P < 0.05$) in variables such as mean legs, hip, pelvis, femoral neck and intertrochanter. Basketball players showed values that are significantly lower in the intertrochanter (−0.11 g · cm^{-2}; CI 95%: −0.21 to 0.02 g · cm^{-2}; ES = 0.59) than handball players ($P < 0.05$), but they had values that are significantly higher in the hip ($P < 0.01$) compared with the control group (0.08 g · cm^{-2}; CI 95%: 0.02 to 0.16 g · cm^{-2}; ES = 1.14). Lastly, swimmers had 15.6% more BMD than the control group (0.04 g · cm^{-2}; CI 95%: 0.01 to 0.08 g · cm^{-2}; ES = 2.00) in the variable of mean arms ($P < 0.01$).

Discussion

The goal of this study was to assess the influence of different sport types in bone mass in prepubertal and peripubertal girls. In this manner, we discover which sport type is better to obtain higher benefits at the osteogenic level in growing girls. The recommended exercise to improve BMC and BMD is mainly based on impact, i.e., plyometric exercises, jumps, races and any activity based on own body weight, as soccer, basketball and handball (Asikainen et al., 2004). The first result observed after analysing the collected data was that in the pubertal status, the bone development is more advanced, so, the differences between groups are more evident. That might be because there are higher bone mass peaks during the prepubertal stage (Długołęcka, Czeczelewski, & Raczyńska, 2011; Vicente-Rodríguez et al., 2008). That result is similar to the study made by Gustavsson et al. (2003) where they showed how the physical activity has, as a result, an increasing effect in BMD in those participants who had passed the prepubertal period. Because girls who participated in this study trained a mean of 3.2 ± 0.6 h per week, it was shown that there are osteogenic benefits with only 3 h of impact of physical activity per week, as in the study of Vicente-Rodriguez et al. (2004).

The control group has obtained the lowest results in all the variables. Zouch et al. (2008) conclude that bone mass is higher in those bones that support the impacts and changes of directions, as it happens in sports such as soccer, basketball and handball; the reason is that people who do sport and force their bones to support impacts and load have better bone health than sedentary people (Bedogni et al., 2002). According to Ermin, Owens, Ford, and Bass (2012) and Nikander, Sievänen, Heinonen, and Kannus (2005), exercises with high impact improve the BMD in femoral neck. In our study, the sports of high impact are soccer, basketball and handball, which show higher values compared with sports of low impact (swimming) and a lack of exercise.

Our results show that soccer practice improves BMC levels in comparison with swimming practice in prepubertal and pubertal girls. In terms of BMD, the practice of soccer results in higher values in the hip area if compared to sedentary activities and swimming in pubertal girls. The researchers about soccer show that this sport increases the level of BMD in comparison with swimming and sedentary in different age groups, such as adults (Creighton, Morgan, Boardley, & Brolinson, 2001; Morel, Combe, Francisco, & Bernard, 2001), teenagers (Bellew & Gehrig, 2006; Seabra et al., 2012) and prepubertal boys and girls (vicente-Rodriguez et al., 2004; Vicente-Rodriguez et al., 2003). The hip is the weight-bearing zone, which is very influenced by the mechanical loading (Nikander et al., 2005).

In relation to handball, there are only few studies that analyse the bone mass in this sport. It is a sport in which there are many jumps and sprints, which cause a big mechanical loading on the bones of the lower extremities because of the reaction forces made during the races (Freychat, Belli, Carret, & Lacour, 1996). Also, there is a big involvement of the upper extremities in actions such as shooting and blocking (Vicente-Rodriguez et al., 2004). All these make the handball a sport that brings big benefits on bone mass (Calbet, Herrera, & Rodríguez, 1999). Besides, Vicente-Rodriguez et al. (2004) showed better BMD and BMC in variables such as the pelvis, lower body and femur neck in handball players in comparison with the control group. Our results support this conclusion because the participation in handball is associated with higher BMC and BMD in girls, especially during the pubertal stage.

The second group with the lowest values of bone mass is the swimming group. In prepubertal girls, a higher BMD in the variable of mean arms was observed, compared with the control group. It might be because they develop more muscle mass in the upper body; therefore, it is related to improve the bone mass (Andreoli et al., 2001). In fact, previous studies in boys have demonstrated that lean mass is the best predictor of deposition of bone mass (Faulkner et al., 1993). This may be because more developed muscles are able to apply higher forces on bones where they are joined together (Vicente-Rodriguez et al., 2004). Results demonstrate that because of water weightlessness, bones obtain fewer stimuli than when someone does sport outside it. For that reason, in sports such as basketball, soccer and handball in which the player must support his own weight, the values of BMC and BMD are higher (Derman et al., 2008; González-Aramendi, 2003).

Basketball players have obtained the highest significant values in some variables, compared with swimmers and the control group. Despite the fact that there are only few differences, we support the studies carried out by Carbuhn, Fernandez, Bragg, Green, and Crouse (2010) and Banfi, Lombardi, Colombini, and Lippi (2010), where they concluded that those people who do sport with jumps, for example, soccer, basketball and handball, have higher levels of BMC and BMD. In basketball, these differences have only been in BMC and not in BMD.

This study could include more sports because it would have been interested to see if higher values of BMC and BMD are produced in other sports with higher and lower osteogenic impact. Also, we could have included boys to see if there are differences between sports and gender, as it is done in other studies (Gracia-Marco et al., 2011). Moreover, a larger sample size could have made the differences between groups clearer, especially in basketball, where the SE (standard error of the mean) is quite high. In future research, it might be interesting to develop this study longitudinally so as to see if there is a cause–effect relation. Longitudinal studies are required to check if elevated values of BMC and BMD at this stage can be maintained in adulthood.

Conclusion

Our study shows that the type of sport is a variable that can have an influence on girls' bone health during childhood. The results of this research can be useful as a prevention method of bone diseases in adulthood. In relation to the academic formation years in Spain, Physical Education is divided into stages in which different sports (including impact and non-impact sports) are learnt. The schools are relatively free to organise the contents of these stages, so differences about the stages can be found at different schools. Even so, this study demonstrated that physical activity done at schools, just 2 h per week, is not enough to improve bone health at early ages, as affirmed by previous studies (McKay et al., 2000; Valdimarsson, Linden, Johnell, Gardsell, & Karlsson, 2006). In short, we conclude that the practice of a sport with high osteogenic impact at early ages ensures greater accumulation of bone mass compared with sports with low osteogenic impact and with lack of sports. Therefore, these types of sports may constitute a preventive measure in osteoporosis in the future.

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ORIGINAL ARTICLE

Bone mass in girls according to their BMI, VO_2 max, hours and years of practice

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Abstract
The accumulation of bone mass during puberty is related with bone health in adulthood. This accumulation is influenced by diverse factors such as body mass index (BMI), maximal oxygen uptake (VO_2 max), hours of training and years of sport practice. For this reason, the objective of this study is to analyse the influence of these variables on bone mass in young female athletes. The sample is formed of 120 healthy girls with ages between 9 and 13 (11.32 ± 1.6 years old), divided into two groups depending on their BMI, VO_2 max, hours of training and years of sport practice. The participants completed a series of tests to evaluate level of sexual development, body composition (fat mass, lean mass and bone mass) and physical condition. The results show higher values of total lean mass, total fat mass and percentage of body fat in the groups with higher BMI in prepubertal girls and pubertal girls ($p < .05$). In relation to VO_2 max, in the prepubertal group, girls with lower VO_2 max had higher values of total fat mass ($p < .05$) and percentage of body fat ($p < .05$). In the pubertal group, girls with lower VO_2 max also showed a higher total fat mass ($p < .05$). The studied variables account for a 85% and 75.4% of the variance of total bone mineral content and bone mineral density (BMD), respectively. In conclusion, the content and BMD are closely related with muscle mass and sports practice in young females. The amount of fat mass showed no association with bone mass and physical condition has an indirect relationship with bone development.

Keywords: *Body composition; children; bone health; exercise*

Introduction

Currently, osteoporosis is considered as a public health problem at world level because of the high number of cases and the socio-economic repercussions that it generates, including treatment and rehabilitation (Cruz et al., 2009). During puberty, the accumulation of bone mass seems to be related with bone health in adulthood (Bailey, Faulkner, & McKay, 1996). In fact, the risk of suffering osteoporosis is related with the peak of bone mass reached during puberty (Bailey, McKay, Mirwald, Crocker, & Faulkner, 1999).

Bone development is influenced by diverse variables such as genes, hormones, nutrition and physical activity (Cooper et al., 2006). Amongst others, body mass index (BMI) has proved to be associated with bone mineral density (BMD) and bone mineral content (BMC). Researchers such as Ceschia et al. (2015) affirm that an increased BMI was associated with lower performance capabilities, which directly affects the ability of children to take on sports skills. Some investigations conclude that a higher BMI is related with higher values of bone mass and that the loss of weight can lead to loss of bone (Guney et al., 2003; Radak, 2004). This association is not always like this as other investigations have related excess weight with lower bone mass (Goulding et al., 2000; Rocher, Chappard, Jaffre, Benhamou, & Courteix, 2008) whilst others have found no association between BMI and BMD (El Hage, Jacob, Moussa, Benhamou, & Jaffré, 2009). For this, there is no clear relation between the two parameters.

Although the effect of single factors contributing to weight gain in children has been investigated, the

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combined association of sports participation physical fitness with body weight in children (Drenowatz, Kobel, Kettner, Kesztyüs, & Steinacker, 2014) is necessary. In different studies correlations between bone mass and physical condition have been studied (Vicente-Rodríguez, Dorado, Pérez-Gómez, González-Henríquez, & Calbet, 2004). Physical condition has been related to variables such as speed, maximum strength and anaerobic capacity with variables of bone mass (BMC and BMD) (Vicente-Rodríguez et al., 2003). This may be explained by the relation between muscle mass and bone mass, as a higher muscle mass could generate higher bone tensions (Heinonen, Sievänen, Kannus, Oja, & Vuori, 2002).

Also, a significant relationship between the hours of training and bone mass has been demonstrated. Studies in handball players show how a volume of exercise of three weekly hours produces osteogenesis (Vicente-Rodríguez, Dorado, Pérez-Gómez, González-Henríquez, et al., 2004). What is more, Zouch et al. (2008) showed with their study that practising football 4 h a week versus 2 h a week causes an improvement in bone mass accumulation. Hence investigations on this are not clear. Finally, no investigations have been found that analyse the possible relation between years of training and bone mass. Exercise training is a potent stimulus to the development of aerobic and anaerobic fitness in the case of adults, but in young children it is unclear (McNarry & Jones, 2014).

As a result, the objective of the current investigation consists in analysing the influence of BMI, maximal oxygen uptake (VO_2 max), hours of training and years of sport practice on bone mass in young female athletes in developing ages. This study will help identify the incidence of these parameters on bone health of growing girls.

Methods

Subjects

Healthy prepubertal (Tanner I) and pubertal (Tanner II–III) female children from Toledo, Ciudad Real and Madrid (Spain) were recruited for the study. In total, 120 girls aged 9–13 years (11.32 ± 1.6 years old) were divided into two groups depending on BMI, VO_2 max, years of practice and hours of practice per week. The participants underwent a series of tests to assess the degree of sexual development, body composition (fat mass, lean mass and bone mass) and physical condition.

The general questions about health and sport activity habits (which included information regarding type and years of sport practice, number of hours of sport activity, bone diseases, any other known disease, injuries, other sport practice and medication) were asked at the beginning of the study. Nobody in the group was taking medications that affected bone and muscle metabolism. The participants have been practising sport for an average of 3.52 ± 1.56 years in the prepubertal group and 4.23 ± 1.63 years in the pubertal group. In relation to the weekly hours of physical activity, prepubertal group practises for 2.98 ± 0.27 hours a week and pubertal group for 4.28 ± 2.14. Sports practised are football ($N = 40$), basketball ($N = 40$) and handball ($N = 40$). The general characteristics of each group are described in Table I, divided per prepubertal (Tanner I) and pubertal (Tanner II–III) girls.

All participants provided written informed consent to take part in the present study, which was approved by the local Ethics Committee (Hospital of Toledo) and was performed in accordance with the code of ethics of the World Medical Association (Declaration of Helsinki). Both parents and children were informed about the aims and procedures of the study, as well as the possible risks and benefits prior to the start of the study. Children gave their verbal assent, and a written informed consent was signed by their parents.

Anthropometry and body composition

Weight (kg) and height (cm) were measured using a SECA scale (model 711; SECA GmbH & Co, KG, Hamburg, Germany). BMI was calculated as weight (kg)/height (m)^2. Fat mass (g), lean mass (g) (body mass – [fat mass + bone mass]), BMC (g) and BMD ($g \cdot cm^{-2}$) were measured using the DXA (Hologic Serie Discovery QDR., Software Physician's Viewer, APEX System Software Version 3.1.2. Bedford, MA, USA). DXAs were performed for the whole body (arms, trunk and legs) and hip. The DXA was calibrated using a lumbar spine phantom as recommended by the manufacturer Hologic. Participants were placed in supine position with the body and limbs fully extended and within the limits set by the scan lines. All scanning and analyses were performed by the same operator to ensure consistency.

Physical condition: Course Navette Test

VO_2 max was estimated using the Course Navette Test, which consists in a maximum and progressive test that allows to measure maximum aerobic potential and VO_2 max indirectly in millimetres by kilogram by minute. To calculate VO_2 max in youngsters aged between 8 and 18 years of age, the

Table I. Descriptive characteristics of different groups of prepubertal and pubertal girls

	Prepubertal							
	BMI ($kg \cdot m^{-2}$)		VO_2 max ($ml \cdot kg \cdot min^{-1}$)		Years of practice		Hours of practice	
	≤16.84	>16.84	≤47.18	>47.18	≤3	>3	≤3	>3
N	30	30	30	30	33	27	7	53
Total BMC (g)	1043.03 ± 33.86	1230.20 ± 263.47*	1168.72 ± 253.34	1104.50 ± 235.87	1106.39 ± 157.48	1173.55 ± 320.81	1020.47 ± 178.80	1151.95 ± 249.53
Total BMD ($g \cdot cm^{-2}$)	0.80 ± 0.07	0.86 ± 0.08*	0.84 ± 0.08	0.82 ± 0.08	0.82 ± 0.06	0.84 ± 0.10	0.78 ± 0.07	0.84 ± 0.08
Total lean mass (kg)	21.20 ± 4.12	27.41 ± 5.11*	25.28 ± 5.95	23.39 ± 5.12	24.24 ± 4.76	24.45 ± 6.55	22.14 ± 4.14	24.63 ± 5.72
Total fat mass (kg)	7.44 ± 2.35	13.10 ± 4.40*	12.13 ± 4.98	8.40 ± 3.08*	10.90 ± 5.28	9.49 ± 3.29	9.43 ± 3.19	10.37 ± 4.67
Percent body fat (%)	24.84 ± 5.27	30.90 ± 6.06*	30.58 ± 5.80	25.16 ± 5.90*	28.69 ± 6.75	26.87 ± 5.93	28.45 ± 4.49	27.79 ± 6.65
	Pubertal							
	BMI ($kg \cdot m^{-2}$)		VO_2 max ($ml \cdot kg \cdot min^{-1}$)		Years of practice		Hours of practice	
	≤19.84	>19.84	≤46.78	>46.78	≤5	>5	≤5	>5
N	30	30	30	30	35	25	35	25
Total BMC (g)	1423.10 ± 271.08	1911.58 ± 340.64*	1853.81 ± 341.53	1479.01 ± 350.37	1659.08 ± 319.38	1669.46 ± 484.58	1645.26 ± 374.26	1687.67 ± 420.38
Total BMD ($g \cdot cm^{-2}$)	0.92 ± 0.09	1.05 ± 0.11*	1.02 ± 0.10	0.94 ± 0.11	0.97 ± 0.09	0.99 ± 0.14	0.97 ± 0.12	0.99 ± 0.11
Total lean mass (kg)	30.52 ± 41.50	39.70 ± 3.88*	38.36 ± 4.33	31.82 ± 5.90	34.89 ± 5.01	35.24 ± 7.53	34.06 ± 5.98	36.35 ± 6.16
Total fat mass (kg)	10.04 ± 3.12	19.02 ± 4.32*	18.09 ± 5.11	10.94 ± 4.19*	14.35 ± 5.72	14.61 ± 6.17	14.29 ± 6.10	14.68 ± 5.64
Percent body fat (%)	23.58 ± 5.05	31.10 ± 4.28*	30.47 ± 5.07	24.18 ± 5.19	27.26 ± 6.40	27.31 ± 5.50	27.47 ± 6.15	27.02 ± 5.88

*Differences between groups *d* $p < .05$.

Leger, Mercier, Gadoury, and Lambert (1988) formula is used:

$$Y = 31.025 + 3.238X_1 - 3.248X_2 + 0.1536X_1X_2.$$

The participant starts the test at a very slow pace moving from one point to another situated at a distance of 20 m, changing direction when the audible signal indicates. This signal accelerates progressively so that the participant's rhythm increases as the test goes on. The test finalises in the moment in which the participant cannot reach the change of direction when the signal is heard. Several articles use the Course Navette Test as a method to calculate indirectly VO_2 max in children (Plaza-Carmona et al., 2014; Vicente-Rodríguez et al., 2003; Vicente-Rodríguez, Dorado, Pérez-Gómez, González-Henríquez, et al., 2004).

Pubertal stage

Maturity assessment is necessary for studies on growing children because the maturation range between individuals of the same chronological age is wide, especially during the pubertal years (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). Pubertal status was determined by self-assessment using photographs of the Tanner stages (Duke, Litt, & Gross, 1980), a tool designed by Marshall and Tanner (1969). Pubertal status was classified as prepubertal (stage I) and pubertal (stages II and III).

Statistical analyses

All data were analysed statistically by means of the SPSS program, V19.0 for Windows, with a significance level of $p < .05$. The Kolmogórov–Smirnov test resulted in a normal distribution of the variables. The characteristics of the study groups (mean and standard error of the mean) were determined through basic descriptive tests. The differences between groups were determined using a covariance analyses (ANCOVA), including total lean mass, total fat mass and percentage of body fat as covariates. This covariate was used because of the scientific evidence of its influence on body composition (Crabtree et al., 2004; Milanese, Piscitelli, Cavedon, & Zancanaro, 2014). A preliminary analysis indicated that the fat and lean mass differed for prepubertal and pubertal. Therefore, because of the interactions between Tanner groups and the bone mass variables, every analysis was performed independently for the prepubertal and pubertal group. To identify meaningful changes, confidence intervals (CI 95%) and effect sizes (ES; Cohen's *d*) were calculated. ES was assessed using the following criteria: 0–0.2 = trivial, 0.2–0.5 = small, 0.5–0.8 = moderate and >0.8 = large (Cohen, 1992).

A lineal regression analysis was used for the BMI, VO_2 max, years and hours of practice as independent variables and the results from bone mass as dependent variables. Potential moderating factors were evaluated by subgroup analysis comparing prepubertal or pubertal grouped by continuous variables potentially influencing body composition. Median values of continuous variables were used as cut-off values for each group.

Results

Descriptive results of the sample reveal higher values of total lean mass, total fat and percentage of body fat in the groups with higher BMI in prepubertal and pubertal girls (Table I; $p < .05$). In relation to VO_2 max, in the prepubertal group, girls with less VO_2 max, (≤ 47.18 ml·kg^{-1}·min^{-1}) revealed higher values of total fat mass (+3.72 kg; CI 95%: 1.58–5.86 kg; $p < .05$) and percentage of body fat (+5.41%; CI 95%: 2.39–8.43%; $p < .05$). The results did not reveal any significant differences in body composition in function of years and hours of practice in none of the groups ($p > .05$). In the pubertal group, girls with lower VO_2 max, also showed a higher total fat mass (+7.15 kg; CI 95%: 4.75–9.53 kg; $p < .05$).

Prepubertal group

In relation to BMI, the group with higher BMI showed higher significant levels ($p < .05$; Table II) of BMC and BMD of the whole body ($ES_{BMC} = 0.83$; $ES_{BMD} = 0.80$), arms ($ES_{BMC} = 0.84$; $ES_{BMD} = 1.45$), legs ($ES_{BMC} = 0.90$; $ES_{BMD} = 1.24$), pelvis ($ES_{BMC} = 0.93$; $ES_{BMD} = 1.36$), femoral neck ($ES_{BMC} = 0.83$; $ES_{BMD} = 0.86$), trochanter ($ES_{BMC} = 0.73$; $ES_{BMD} = 0.93$) and intertrochanter ($ES_{BMC} = 0.68$; $ES_{BMD} = 1.08$) compared with the group with less BMI. However, the results did not reveal significant differences in function of VO_2 max.

The group with more than 3 years of practice showed higher BMC in legs (+16.26 g; CI 95%: −12.08 to 44.60 g; ES = 0.30), as well as a higher BMC (+0.09 g; CI 95%: 0.003–0.17 g; ES = 0.56) and BMD (+0.09 g·cm^{-2}; CI 95%: 0.03–0.15 g·cm^{-2}; ES = 0.78) in the Ward's triangle. Finally, prepubertal girls with more than 3 h of practice a week showed a higher BMC in pelvis (+33.31 g; CI 95%: −0.77 to 67.39 g; ES = 0.86) and intertrochanter (+5.05 g; CI 95%: 0.50 to 9.60 g; ES = 0.95). Also, this group presented higher levels of BMD in legs (+0.09 g·cm^{-2}; CI 95%: −0.01 to 0.19 g·cm^{-2};

Table II. BMD and BMC at different sites in the groups of prepubertal girls

	BMC (g)							
	BMI (kg·m^{-2})		VO_2 max (ml·kg·min^{-1})		Years of practice		Hours of practice	
	≤16.84	>16.84	≤47.18	>47.18	≤3	>3	≤3	>3
Whole body	1043.03 ± 185.50	1230.20 ± 263.47*	1168.72 ± 253.34	1104.50 ± 235.87	1106.39 ± 157.48	1173.55 ± 320.81	1020.47 ± 178.80	1151.95 ± 249.53
Mean arms	55.21 ± 11.26	67.36 ± 17.67*	63.60 ± 16.79	58.97 ± 14.91	59.72 ± 9.49	63.20 ± 21.38	54.19 ± 11.29	62.22 ± 16.28
Mean legs	177.14 ± 41.29	221.76 ± 57.91*	207.50 ± 54.98	191.40 ± 54.14	192.14 ± 37.75	208.39 ± 69.90*	176.93 ± 37.71	202.43 ± 56.16
Pelvis	118.31 ± 33.74	154.63 ± 44.73*	137.99 ± 43.91	134.95 ± 43.46	132.15 ± 25.59	141.74 ± 58.35	107.04 ± 34.33	140.35 ± 43.17*
Hip	24.08 ± 3.34	24.98 ± 2.36	24.08 ± 3.21	24.98 ± 2.53	24.71 ± 3.21	24.31 ± 2.52	23.17 ± 4.33	24.71 ± 2.66
Femoral neck	2.42 ± 0.58	2.97 ± 0.75*	2.79 ± 0.70	2.60 ± 0.74	2.61 ± 0.56	2.81 ± 0.88	2.50 ± 0.64	2.73 ± 0.73
Trochanter	4.20 ± 1.02	5.12 ± 1.49*	4.64 ± 1.22	4.68 ± 1.48	4.52 ± 0.99	4.83 ± 1.69	4.13 ± 1.52	4.73 ± 1.32
Intertrochanter	14.95 ± 5.21	18.74 ± 5.89*	17.57 ± 6.98	16.11 ± 4.42	17.23 ± 5.31	16.36 ± 6.49	12.38 ± 4.90	17.43 ± 5.73*
Ward's triangle	0.80 ± 0.18	0.87 ± 0.14	0.84 ± 0.16	0.83 ± 0.17	0.80 ± 0.15	0.89 ± 0.17*	0.76 ± 0.18	0.85 ± 0.16
	BMD (g/cm^2)							
	BMI (kg·m^{-2})		VO_2 max (ml·kg·min^{-1})		Years of practice		Hours of practice	
	≤16.84	>16.84	≤47.18	>47.18	≤3	>3	≤3	>3
Whole body	0.80 ± 0.07	0.86 ± 0.08*	0.84 ± 0.08	0.82 ± 0.08	0.82 ± 0.06	0.84 ± 0.10	0.78 ± 0.07	0.84 ± 0.08
Mean arms	0.50 ± 0.06	0.58 ± 0.05*	0.54 ± 0.07	0.53 ± 0.07	0.53 ± 0.06	0.54 ± 0.08	0.53 ± 0.08	0.54 ± 0.07
Mean legs	0.79 ± 0.10	0.92 ± 0.11*	0.87 ± 0.13	0.84 ± 0.12	0.85 ± 0.10	0.86 ± 0.15	0.77 ± 0.11	0.86 ± 0.12*
Pelvis	0.76 ± 0.11	0.91 ± 0.11*	0.86 ± 0.13	0.80 ± 0.13	0.83 ± 0.10	0.84 ± 0.17	0.75 ± 0.11	0.84 ± 0.13*
Hip	0.80 ± 0.06	0.82 ± 0.05	0.80 ± 0.05	0.82 ± 0.06	0.80 ± 0.06	0.82 ± 0.06	0.81 ± 0.08	0.81 ± 0.05
Femoral neck	0.63 ± 0.10	0.72 ± 0.11*	0.69 ± 0.11	0.66 ± 0.12	0.66 ± 0.09	0.69 ± 0.13	0.58 ± 0.11	0.69 ± 0.11*
Trochanter	0.65 ± 0.08	0.72 ± 0.07*	0.69 ± 0.08	0.68 ± 0.08	0.67 ± 0.07	0.70 ± 0.09	0.63 ± 0.07	0.69 ± 0.08
Intertrochanter	0.84 ± 0.12	0.97 ± 0.12*	0.92 ± 0.15	0.89 ± 0.13	0.89 ± 0.11	0.92 ± 0.16	0.82 ± 0.12	0.91 ± 0.14
Ward's triangle	0.67 ± 0.14	0.73 ± 0.10	0.70 ± 0.12	0.70 ± 0.13	0.66 ± 0.11	0.75 ± 0.12*	0.65 ± 0.11	0.71 ± 0.13

Note:
BMC, bone mineral content; BMD, bone mineral density.
*Differences between groups d $p < .05$.

ES = 0.78), pelvis (+0.09 g·cm^{-2}; CI 95%: −0.01 to 0.20 g·cm^{-2}; ES = 0.75) and femoral neck (+0.11 g·cm^{-2}; CI 95%: 0.02–0.19 g·cm^{-2}; ES = 1) in comparison with the group that practised three or less hours a week.

Pubertal group

The analysis of the differences in function of BMI revealed higher levels of BMC (ES between 0.79 y 1.88) and BMD (ES between 1.20 y 2) in the group with higher BMI (>19.84 kg·m^{-2}) in all of the variables analysed, except in the hip. Although no significant differences were observed between the groups with heterogeneous rates of VO_2 max ($p > .05$; Table III).

In relation to years of practice, the results reveal higher BMD in the hip of the group with more than 5 years of practice (+0.04 g·cm^{-2}; CI 95%: 0–0.08 g·cm^{-2}; ES = 0.57) compared to the group with five or less years of practice. Last of all, the amount of hours practised per week showed a significant influence on bone mass ($p < .05$). The group with more hours of practice (>5 h) presented higher BMC in the intertrochanter (+3.13 g; CI 95%: 0.09–6.18 g; ES = 0.55) and Ward's triangle (+0.10 g; CI 95%: 0.01–0.18 g; ES = 0.65). Furthermore, the group with five or less hours of practice a week proved to have 6.34% less BMD in the arms (−0.03 g·cm^{-2}; CI 95%: −0.06 to −0.002 g·cm^{-2}; ES = 0.73).

A nearly perfect correlation was found between lean mass and total BMC and BMD ($r = 0.918$ and $r = 0.858$; $p < .001$, respectively). Multiple regression revealed an independent relationship between these variables ($p < .001$), explaining the lean mass 84.3% and 74.2% of the total variance in whole body BMC and BMD. However, there was not a relationship between fat mass and bone mass ($p > .05$).

Linear regression analysis evidenced a significant influence of total lean mass and weekly hours of training on bone mass ($p < .05$; Table IV). In particular, total lean mass reflected a positive influence on BMC and BMD of all the variables analysed. Ultimately, the parameters studied account for 85% and 75.4% of BMC and BMD total, respectively.

Discussion

The main finding of this study was that the BMC and BMD of the whole body are directly associated with BMI and specifically with lean mass in prepubertal and pubertal girls. Furthermore, the hours of weekly practice evidenced a positive relation on the total BMC ($r = 0.310$). These results confirm previous longitudinal findings that associate bone growth in children according to muscle development (Rauch, Bailey, Baxter-Jones, Mirwald, & Faulkner, 2004; Vicente-Rodríguez, Dorado, Pérez-Gómez, González-Henríquez, et al., 2004). For this reason, it is necessary to take into account activity parameters of this group with the aim to guarantee correct muscle development that derives in an adequate bone growth.

BMI, obtained by height and weight of the participants, showed a significant relation with bone mass in girls that are growing. Previous studies demonstrated elevated levels of BMD in subjects with a higher height (Guney et al., 2003; Radak, 2004). However, it is necessary to know the total mass of the subject, as well as the distribution of the rest of the parameters of body composition (fat mass and muscle mass) to determine their direct relation with bone development. For that matter, previous studies show disparity in relation to the associations between BMI and gain of bone mass (Goulding et al., 2000; Guney et al., 2003; Radak, 2004; Rocher et al., 2008). This absence of consensus could be because of the lack of segmentation of the body weight in muscle mass and fat mass.

Diverse studies suggested that lean mass is the best indicator for the accumulation of bone during puberty (Courteix et al., 1998; Vicente-Rodríguez, Ara, Pérez-Gómez, Dorado, & Calbet, 2005), coinciding with the main finding of the current research. Also, this prediction does not only happen during puberty, as Vicente-Rodríguez et al. (2008) conducted a study with teenagers, concluding that lean mass explains part of the differences in the BMC of the whole body between men and women during adolescence.

This relationship between lean mass and bone mass can be explained through the Mechanostat theory, according to this theory, the biggest muscles apply high forces of tension on the bones (Schoenau & Frost, 2002). In our study, a high correlation exists between lean mass and BMC and BMD, being the girls that had higher muscle mass the ones with higher BMC and BMD. So that, this study confirms muscle mass as one of the main determining factors of bone development (Rauch et al., 2004).

Regarding the relation between fat mass and bone mass, studies, for example, by Vicente-Rodríguez et al. (2005) show that no correlation exists between the increase of fat mass and an improvement of bone mass in children. The results of the current study show that fat mass is not associated with bone mass in growing girls, as previous studies have confirmed (Pietrobelli et al., 2002; Rodríguez-Martínez, Blay, Blay, Moreno, & Bueno, 2002). This evidence positions muscle mass as the body composition parameter that is directly related with bone development

Table III. BMD and BMC at different sites in the groups of pubertal girls

	BMC (g)							
	BMI (kg·m^{-2})		VO_2 max (ml·kg·min^{-1})		Years of practice		Hours of practice	
	≤19.84	>19.84	≤46.78	>46.78	≤5	>5	≤5	>5
Whole body	1423.10 ± 271.08	1911.58 ± 340.64*	1853.81 ± 341.53	1479.01 ± 350.37	1659.08 ± 319.38	1669.46 ± 484.58	1645.26 ± 374.26	1687.67 ± 420.38
Mean arms	82.06 ± 17.65	116.88 ± 19.43*	113.13 ± 19.77	85.70 ± 23.08	99.64 ± 21.57	98.54 ± 30.61	96.63 ± 23.64	102.63 ± 27.74
Mean legs	257.99 ± 48.53	360.75 ± 80.54*	351.79 ± 78.78	266.66 ± 65.65	306.37 ± 63.95	311.64 ± 107.28	307.85 ± 82.53	309.44 ± 86.74
Pelvis	183.36 ± 46.92	266.96 ± 70.08*	252.79 ± 74.03	197.07 ± 60.22	221.58 ± 28.50	228.64 ± 90.03	213.89 ± 61.06	238.72 ± 84.64
Hip	36.04 ± 4.25	36.82 ± 4.14	36.83 ± 4.01	36.03 ± 4.36	37.01 ± 4.16	35.59 ± 4.13	36.62 ± 4.62	36.16 ± 3.56
Femoral neck	3.29 ± 0.72	4.31 ± 0.72*	4.24 ± 0.67	3.35 ± 0.84	3.84 ± 0.73	3.72 ± 1.07	3.80 ± 0.77	3.77 ± 1.02
Trochanter	5.66 ± 1.21	7.42 ± 1.48*	7.05 ± 1.61	6.01 ± 1.45	6.54 ± 1.44	6.50 ± 1.85	6.42 ± 1.44	6.67 ± 1.82
Intertrochanter	19.82 ± 5.86	24.28 ± 5.42*	22.56 ± 6.84	21.48 ± 5.21	21.73 ± 6.63	22.42 ± 5.17	20.68 ± 6.44	23.81 ± 5.02*
Ward's triangle	0.86 ± 0.13	1.03 ± 0.15*	1.00 ± 0.17	0.89 ± 0.13	0.92 ± 0.13	0.97 ± 0.20	0.90 ± 0.15	1.00 ± 0.16*

	BMD (g/cm^2)							
	BMI (kg·m^{-2})		VO_2 max (ml·kg·min^{-1})		Years of practice		Hours of practice	
	≤19.84	>19.84	≤46.78	>46.78	≤5	>5	≤5	>5
Whole body	0.92 ± 0.09	1.05 ± 0.11*	1.02 ± 0.10	0.94 ± 0.11	0.97 ± 0.09	0.99 ± 0.14	0.97 ± 0.12	0.99 ± 0.11
Mean arms	0.61 ± 0.05	0.69 ± 0.03*	0.67 ± 0.04	0.63 ± 0.07	0.64 ± 0.05	0.65 ± 0.07	0.63 ± 0.06	0.67 ± 0.05*
Mean legs	0.97 ± 0.08	1.15 ± 0.14*	1.12 ± 0.14	1.00 ± 0.12	1.04 ± 0.09	1.09 ± 0.20	1.04 ± 0.15	1.07 ± 0.14
Pelvis	0.94 ± 0.13	1.17 ± 0.17*	1.15 ± 0.18	0.97 ± 0.16	1.05 ± 0.13	1.06 ± 0.25	1.05 ± 0.18	1.06 ± 0.21
Hip	0.99 ± 0.08	1.00 ± 0.06	1.00 ± 0.06	0.99 ± 0.08	0.97 ± 0.07	1.01 ± 0.07*	1.01 ± 0.07	0.98 ± 0.07
Femoral neck	0.75 ± 0.08	0.91 ± 0.11*	0.88 ± 0.11	0.78 ± 0.11	0.82 ± 0.09	0.84 ± 0.16	0.81 ± 0.11	0.84 ± 0.14
Trochanter	0.72 ± 0.06	0.81 ± 0.09*	0.79 ± 0.08	0.74 ± 0.08	0.76 ± 0.06	0.77 ± 0.11	0.75 ± 0.07	0.79 ± 0.09
Intertrochanter	0.97 ± 0.13	1.16 ± 0.14*	1.11 ± 0.17	1.02 ± 0.14	1.06 ± 0.16	1.08 ± 0.18	1.05 ± 0.16	1.09 ± 0.17
Ward's triangle	0.73 ± 0.09	0.87 ± 0.12*	0.84 ± 0.12	0.76 ± 0.12	0.79 ± 0.11	0.82 ± 0.15	0.78 ± 0.12	0.83 ± 0.13

Note: Differences between groups *d* $p < .05$.
BMC, bone mineral content; BMD, bone mineral density.

Table IV. Regression analysis of BMI, VO_2 max, years and hours of practice on BMC and BMD variables (standard errors in parentheses)

BMC (g)	Whole body	Mean legs	Pelvis	Hip	Femoral neck	Trochanter	Intertrochanter	Ward's triangle
Total lean mass (kg)	52.913***	11.083***	9.049***	0.627***	0.118 ***	0.227***	0.596***	0.010***
	(3.221)	(0.710)	(0.701)	(0.101)	(0.010)	(0.018)	(0.090)	(0.003)
Total fat mass (kg)	−3.495	−0.366	−0.846	−0.238	−0.009	−0.037	−0.025	0.004
	(4.761)	(1.050)	(1.036)	(0.150)	(0.014)	(0.027)	(0.132)	(0.004)
VO_2 max ($ml \cdot kg \cdot min^{-1}$)	3.393	0.315	1.936	−0.109	0.463[a]	0.067*	0.312*	0.005
	(5.166)	(1.139)	(1.124)	(0.163)	(0.015)	(0.029)	(0.144)	(0.005)
Years of practice (years)	3.523	2.903	−0.803	0.063	0.012	−0.021	−0.438	0.006
	(8.179)	(1.804)	(1.780)	(0.257)	(0.024)	(0.046)	(0.228)	(0.007)
Hours of practice (h)	−14.166*	−5.333***	−0.690	0.338	−0.060**	−0.081*	0.265	−0.001
	(6.674)	(1.472)	(1.452)	(0.210)	(0.020)	(0.037)	(0.186)	(0.006)
Constant	−236.788	−73.111	−162.375**	18.091*	0.066	−3.390*	−11.983	0.307
	(266.607)	(58.799)	(58.018)	(8.389)	(0.789)	(1.485)	(7.417)	(0.235)
R^2	0.850	0.839	0.772	0.460	0.753	0.732	0.509	0.291
N	120	120	120	120	120	120	120	120
BMD ($g \cdot cm^{-2}$)	**Whole body**	**Mean legs**	**Pelvis**	**Hip**	**Femoral neck**	**Trochanter**	**Intertrochanter**	**Ward's triangle**
Total lean mass (kg)	0.015***	0.021***	0.021***	0.010***	0.016***	0.009***	0.017***	0.010***
	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
Total fat mass (kg)	−0.001	−0.286[a]	0.005	−0.006*	−0.001	0.001	0.003	0.002
	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)
VO_2 max ($ml \cdot kg \cdot min^{-1}$)	0.004*	0.004	0.005	−0.003	0.003	0.003	0.010**	0.005
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)
Years of practice (years)	0.001	0.004	−0.002	−0.001	0.002	−0.261[a]	−0.005	0.007
	(0.003)	(0.004)	(0.005)	(0.005)	(0.004)	(0.003)	(0.005)	(0.005)
Hours of practice (h)	−0.004	−0.008**	−0.008*	0.005	−0.004	−0.001	−0.004	−0.004
	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)
Constant	0.287**	0.152	0.044	0.780***	0.169	0.307**	−0.003	0.204
	(0.101)	(0.114)	(0.154)	(0.149)	(0.130)	(0.104)	(0.167)	(0.175)
R^2	0.754	0.829	0.775	0.363	0.679	0.526	0.647	0.362
N	120	120	120	120	120	120	120	120

[a]Coefficient × 10^{-3}.
*$p < .05$.
**$p < .01$.
***$p < .001$.

beyond fat mass (Vicente-Rodríguez et al., 2005). However, some authors reveal an indirect relation between fat mass and bone development because of the elevated contribution of fat mass in the total body mass of women (Vicente-Rodríguez et al., 2005). Once demonstrated the importance of body composition on bone development, it is necessary to favour habits to increment muscle mass and reduce fat mass. In fact, in the present investigation, body composition and physical activity habits explain 85% and 75.4% of the variance of BMC and BMD of the whole body, respectively.

With regard to physical condition, regardless of the influence of muscle mass on bone development (Vicente-Rodríguez, Dorado, Pérez-Gómez, González-Henríquez, et al., 2004), maximum oxygen consumption (VO_2 max) has also been identified as a determining variable (Eliakim, Burke, & Cooper, 1997). In fact, previous studies have demonstrated a direct relation between body composition and VO_2 max. Precisely, the percentage of body fat manifested a negative relation with VO_2 max (Ekelund, Franks, Wareham, & Åman, 2004). The current study affirms the negative influence of a high total fat mass on VO_2 max in both age groups. This limitation can negatively affect sport practice habits that have demonstrated a direct association with bone mass in this population group (Bassett & Howley, 2000).

On the other hand, VO_2 max did not reveal a direct relationship with bone mass of the participants, including the values of body composition as a covariate. The presence of differences, without adjusting the results, seems to evidence an indirect relationship between VO_2 max and bone mass, motivated by body composition. This can mean that a reduced VO_2 max is associated to elevated levels of fat mass and low muscle mass that derive in a poor bone development (Bassett & Howley, 2000).

Concerning the weekly hours and years of sport practice, the results show a significant influence on the improvement of bone mass in growing girls. In this regard, the results of this investigation coincide with Vicente-Rodríguez, Dorado, Pérez-Gómez, González-Henríquez, et al., 2004 that affirm that more than three weekly hours of sport practice positively impacts on bone mineralisation. Particularly, the present study evidences higher levels in BMC of the pelvis and intertrocanther, as well as of the BMD in the legs, femoral neck and pelvis in prepubertal girls. On the other hand, the pubertal group with more than five weekly hours revealed higher levels of BMC in the Ward's triangle and intertrocanther. The measurement of the level of bone mass of the hip predicts the global risk of fractures in posterior stages of life, having the advantage of that it is not usually affected by articular degenerative processes associated to age found in other zones of the body (Planas & Morote, 2006).

These data manifest the importance of incrementing the hours of sport practice in growing ages. The hours of obligatory sport practice in education centres does not surpass 2 h per week and motor time committed is even less. For this reason, exercise limited to education centres is not sufficient to obtain improvements in bone mass as previous studies confirm (Valdimarsson, Linden, Johnell, Gardsell, & Karlsson, 2006). Results of studies like the one of Vicente-Rodríguez (2006) and Vicente-Rodríguez et al. (2004) explain that with only 3 h of football practice a week, an osteogenesis effect is obtained on different zones of the hip and inferior trunk, coinciding with the results obtained in the present study.

Also, the number of years of sport practice also forms a determining variable factor to predict the BMC and BMD in growing girls. Studies like the ones of Linden, Ahlborg, Besjakov, Gardsell, and Karlsson (2006) and Valdimarsson et al. (2006) show that 2 years of moderate general physical exercise increments to a larger extent the values of BMC and BMD in the body in general and in the lumbar column, compared to the same physical exercise during a year. In this case, girls with an experience of more than 3 years in sport have higher values in legs and Ward's triangle in BMC and BMD in the prepubertal group. In the pubertal group, a sport experience higher to 5 years evidenced higher BMD in the hip. For this reason, the adherence to sport practice in early ages is necessary for a correct bone development.

One of the limitations of this study was the absence of a dietetic–nutritional control of the girls to evaluate food habits and its influence on the body composition. Diets can generate a reduction in fat mass but also a reduction in muscle mass affecting bone development in girls (Weiss et al., 2007). In this way, the control of blood biomarkers could also provide complementary information on the bone mineralisation process in infantile populations. Another limitation of this study was the indirect study of the physical condition of the participants. Finally, the prepubertal group sample divided by hours of practices was not homogeneous. In future studies it is recommended that a specific sport test of the practised sport of the sample of the study is done.

Conclusion

In conclusion, the BMC and BMD are directly related with muscle mass and sport practice habits in growing girls. However, fat mass did not evidence a significant association with bone mass. On the other hand, the physical condition of the girls proves an indirect relation with bone development as it is adjusted according to the body composition. For this reason, it is necessary to assure adequate exercise habits to increment muscle mass and favour correct bone development in growing girls. This study represents an important topic in sports medicine from a health perspective. The results of this research can be useful as a prevention method of bone diseases in adulthood.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Fitness, bone mineral density and hip geometry in young males: The PRO-BONE study.

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Title: Fitness, bone mineral density and hip geometry in young males: The PRO-BONE study.

Abstract

Objective: the main aim was to evaluate associations between fitness indices and bone outcomes, including hip geometry estimates in young males.

Methods: one hundred twenty one males (13.1±0.1 years) were included: 41 swimmers, 37 footballers, 29 cyclists and 14 non-athletes. Lean mass, areal bone mineral density (aBMD) and hip structural estimates were measured using dual-energy X-ray absorptiometry. Relationships of physical fitness tests (vertical jump, standing long jump and 20 m shuttle run test) with bone outcomes were analysed using three regression models: Model 1, adjusted by age and stature; Model 2, model 1+vigorous physical activity (VPA); Model 3, model 2+lean mass. Bonferroni correction was applied and only values of $p<0.006$ were considered statistically significant.

Results: performance in vertical jump (except for femoral neck aBMD and narrow neck width), standing long jump (except for narrow neck width) and 20m shuttle run test (except for narrow neck width) was positively associated with all bone outcomes in models 1 and 2 ($p<0.006$). In model 3, most previous associations disappeared except those between standing long jump and total hip and trochanter aBMD ($p=0.004$ and 0.003, respectively), which were slightly attenuated. Interestingly, all significant associations but the one at lumbar spine and femoral neck aBMD ($p=0.097$ and 0.008, respectively) remained significant after adding lean mass as a covariate (model 3).

Conclusion: we concluded that VPA did not explain fitness associations on bone outcomes and both the muscular fitness and skeletal benefits of sport participation appear to be a function of lean mass in young males.

Keywords: Body composition; Bone health; Children; Exercise; Fitness

Trial registration: ISRCTN17982776

Introduction

A systematic review concluded that there is strong evidence suggesting that PA during adolescence is related to bone health, both at that age as well as later in life (Hallal, Victora, Azevedo, & Wells, 2006). This seems to be due to the increased sensitivity of the skeleton to adapt to mechanic loading. Previous studies in preadolescent boys have suggested that cortical bone mineral content (BMC) and geometry (assessed by tibial peripheral quantitative computed tomography) are positively related with vigorous PA (VPA) (Sayers et al., 2011; Tobias, Steer, Mattocks, Riddoch, & Ness, 2007). Data from the ALSPAC study showed habitual levels of high, but not moderate or low, impact activity to be positively related to hip areal bone mineral density (aBMD) and geometry in adolescent population (Deere, Sayers, Rittweger, & Tobias, 2012). In fact, it has been shown that periods of at least 28 minutes per day of VPA are associated with high femoral neck aBMD in adolescents (Gracia-Marco, Moreno, et al., 2011).

In this line, studies investigating the influence of different sports on bone mass (Ubago-Guisado, Gómez-Cabello, Sánchez-Sánchez, García-Unanue, & Gallardo, 2015) and bone geometry (Ferry et al., 2011) in youth have shown that weight-bearing and high impact sports, such as football, have a greater positive effect on bone while non weight-bearing and low impact sports, such as swimming and cycling, are associated with lower benefits (Vlachopoulos et al., 2016). However, to accurately measure objective PA (i.e. using accelerometers) in certain sports, such as swimming and cycling represents a challenge.

Physical fitness is considered an important marker of health and its relationships with bone mass (Gracia-Marco, Vicente-Rodríguez, et al., 2011; Ubago-Guisado, Martinez-Rodriguez, Gallardo, & SáNchez-Sánchez, 2016) and geometry (Daly, Stenevi-Lundgren, Linden, & Karlsson, 2008) have also been investigated. Muscular and cardiorespiratory fitness have been positively associated with BMC in 16- to 18-year-old boys (Ginty et al., 2005). In contrast, Vicente-Rodriguez et al. (2004) did not observe an association between cardiorespiratory fitness and bone mass in pre-pubertal boys, although positive associations were found between muscular fitness and bone mass. Discrepancies among studies could be due to the fact of using different covariates, with some of them missing important predictors of bone mass development during growth, such as VPA and lean mass (Deere et al., 2012; Gracia-Marco, Moreno, et al., 2011; Gracia-Marco et al., 2012). Therefore, the role of VPA and/or lean mass in the association between fitness and bone outcomes requires further investigation.

The objective of this study in young males was to examine the association between muscular and cardiorespiratory fitness with aBMD and hip geometry estimates after evaluation of different covariates, including VPA and lean mass.

Material and methods

Participants

The study represents a cross-sectional analysis of the baseline data derived from the PRO-BONE study, whose purpose and methodology have been described elsewhere (Vlachopoulos et al., 2015). Data was collected between autumn and winter 2014/15 in one hundred and twenty one male adolescents: 41 swimmers, 37 footballers, 29 cyclists and 14 non-athletes. The inclusion criteria were: 1) males 12–14 years old, engaged (≥3 h/week) in osteogenic (football) and/or non-osteogenic (swimming and cycling) sports for the last 3 years or more; this was based on previous research showing a lower threshold of three hours per week activity exposure was associated with bone benefits in adolescents (Ubago-Guisado et al., 2015); 2) males 12–14 years old not engaged in any of these sports (≥3 h/week) in the last 3 or more years (control group).

Participants were recruited from athletic clubs and schools across the South West of England. Parental consent and participant assent forms were signed and all participants underwent their first visit at the research centre as part of the study. The methods and procedures conformed to the Code of Ethics of the Wold Medical Association (Declaration of Helsinki) and have been checked and approved: 1) the

Ethics Review Sector of Directorate-General of Research (European Commission, ref. number 618496); 2) the Sport and Health Sciences Ethics Committee (University of Exeter, ref. number 2014/766) and 3) the National Research Ethics Service Committee (NRES Committee South West – Cornwall & Plymouth, ref. number 14/SW/0060).

Dual energy x-ray absorptiometry

A DXA scanner (GE Lunar Prodigy Healthcare Corp., Madison, WI, USA) was used to measure aBMD (g/cm^2) and lean mass (g). Four scans were performed to obtain data for the whole body (less head), lumbar spine (LS, L1-L4), right and left hip (including femoral neck, trochanter and total hip; the mean of right and left hip scans was used). All DXA scans and subsequent in-software analyses were completed by the same researcher, using the same DXA scanner and the GE encore software (2006, version 14.10.022). The DXA equipment was calibrated prior to each testing day by using a LS phantom following manufacturer recommendations.

Hip structural analysis

Recent studies have used hip structural analysis (HSA) software to obtain geometrical parameters associated with bone strength and this technique, using the same DXA scanner used in the present study, has been favourably compared with volumetric quantitative computed tomography (QCT) (Prevrhal et al., 2008). Using the HSA software, analyses were performed at the narrow neck region across the narrowest point of the femoral neck. The HSA programme uses the distribution of bone mineral mass in line of pixels across the bone axis to measure the structural dimensions of bone cross sections. The geometric properties of the bone were obtained and the following variables used: 1) the narrow neck width (mm), 2) the cross-sectional moment of inertia (CSMI, mm^4), 3) section modulus (Z, mm^3), and 4) the cross sectional area (CSA, mm^2). The short term precision percentage coefficient of variation of these variables has been reported to be between 2.4 % and 7.9 % (Khoo et al., 2005).

Physical fitness

The fitness tests used in the present investigation have been shown to be reliable and valid in youth (Castro-Piñero et al., 2010). Standing long jump (cm) and vertical jump (cm) were used to provide an estimate of lower limb muscular fitness. The vertical jump was performed using a jump mat (Probotics Inc., Huntsville, USA), which calculates the height of the jump based on the flight time. Each participant performed three maximal jumps and the best performance was used for the analysis.

Cardiorespiratory fitness was evaluated using the 20 m shuttle run test. The participants were asked to run between two lines set 20 m apart by following the pace of the audio signals produced from a CD player. The participants were equally encouraged to continue the test until they reached maximal effort. The test ended when the participants failed to reach the line two consecutive times. The count of the last completed shuttle run was recorded as the score.

Anthropometry, sexual maturation and physical activity

Stature (cm) and body mass (kg) were measured by using standard procedures. Body mass index was calculated as body mass (kg) divided by the stature (m) squared. Sexual maturation was self-reported using adapted drawings of the five stages (Tanner) of pubertal hair development (Marshall & Tanner, 1970).

Physical activity was objectively measured for seven consecutive days using wrist accelerometers (GENEActiv, GENEA, UK). Participants were instructed to place the accelerometer on their non-dominant wrist and data was collected at 100Hz. Data were analysed at 1 s epoch intervals to establish time spent in different intensities. Time spent in VPA was calculated using a cut-off point of $\geq$ 3600 counts per minute (Phillips, Parfitt, & Rowlands, 2013). The validity and reliability of the accelerometer has been established previously in children and adolescents (Phillips et al., 2013).

Statistical analysis

The distribution of the variables was checked and verified using Shapiro-Wilk's test, skewness and kurtosis values, visual check of histograms, Q-Q and box plots. Variables were also checked for collinearity using variance inflation factor values. Descriptive data are reported as mean ± standard deviation unless otherwise stated. Differences between groups were determined using analysis of variance (ANOVA) for continuous variables or Chi-Square test for categorical variables. Bivariate Pearson's correlations were performed to examine the association between predictors and outcomes. Relationships of physical fitness tests (vertical jump, standing long jump and 20 m shuttle run test) with bone-related outcomes (aBMD and hip geometry estimates) were analysed using multiple linear regression models according to three regression model structures: Model 1: adjusted by age and stature; Model 2: model 1+VPA; Model 3: model 2+lean mass. Statistical analyses were performed using the SPSS IBM statistics (version 22.0 for Windows, Chicago, IL, USA). Bonferroni correction was applied to control for multiple testing, which is considered as the most conservative method to control the familywise error rate. Based on a desired alpha level of 0.05 and nine different hypotheses (outcomes) values of $p<0.006$ were considered statistically significant (0.05/9).

Results

Table 1 shows raw descriptive characteristics of the participants. Swimmers had higher values of age, stature and lean mass than footballers and non-athletes. Footballers were less heavy compared to swimmers. Cyclists were older than non-athletes. Footballers spent more time doing MVPA and VPA than swimmers and non-athletes and cyclists more time in MVPA than swimmers. For aBMD outcomes, footballers had higher total hip and trochanter aBMD compared to swimmers and cyclists. Non-athletes had lower aBMD than the sporting groups at all sites but lumbar spine (at this site only swimmers had significantly greater values). Regarding HSA estimates, non-athletes had lower CSMI, section modulus and CSA than the sporting groups. Finally, non-athletes performed worse in all fitness tests compared with the sporting groups except for the vertical jump versus cyclists (p=0.101). In the 20 m shuttle run test, footballers had the best performance compared to all other groups.

Table 2 shows bivariate Pearson's correlations between bone outcomes and predictors. Age was positively correlated with stature (r=0.7) but negatively with VPA (r=-0.23). Stature was positively correlated with all bone parameters (r=0.39-0.75) except narrow neck width. Lean mass was positively correlated with all bone parameters (r=0.44-0.84) except narrow neck width. VPA was positively correlated with cardiorespiratory fitness (r=0.25) and narrow neck width (r=0.22). Muscular fitness was positively correlated with all bone parameters (r=0.35-0.60) and also cardiorespiratory fitness (r=0.5-0.62). Finally, cardiorespiratory fitness was positively correlated with all bone parameters (r=0.25-0.57).

Table 3 shows the adjusted associations between muscular fitness and bone outcomes. In model 1, performance in vertical jump and standing long jump was positively associated with aBMD at all sites [semi partial correlation (semip corr), 0.221 to 0.362] except for femoral neck in vertical jump (p=0.011), and also positively associated with all hip geometry estimates (semip corr, 0.170 to 0.289) except for narrow neck width (p=0.365 and 0.096 for vertical jump and standing long jump, respectively). Significant associations remained unchanged after VPA was added into the model (model 2) (semip corr, 0.174 to 0.322). Finally, once lean mass was added into the model (model 3), most previous significant associations disappeared except those related to standing long jump at the total hip (semip corr, 0,221) and trochanter (semip corr, 0.225).

Table 4 shows the adjusted associations between cardiorespiratory fitness and bone outcomes. In model 1, performance in the 20 m shuttle run test was positively associated with all bone outcomes (semip corr, 0.269 to 0.474) except for narrow neck width (p=0.016). Significant associations remained unchanged after additional adjustment for VPA (model 2) (semip corr, 0.263 to 0.425). Finally, after adjusting for lean mass (model 3), only significant associations at the lumbar spine (p=0.097) and femoral neck (p=0.008) disappeared, the rest remained significant (p<0.006).

Discussion

The findings from the present study in young males suggest that 1) the VPA data from the present study does not seem to explain fitness associations with bone outcomes and 2) positive associations between muscular fitness and aBMD and hip geometry estimates are dependent on lean mass.

Previous studies have suggested that objectively measured VPA is a key determinant of bone mass, geometry and strength (Tobias et al., 2007). In children, 25 minutes of VPA per day has been suggested to enhance bone mass and geometry (Sardinha, Baptista, & Ekelund, 2008) while more than 28 minutes of VPA per day appears to predict high aBMD at the femoral neck in adolescents (Gracia-Marco, Moreno, et al., 2011). However, others have suggested that the association between VPA and bone outcomes is mediated by other factors. A study showed that VPA explained 6.9% of the variability in geometry-related variables in children, such as CSA and Z (Janz et al., 2004). However, the association was weakened (to 3.7%) once lean mass was added into the regression model. In addition, another study conducted in boys and girls aged 8 to 15 years, observed that the association between PA and femoral neck bone strength disappeared after adjusting for lean mass (Forwood et al., 2006). In this study, objectively measured VPA does not seem to explain fitness (muscular and cardiorespiratory) associations with aBMD and hip geometry estimates. In fact, once the multiple linear regressions were adjusted for VPA (model 2), the *semip corr* did not vary at all neither for muscular fitness (from a range of 0.170-0.362 in model 1 to 0.174-0.322 in model 2) nor for cardiorespiratory fitness (from a range of 0.269-0.474 in model 1 to 0.263-00.425 in model 2).

Vigorous PA has been linked to muscular (Leppänen et al., 2016) and cardiorespiratory fitness (Gutin, Yin, Humphries, & Barbeau, 2005) and VPA has been shown to be better correlated with muscular and cardiorespiratory fitness than moderate PA. In the present study, VPA correlated only with cardiorespiratory fitness (r=0.25) but not with muscular fitness. A study in adolescents showed that for a given fitness level (muscular and cardiorespiratory), those who met the PA guidelines had higher

BMC than their inactive peers and, for a given PA level, those with higher fitness had higher BMC than those with lower fitness (Gracia-Marco, Vicente-Rodríguez, et al., 2011). These findings could be partially extrapolated to our study in which positive associations between fitness (muscular and cardiorespiratory) and bone outcomes were found; however, in the present study time spent in VPA did not play any significant role. Our participants exceeded the current PA guidelines of 60 minutes of moderate-to-vigorous PA/day (101.3 ±33.8) and spent on average 16.4 ± 10.4 minutes/day on VPA. The former falls below the suggested VPA threshold of >25 minutes/day in children and >28 minutes/day in adolescents suggested to enhance bone outcomes and geometry, which could explain the non-significant role of VPA in our study. In addition, it is likely that our PA levels were underestimated especially in those adolescents engaged in non-weight bearing activities, which is a common limitation in studies using accelerometers.

Previous studies demonstrated a direct association between muscular fitness and bone outcomes in adolescents (Vicente-Rodriguez et al., 2004). However, there are discrepancies in the evaluation of covariates. A poor performance in the standing long jump test and in the handgrip test was related with a lower BMC in the whole body and lower limbs in adolescents after adjusting for sex, height, lean mass, calcium intake and pubertal status (Gracia-Marco, Vicente-Rodríguez, et al., 2011). Similarly, the performance in vertical jump was positively associated with hip and lumbar bone accretion in pre-pubertal boys (Vicente-Rodriguez et al., 2004) using height, body mass and age as covariates. A further study found a relationship between BMC and muscular fitness in adolescents, independently of maturation status and lean mass (Vicente-Rodríguez et al., 2008). Findings from the present study indicate that muscular fitness is positively related to aBMD and bone geometry estimates in active boys, as a function of lean mass. In this regard, lean mass is considered one of the best predictors of bone mass both during growth and throughout the lifespan (Gracia-Marco, Moreno, et al., 2011). This relationship can be explained by the mechanostat theory, which states that bone strength is regulated by modelling and remodelling processes depending on the mechanical forces applied on the skeleton (Rauch, Bailey, Baxter-Jones, Mirwald, & Faulkner, 2004). The present findings suggesting that lean mass could be a mediator of the association between muscular fitness and bone outcomes (Torres-Costoso et al., 2015).

The present study indicates that cardiorespiratory fitness is also positively related to aBMD and hip geometry estimates in active boys. However, most of the associations found between cardiorespiratory fitness and bone outcomes do not seem to be a function of lean mass. In young males, we found that further adjustments for lean mass (model 3) only attenuated the positive associations found in models 1 and 2 in most of the regions. In contrast, those at the lumbar spine aBMD and femoral neck aBMD disappeared. Our results are in line with other study in which a low performance in the 20 m shuttle run test was related to lower whole body BMC in active adolescents, after adjusting for sex, height, lean mass, calcium intake and pubertal status (Gracia-Marco, Vicente-Rodríguez, et al., 2011). Results from a 15-year longitudinal study showed that the associations between cardiorespiratory fitness (directly measured as VO_2max) and lumbar spine aBMD and hip aBMD in adolescents disappeared after adjusting for sex, stature, weight, skinfolds, biological age and calcium intake (Kemper et al., 2000). These findings are comparable to our results since the effect of lean mass is contained within the effect of total body weight and we also observed a function of lean mass in lumbar spine aBMD and a sub-region of the hip (i.e. femoral neck aBMD).

Limitations and strengths

Data used for these analyses are cross-sectional; hence we cannot establish cause-effect relationships. Sexual maturation was not used as a covariate in our analyses. However, preliminary analyses showed that age was more strongly associated with bone outcomes and therefore it was used instead. The accelerometer methodology that we used to quantify VPA did not detect any association with bone outcomes. Accelerometers only register accelerations and therefore we may underestimate the intensity of activities with extra weight as well as those that relate to non-weight bearing efforts. Nevertheless, accelerometry has been suggested to be one of the best measures for reporting PA (Sirard & Pate, 2001). The combination of DXA and HSA software provides a thorough insight into the differences in aBMD and hip geometry estimates, and this is the first study in active male adolescents to do so.

Conclusion

We can conclude that 1) objectively measured VPA from the present study does not seem to explain fitness associations with bone outcomes; and 2) lean mass plays a key role in the association between muscular fitness and bone outcomes in young males. These findings contribute to the considerable body of evidence suggesting that investigations of physical fitness and bone mass must be adjusted for the effects of lean mass or muscle size.

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Table 1. Descriptive characteristics (raw data) of the participants using ANOVA and chi-square.

	Swimmers (n=41)	Footballers (n=37)	Cyclists (n=29)	Non-athletes (n=14)
Age (years)	13.4 ± 1.0 [b,d]	12.8 ± 0.9	13.2 ± 1.0 [d]	12.3 ± 0.5
Stature (cm)	165.5 ± 9.7 [b,d]	155.2 ± 9.3	160.8 ± 9.9	154.5 ± 9.9
Body mass (kg)	52.4 ± 9.0 [b]	44.3 ± 7.6	49.5 ± 12.3	48.3 ± 13.0
Pubertal maturation (I/II/III/IV/V) (%) [†]	15/25/13/45/2	24/35/24/16/0	14/28/28/27/3	29/21/21/29/0
BMI (kg/m^2)	19.0 ± 1.7	18.3 ± 1.4	18.9 ± 3.3	20.0 ± 3.4
Lean mass (kg)	41.6 ± 9.1 [b,d]	35.4 ± 7.2	37.7 ± 7.5	31.7 ± 5.5
MVPA (min/day)	85.9 ± 30.4	119.8 ± 29.7 [a,d]	107.2 ± 33.3 [a]	83.2 ± 26.8
VPA (min/day)	11.9 ± 7.3	22.5 ± 9.0 [a,d]	18.5 ± 12.8 [a,d]	8.9± 4.0
Vertical jump (cm)	42.3 ± 6.9 [d]	42.4 ± 6.0 [d]	41.0 ± 6.8	35.9 ± 5.8
Standing long jump (cm)	171.0 ± 28.1 [d]	168.7 ± 24.9 [d]	163.5 ± 25.8 [d]	137.1 ± 24.5
20 metres shuttle run test (shuttle)	69 ± 20[d]	83 ± 18 [a,c,d]	70 ± 21[d]	32 ± 16
aBMD (g/cm^2)				
Whole body less head	0.92 ± 0.07 [d]	0.93 ± 0.07 [d]	0.90 ± 0.09 [d]	0.83 ± 0.07
Total hip	0.96 ± 0.11 [d]	1.03 ± 0.09 [a,c,d]	0.96 ± 0.11 [d]	0.83 ± 0.12
Lumbar spine	0.89 ± 0.11 [d]	0.88 ± 0.09	0.87 ± 0.12	0.79 ± 0.10
Femoral neck	0.95 ± 0.10 [d]	1.00 ± 0.08 [d]	0.98 ± 0.19 [d]	0.83 ± 0.12
Trochanter	0.80 ± 0.09 [d]	0.88 ± 0.08 [a,c,d]	0.80 ± 0.11 [d]	0.68 ± 0.10
Hip geometry estimates				
Narrow Neck Width (mm)	5.96 ± 1.91	6.68 ± 1.85	6.53 ± 2.02	5.27 ± 1.27
CSMI (mm^4)	8943.5 ± 2573.6 [d]	8471.6 ± 2606.6 [d]	8403.1 ± 2552.4 [d]	6020.7 ± 2071.9
Section modulus (mm^3)	558.30 ± 121.35 [d]	548.10 ± 116.75 [d]	530.77 ± 123.31 [d]	395.0 ± 123.4
CSA (mm^2)	137.17 ± 20.23 [d]	140.92 ± 20.38 [d]	135.90 ± 22.72 [d]	109.8 ± 21.0

Values presented as mean ± SD or percentages.
BMI. Body mass index; MVPA, Moderate-to-Vigorous physical activity; VPA, Vigorous physical activity; aBMD, areal bone mineral density; CSMI, Cross sectional moment of inertia; CSA, Cross sectional area.
[†] Chi-square was used to examine differences in pubertal maturation ($p>0.05$)
Superscript letters denote a significant difference ($p<0.05$) compared to: a (swimmers), b (footballers), c (cyclists), d (non-athletes).

Table 2. Pearson correlation coefficients among the studied variables.

							aBMD (g/cm2)					Hip geometry estimates			
	Stature	Lean mass	VPA	VJ	SLJ	20 m SRT	WBLH	Total hip	Lumbar spine	Femoral neck	Trochanter	Narrow Neck Width (mm)	CSMI (mm^4)	Section modulus (mm^3)	CSA (mm^2)
Age (years)	**,699****	,028	**-,233***	,105	,006	-,082	,033	,003	-,027	,009	-,013	,015	,066	,047	0,053
Stature (cm)	-	**,896****	**-,328****	**,333****	**,479****	**,191***	**,647****	**,387****	**,571****	**,368****	**,322****	,074	**,754****	**,728****	**,664****
Lean mass (kg)		-	**-,288****	**,517****	**,612****	**,391****	**,761****	**,477****	**,698****	**,441****	**,449****	,116	**,836****	**,803****	**,740****
VPA (min/day)			-	-,085	-,004	**,246****	-,098	,108	-,100	,096	,163	**,225***	-,051	-0,007	,016
VJ (cm)				-	**,837****	**,499****	**,471****	**,411****	**,526****	**,349****	**,399****	,120	**,427****	**,444****	**,449****
SLJ (cm)					-	**,616****	**,553****	**,514****	**,567****	**,433****	**,516****	,130	**,584****	**,598****	**,588****
20 m SRT (shuttle)						-	**,500****	**,524****	**,428****	**,423****	**,569****	**,252****	**,500****	**,535****	**,540****

VPA, Vigorous Physical Activity; VJ, Vertical Jump; SLJ, Standing Long Jump; 20m SRT, 20 metres Shuttle Run Test; WBLH, Whole Body Less Head; CSMI, Cross Sectional Moment of Inertia; CSA, Cross Sectional Area.
Significant results are in bold (*p<0.05 and **p<0.01).

Table 3. Multiple linear regression: explanatory value of muscular fitness test results as a factor in areal bone mineral density (aBMD; g/cm^2) and hip geometry estimates.

VERTICAL JUMP									
	Model 1			Model 2			Model 3		
Dependent variables	*β* †	*Semip Corr* ¥	p	*β* †	*Semip Corr* ¥	p	*β* †	*Semip Corr* ¥	p
aBMD (g/cm^2)									
Whole body less head	0,273	0,240	**<0,001**	0,277	0,243	**<0,001**	0,105	0,082	0,163
Total hip	0,308	0,270	**0,001**	0,314	0,276	**0,001**	0,227	0,177	0,022
Lumbar spine	0,362	0,318	**<0,001**	0,363	0,318	**<0,001**	0,209	0,163	0,012
Femoral neck	0,244	0,213	0,011	0,249	0,219	0,008	0,169	0,132	0,102
Trochanter	0,312	0,274	**0,001**	0,318	0,279	**0,001**	0,194	0,151	0,050
Hip geometry estimates									
Narrow neck width (mm)	0,095	0,083	0,365	0,096	0,084	0,347	0,063	0,049	0,583
CSMI (mm^4)	0,194	0,170	**0,004**	0,198	0,174	**0,002**	0,019	0,015	0,760
Section modulus (mm^3)	0,213	0,187	**0,002**	0,218	0,191	**0,001**	0,068	0,053	0,298
CSA (mm^2)	0,256	0,225	**0,001**	0,262	0,230	**<0,001**	0,126	0,099	0,089
STANDING LONG JUMP									
Dependent variables	Model 1			Model 2			Model 3		
aBMD (g/cm^2)	*β* †	*Semip Corr* ¥	p	*β* †	*Semip Corr* ¥	p	*β* †	*Semip Corr* ¥	p
Whole body less head	0,262	0,221	**0,001**	0,255	0,212	**0,001**	0,113	0,088	0,134
Total hip	0,391	0,330	**<0,001**	0,358	0,297	**<0,001**	0,284	0,221	**0,004**
Lumbar spine	0,291	0,246	**0,001**	0,289	0,240	**0,001**	0,148	0,115	0,078
Femoral neck	0,309	0,261	**0,002**	0,276	0,299	**0,005**	0,208	0,162	0,045
Trochanter	0,429	0,362	**<0,001**	0,387	0,322	**<0,001**	0,289	0,225	**0,003**
Hip geometry estimates									
Narrow neck width (mm)	0,180	0,152	0,096	0,131	0,108	0,226	0,106	0,083	0,356
CSMI (mm^4)	0,273	0,231	**<0,001**	0,239	0,198	**<0,001**	0,104	0,081	0,088
Section modulus (mm^3)	0,297	0,251	**<0,001**	0,257	0,213	**<0,001**	0,142	0,110	0,028
CSA (mm^2)	0,342	0,289	**<0,001**	0,303	0,252	**<0,001**	0,197	0,153	0,008

Bold letters denote significant differences after controlling for multiple testing. A value of $p<0.0055$ was considered statistically significant.

† β is the estimated standardised regression coefficient of the focal fitness test

¥ *Semip Corr:* Semi-partial correlation coefficients reflecting fitness explanatory value after accounting for the other variables included within the models.

VPA, vigorous physical activity; CSMI, cross-sectional moment of inertia; CSA, cross-sectional area

Model 1: age and stature; Model 2: age, stature and VPA; Model 3: age, stature, VPA and lean mass.

Table 4. Multiple linear regression: explanatory value of aerobic fitness test results as a factor in areal bone mineral density (aBMD; g/cm^2) and hip geometry estimates.

20 METRES SHUTTLE RUN TEST									
	Model 1			**Model 2**			**Model 3**		
Dependent variables	*ß* †	*Semip Corr* ¥	p	*ß* †	*Semip Corr* ¥	p	*ß* †	*Semip Corr* ¥	p
aBMD (g/cm^2)									
Whole body less head	0,379	0,337	**<0,001**	0,390	0,331	**<0,001**	0,245	0,187	**0,001**
Total hip	0,475	0,423	**<0,001**	0,450	0,382	**<0,001**	0,392	0,299	**<0,001**
Lumbar spine	0,303	0,269	**<0,001**	0,310	0,263	**<0,001**	0,142	0,108	0,097
Femoral neck	0,369	0,328	**<0,001**	0,338	0,287	**<0,001**	0,277	0,211	0,008
Trochanter	0,533	0,474	**<0,001**	0,501	0,425	**<0,001**	0,417	0,391	**<0,001**
Hip geometry estimates									
Narrow neck width (mm)	0,247	0,220	0,016	0,175	0,149	0,096	0,160	0,122	0,172
CSMI (mm^4)	0,386	0,343	**<0,001**	0,358	0,304	**<0,001**	0,219	0,167	**<0,001**
Section modulus (mm^3)	0,419	0,372	**<0,001**	0,384	0,325	**<0,001**	0,274	0,209	**<0,001**
CSA (mm^2)	0,450	0,400	**<0,001**	0,418	0,355	**<0,001**	0,320	0,244	**<0,001**

Bold letters denote significant differences after controlling for multiple testing. A value of $p<0.006$ was considered statistically significant.

†β is the estimated standardised regression coefficient of the focal fitness test

¥ *Semip Corr:* Semi-partial correlation coefficients reflecting fitness explanatory value after accounting for the other variables included within the models.

VPA, vigorous physical activity; CSMI, cross-sectional moment of inertia; CSA, cross-sectional area

Model 1: adjusted for age and stature; Model 2: adjusted for age, stature and VPA; Model 3: adjusted for age, stature, VPA and lean mass.

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Association of different types of playing surfaces with bone mass in growing girls

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ABSTRACT
The aim of this cross-sectional study was to compare bone mass in young female athletes playing ball games on different types of playing surfaces. About 120 girls, 9–13 years of age (10.6 ± 1.5 years old Tanner I–III) were recruited and divided into prepubertal and pubertal groups. The sample represented 3 groups of athletes: soccer (N = 40), basketball (N = 40), and handball (N = 40); and 6 different playing surfaces (soccer – ground, soccer – artificial turf, basketball – synthetic, basketball – parquet, handball – synthetic, and handball – smooth concrete). Total and regional body composition (bone mass, fat mass, and lean mass) were measured by dual-energy X-ray absorptiometry (DXA). The mechanical properties of the surfaces (force reduction, vertical deformation, and energy return) were measured with the Advanced Artificial Athlete (Triple A) method. The degree of sexual development was determined using Tanner test. The pubertal group showed that soccer players on the ground, basketball players on synthetic, and handball players on smooth concrete had higher values of bone mineral content (BMC) and bone mineral density (BMD) (P < 0.05) than the soccer players on the artificial turf, basketball players on parquet, and handball players on synthetic. In conclusion, a hard playing surface, with less vertical deformation and force reduction, and greater energy return, is associated with higher levels of BMD and BMC in growing girls, regardless of the sport they practice.

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Sports; body composition; DXA; female players; physical activity

Introduction

Studies on bone development during the growth period are fundamental due to the acquisition of bone mass during childhood, which later reflects good bone health in adulthood (Rizzoli, Bianchi, Garabédian, McKay, & Moreno, 2010). There are some sports that have been defined especially as osteogenic because of their characteristics. The main features of these sports consist of important ground reaction forces caused by own body weight in different actions such as those produced in jumps, drastic changes of direction, and abrupt accelerations and stops (Vicente-Rodríguez, 2006).

Exercise with a minimum duration and intensity is needed to reach an osteogenic effect (Vicente-Rodríguez, 2006). Impact and mechanical loads produced whilst practising sport result in modelling and remodelling processes of the bone. These are required to adequately adapt the bone to meet the new demands, causing an increase of the bone mineral content (BMC), bone mineral density (BMD), and possible structural and microarchitecture trabecular adaptations (Wolff, Van Croonenborg, Kemper, Kostense, & Twisk, 1999).

The affinity between the player and the playing surface is important for player's performance and health. Most researches have focused on studying the influence on injury rate (Hershman et al., 2012; Iacovelli et al., 2013) and performance (Hughes et al., 2013; Sánchez-Sánchez, García-Unanue, et al., 2014), but the association of different indoor playing surfaces with BMD and BMC has not been studied yet. Plaza-Carmona et al. (2014) showed no significant differences of bone development in boys for the regions of limbs, pelvis, and hip in a cross-sectional study between non-grass ground and artificial turf ground.

The study of sport surfaces is an important topic that covers the aspects of design, materials, construction, performance, and durability in either indoor or outdoor surfaces (Fleming, 2011; Sánchez-Sánchez, García-Unanue, et al., 2014). The main functions of sport surfaces are to provide good security for the player and to generate an appropriate level of performance of the ball–surface interaction (Fleming, 2011). There are different types of surfaces in which sports are practiced, for instance, natural grass, smooth concrete, synthetic surfaces, and parquet. In general, the most common topic studied has been the difference between natural grass and artificial turf with regard to the influence on injuries (Akkaya, Serinken, Akkaya, Türkçüer, & Uyanık, 2011; Soligard, Bahr, & Andersen, 2012), the mechanical behaviour (Sánchez-Sánchez, Felipe, Burillo, Del Corral, & Gallardo, 2014), personal satisfaction of both athletes and coaches (Gallardo-Guerrero, Felipe, Burillo, & Gallardo, 2010), and the performance of the athletes (Fleming, 2011). According to Ekstrand, Timpka, and Hägglund (2006), artificial turf increases the risk of injury in soccer players. In addition, Akkaya et al. (2011) conclude that soccer matches on synthetic surfaces can cause grave muscle injuries. Studies about this topic in indoor multi-use surfaces are limited.

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The mechanical response of the surface proves to be important on bone mass. Some of the most important parameters to be taken into account are force reduction and vertical deformation. Force reduction is defined as the capacity of a material to reduce the effect of impact forces through the absorption and dissipation of energy (Rosa, Sanchís, Alcántara, & Zamora, 2008), whereas vertical deformation is defined as the degree to which a surface causes a loss of lateral balance in athletes due to an unexpected response of the surface (Alcántara, Gámez, Rosa, & Sanchís, 2009). Soccer players experience different kinds of forces on the tissues depending on the surface, which has an impact on the type and frequency of the injuries among players (Kordi, Hemmati, Heidarian, & Ziaee, 2011). Another important factor in the surface–player interaction is the energy return (Baroud, Nigg, & Stefanyshyn, 1999) that associates the force applied against the surface with the returned energy, which has an influence on elastic behaviour of the surface and its interaction with athletes. According to Kerdok, Biewener, McMahon, Weyand, and Herr (2002), greater energy return enhances player performance.

The aim of this study was therefore to investigate the association of different types of playing surfaces with the BMC and BMD in prepubertal and pubertal girls who practice different kinds of sports (soccer, basketball, and handball). Thus, this study gives information about the importance of the association between surface and bone mass before and during puberty in girls.

Materials and methods

Participants

About 120 girl participants between the age of 9 and 13 years (10.6 ± 1.5 years (Tanner I–III) from Madrid, Toledo, and Ciudad Real (Spain) were recruited for the study. The sample represented 3 groups of athletes: soccer (N = 40), basketball (N = 40) and handball (N = 40), and 6 different playing surfaces (22 soccer – ground, 18 soccer – artificial turf, 21 basketball – synthetic, 19 basketball – parquet, 20 handball – synthetic, and 20 handball – smooth concrete). All athletes practised sport for at least 3 h a week (Vicente-Rodríguez, Dorado, Perez-Gomez, Gonzalez-Henriquez, & Calbet, 2004) (prepubertal group 2.99 ± 0.14 h a week; pubertal group 4.31 ± 1.28 h a week) and had been playing their sport for at least 8 months (Ferry, Lespessailles, Rochcongar, Duclos, & Courteix, 2013) on the same type of surface (prepubertal group 3.57 ± 1.56 years; pubertal group 4.24 ± 1.70 years). They must play just 1 sport. All participants provided written informed consent to take part in the present study, which was approved by the local Ethics Committee (Hospital of Toledo) and was performed in accordance with the code of ethics of the World Medical Association (Declaration of Helsinki). The general characteristics of each group are described in Table 1, divided in prepubertal (Tanner I) and pubertal (Tanner II–III) girls. There were no significant differences between groups of sports (soccer – ground vs. soccer – artificial turf, basketball – synthetic vs. basketball – parquet, and handball – synthetic vs. handball – smooth concrete) in any of the variables studied. Therefore,

Table 1. Descriptive characteristics of groups of prepubertal and pubertal girls.

Prepubertal	Soccer – ground	Soccer – artificial turf	Sig.	Basketball – synthetic	Basketball – parquet	Sig.	Handball – synthetic	Handball – smooth concrete	Sig.
N	11	9		14	6		12	8	
Age (year)	10.02 ± 0.92	9.14 ± 0.88	0.11	10.30 ± 0.59	10.48 ± 0.26	1.00	9.74 ± 0.64	10.03 ± 0.65	1.00
Height (cm)	142.90 ± 10.45	139.13 ± 9.21	1.00	151.24 ± 10.30	151.03 ± 12.77	1.00	140.55 ± 7.12	144.28 ± 9.74	1.00
Body mass (kg)	36.81 ± 9.10	34.40 ± 8.62	1.00	42.35 ± 8.30	44.66 ± 12.16	1.00	38.91 ± 9.65	35.38 ± 7.09	1.00
BMI (kg · m^{-2})	17.76 ± 2.47	17.55 ± 2.89	1.00	18.55 ± 3.32	19.18 ± 2.17	1.00	19.62 ± 4.37	16.87 ± 2.30	1.00
Years training	4.27 ± 1.35	3.33 ± 2.24	1.00	3.09 ± 1.47	4.00 ± 1.55	1.00	3.25 ± 1.42	3.50 ± 1.31	1.00
Weekly training hours	3.00 ± 0.00	3.00 ± 0.00	1.00	2.82 ± 0.46	3.00 ± 0.00	1.00	3.00 ± 0.00	3.13 ± 0.35	1.00
Pubertal	Soccer – ground	Soccer – artificial turf	Sig.	Basketball – synthetic	Basketball – parquet		Handball – synthetic	Handball – smooth concrete	
N	11	9		7	13		8	12	
Age (year)	12.55 ± 0.56	12.03 ± 0.55	1.00	13.03 ± 0.40	13.06 ± 0.32	1.00	12.96 ± 0.97	12.52 ± 0.77	1.00
Height (cm)	156.08 ± 5.48	151.13 ± 6.34	1.00	164.61 ± 9.08	162.32 ± 8.07	1.00	162.32 ± 8.07	162.64 ± 9.18	1.00
Body mass (kg)	49.09 ± 9.41	41.36 ± 9.36	1.00	55.21 ± 13.30	57.72 ± 13.61	1.00	58.83 ± 9.04	48.55 ± 10.92	0.74
BMI (kg · m^{-2})	20.09 ± 3.49	17.94 ± 3.05	1.00	20.12 ± 3.38	21.64 ± 3.59	1.00	22.09 ± 1.63	19.18 ± 2.74	0.68
Years training	4.55 ± 1.44	4.33 ± 2.06	1.00	4.14 ± 1.95	4.46 ± 1.13	1.00	4.38 ± 2.20	3.58 ± 1.44	1.00
Weekly training hours	3.46 ± 0.82	3.67 ± 0.71	1.00	3.21 ± 0.27	3.02 ± 0.08	1.00	6.50 ± 3.41	6.00 ± 2.41	1.00

BMI: body mass index.
Data adjusted by height and body mass.

there is homogeneity in the sample in each sport for the subsequent analyses.

Methods

The tests were performed by means of Tanner test, dual-energy X-ray absorptiometry (DXA), and Advanced Artificial Athlete (Triple A). The participants were recruited from sports clubs. All girls answered a medical and physical activity questionnaire designed ad hoc, to collect information about sport experience (years of practice of the sport in question), bone diseases, injuries, training hours per week, if they practise any other sports, and health issues. None of the participants were taking medications that affected bone and muscle metabolism. Both parents and participants were informed about the aims of this study and its procedure, as well as its possible risks. All evaluations were done between September and November 2014.

Anthropometry and body composition

The weight (kg) and height (cm) were measured by means of the SECA scale (model 711; SECA GmbH & Co, KG, Hamburg, Germany). Body mass index (BMI) was calculated using the formula: BMI ($kg \cdot m^{-2}$) = body weight (kg)/body height $(m)^2$. BMC (in g), BMD (in $g \cdot cm^{-2}$) and lean body mass (LBM, in kg) (body mass − [fat mass + bone mass]) were measured with DXA (Hologic Series Discovery QDR, Software Physician's Viewer, APEX System Software Version 3.1.2. Bedford, MA, USA). Thus, 2 scanners were performed. The first one was used to analyse the whole body, the mean of legs, the pelvis, and the hip. On the other hand, the second one was employed to analyse the femoral neck, the trochanter, the intertrochanteric and the Ward's triangle. DXA equipment was calibrated using a lumbar spine phantom and following the Hologic guidelines. Participants were scanned in supine position and the scans were performed at high resolution. BMC (g) was calculated using the formula BMC = BMD · area. Laboratory precision errors for regional analysis of the complete body scan, defined by the coefficient of variation (CV) for repeated measures estimated in young volunteers with repositioning, were as follows: BMC < 3.5%, BMD < 4%, bone area < 4.8%, and fat-free lean mass < 3.3%.

Pubertal stage

Sexual maturity was determined using the criteria described by Tanner (Marshall & Tanner, 1969). The sex characteristics during puberty can be seen in Tanner´s photographs. It consists of 5 stages of breast and pubic hair development. According to these criteria, 2 groups were formed: prepubertal girls (Tanner I) and pubertal girls (Tanner II and III). Tanner pubertal status was determined by self-assessment. This method for the self-assessment of breast and pubic hair development in girls correlates significantly with physician assessment of pubertal development, with coefficients of variations of 0.81 and 0.91 (Duke, Litt, & Gross, 1980).

Surface mechanical properties

The mechanical properties of the 6 sport surfaces selected for this study were assessed *in situ* to estimate the interaction of the player with the playing surface. These tests were performed *in situ* under the standard EN 15,330-1:2014 for artificial turf and EN 14904:2007 for indoor surfaces. The analysed variables were force reduction (%), standard vertical deformation (mm), and energy return (%) to collect information about the response of every surface upon an impact. They were measured by a Triple A (Advanced Artificial Athlete; Deltec Metal, Duiven, Holanda) under the procedures stipulated by the standards EN 149009:2005 and EN 14809:2005. The test consists of dropping a specific mass (total weight, 20 kg) from a predetermined height, employing a spring with a controlled stiffness to simulate the shock-absorbing effect of knee and ankle articulations. Under these mass impacts with the surface, the maximum force applied was registered using a load cell that register the mean signals obtained. Data collection was carried out on a laptop with the software (G-Force v.3.03, DeltecMetaal, Duiven, Holanda).

Energy return

$$ER = \left[\frac{E_2}{E_1}\right] \times 100,$$

where E_1 is the energy before impact. $E_1 = 0.5 \times m\, V^2{}_{max}$; E_2 is the energy after impact. $E_2 = 0.5 \times m\, V^2{}_{min}$; V_{max} is the velocity before impact at T_1 in $m \cdot s^{-1}$; V_{min} is the velocity after impact at T_2 in $m \cdot s^{-1}$; m, is the falling mass including spring, base plate, and accelerometer, expressed in kg; T_1: time when the test foot makes initial contact with the surface (corresponds with the maximum absolute value of the velocity of the falling mass V_{max}); T_2: time of the maximum absolute velocity of the mass during its rebounds after the impact on the test specimen (determined by V_{min}).

Force reduction

Calculate the shock absorption (Fred) with the following formula,

$$SA = \left[1 - \frac{F_{max}}{F_{ref}}\right] \times 100,$$

where SA is the shock absorption in %; F_{max} is the Force max measured on the sport surface, in *N*; F_{ref} is the reference force fixed to 6760 N (theoretical value calculated for a concrete floor).

Vertical deformation

The displacement of the falling mass D_{mass} (t) is calculated by integration of $V_{(t)}$ on the interval $[T_1, T_2]$). Integration starts at (T_1), the moment when the mass has reached its highest velocity.

On the time interval $[T_1\_T_2]$, the vertical deformation (VD) of the test specimen is defined as:

$$VD = D_{mass} - D_{spring},$$

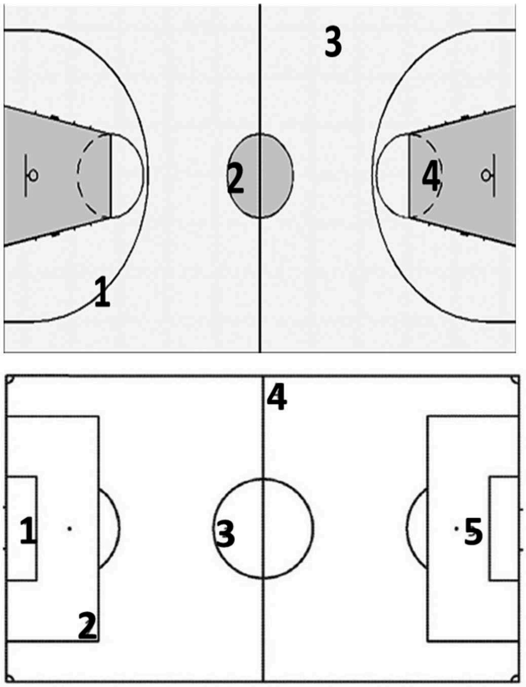

Figure 1. Assessed areas in indoor surfaces and soccer fields.

The figure shows the areas in which the mechanical properties of the field are tested according to the regulations EN 14904:2007 and EN 15,330-1: 2014, respectively.

where: $\boldsymbol{D}_{\text{mass}} = \iint_{T1}^{T2} G \, dt$, with $\boldsymbol{D}_{\text{mass}} = 0$ mm at T_1; $\boldsymbol{D}_{\text{spring}} = (m \times g \times G_{\text{max}})/C_{\text{spring}}$; F_{max} the peak force, expressed in Newton N; G_{max} is the peak acceleration during the impact, expressed in g (1 g = 9.81 $\text{m} \cdot \text{s}^{-2}$); m is the falling mass, including spring, base plate, and accelerometer expressed in kg; g is the acceleration by gravity (9.81 $\text{m} \cdot \text{s}^{-2}$); C_{spring} is the spring constant (given by the certificate of calibration).

This procedure was performed 3 times at intervals of 60 ± 10 s. On indoor surfaces, the test was performed in 4 specific zones (EN 14904:2007), whereas on artificial turf and ground, the test was carried out in 5 specific zones (EN 15,330-1:2014) (Figure 1). The mean value of the second and third impact was registered (EN 14808: 2005 y EN 14809: 2005). The test was repeated in 3 different places separated by more than 100 mm per zone (EN 14808: 2005 y EN 14809: 2005). The data collection was performed under similar weather conditions: from 18°C to 22.5°C temperature and from 20% to 35% of humidity.

Statistical analysis

Initially, a Kolmogórov-Smirnov test was performed and the Levene's test statistic was employed to verify the normality and homogeneity of variances. Second, a variance analysis (ANOVA) and Bonferroni *post hoc* test were performed to test the differences of mechanical properties between the 2 playing surfaces for each of the sports (ground vs. artificial turf in soccer, synthetic vs. parquet in basketball, and synthetic vs. smooth concrete in handball).

Next, a comparison of means was carried out for descriptive characteristics of the participants and the bone mass variables. In all the cases, the analysis was repeated for pubertal and prepubertal participants independently since they are different madurative states and therefore it is required to distinguish between them to get grater validity and reliability (Bailey, McKay, Mirwald, Crocker, & Faulkner, 1999; Vicente-Rodriguez, Dorado, et al., 2004). The comparison between surfaces in each of the sports (soccer – ground vs. soccer – artificial turf, basketball – synthetic vs. basketball – parquet and handball – synthetic vs. handball – smooth concrete) was carried out by analysis of variance of 2 ways (Surface × Sport) (ANCOVA), whereas the differences were identified through the *post hoc* procedure of Bonferroni. Thus, the height and lean mass were used as covariables because of their correlation with the bone mass (Bielemann, Martinez-Mesa, & Gigante, 2013). Finally, a linear regression analysis was made using the mechanical properties of the playing surfaces as independent variables (force reduction, vertical deformation, and energy return), whereas the variables of bone mass were employed as dependent variables.

Data were analysed by means of the statistic software SPSS V19.0 for Windows (SPSS Inc, Chicago, IL, USA). The significance level was set as $P < 0.05$. In addition, confidence interval (CI of 95%) was calculated to identify the magnitude of changes and the effect size (ES; Cohen's d). ES was evaluated following the criteria: 0–0.2 = trivial, 0.2–0.5 = small, 0.5–0.8 = moderate, and 0.8 = significant (Cohen, 1992).

Results

Sport surfaces

Table 2 describes the differences in the mechanical properties of the different playing surfaces. An analysis of the mechanical behaviour of the playing surfaces showed higher force reduction values ($P < 0.05$) for soccer – artificial turf (61.42 ± 1.60%), basketball – parquet (55.86 ± 13.53%), and handball – synthetic (14.47 ± 1.79%) compared with soccer – ground (53.08 ± 1.65%), basketball – synthetic (23.14 ± 2.02%) and handball – smooth concrete (0.00 ± 0.00%), respectively. On the soccer surface, values of vertical deformation were higher

Table 2. Differences in the mechanical properties of surfaces by sort of sports.

Sports	Surface type	Force reduction (%)	Vertical deformation (mm)	Energy return (%)
Soccer	Ground	53.08 ± 1.65	3.92 ± 0.42	36.93 ± 1.12
	Artificial turf	61.42 ± 1.60#	5.44 ± 0.29#	32.66 ± 3.17
Basketball	Synthetic	23.14 ± 2.02	1.02 ± 0.29	60.29 ± 2.43*
	Parquet	55.86 ± 13.53*	2.91 ± 1.31*	45.94 ± 18.78
Handball	Synthetic	14.47 ± 1.79†	1.45 ± 0.58†	62.25 ± 2.40
	Smooth concrete	0.00 ± 0.00	0.22 ± 0.12	92.11 ± 1.05†

$P < 0.05$.
Ground vs. artificial turf.
* Synthetic vs. parquet.
† Synthetic vs. smooth concrete.

($P < 0.01$) for artificial turf (5.44 ± 0.29 mm) compared with ground (3.92 ± 0.42 mm); on the basket surfaces the parquet (2.91 ± 1.31 mm) was higher compared with the basketball synthetic surface (1.02 ± 0.29 mm); and the synthetic handball surface (1.45 ± 0.58 mm) compared with the smooth concrete (0.22 ± 0.12 mm). Regarding the return energy ($P < 0.01$), the synthetic surface of basketball (60.29 ± 2.43%) and the smooth concrete in handball (92.11 ± 0.30%) obtained larger values compared with the parquet in basketball (45.94 ± 18.78%) and synthetic surface in handball (62.25 ± 2.40%), respectively.

Bone mass

The comparative analysis of BMC and BMD in players from the same sport playing on different surfaces showed significant differences in the pubertal group (Table 3). However, in the prepubertal group, there were no significant differences. In the pubertal group, the soccer players who played on ground surface showed higher BMC (6.78 g; CI 95%: 0.83–12.73 g; ES = 1.92) and BMD (0.11 g · cm^{-2}; CI 95%: 0.001–0.22 g · cm^{-2}; ES = 1.00) in the hip than the soccer players who played on artificial turf ($P < 0.05$). The girls who played basketball on synthetic surfaces showed higher BMC (94.37 g; CI 95%: 16.98–171.77 g; ES = 1.80) in legs and in the intertrochanteric region (7.24 g; CI 95%: 1.37–13.10 g; ES = 1.33) than the girls who played on parquet ($P < 0.01$). Finally, the handball players who played on concrete surfaces showed higher BMC (6.51 g; CI 95%: 0.37–12.66 g; ES = 1.43) and BMD (0.12 g · cm^{-2}; CI 95%: 0.003–0.23 g · cm^{-2}; ES = 1.43) in hip than the player who played on the synthetic surface of handball ($P < 0.05$).

Sport surfaces and bone mass

The analysis of linear regression showed some significant associations between the mechanical properties of the association playing surface and the bone mass (Table 4). Force reduction and vertical deformation had a negative association to the BMC variables, whereas the energy return had a positive association. Thus, the mechanical properties of the playing surface explained 7.9% ($P < 0.05$), 8.8% ($P < 0.05$), and 31.4% ($P < 0.01$) of the BMC variance for the whole body, the mean of legs, and the hip, respectively. The energy return was positively associated to BMC for the pelvis ($P < 0.05$) and BMC for the femoral neck ($P < 0.05$). The force reduction was negatively associated to BMC in the femoral neck ($P < 0.05$). Moreover, the force reduction and vertical deformation was negatively associated to BMD, in contrast to the energy return that showed a positive association to the BMD variables. The mechanical properties of the playing surface explained 9.9% ($P < 0.05$), 6.3% ($P < 0.05$), and 11.4% ($P < 0.05$) of the BMD variance for the mean of legs, the pelvis, and the hip, respectively. Finally, the force reduction was negatively associated to BMD in the whole body ($P < 0.05$).

Discussion

This research is the first of its kind that investigates the association between the properties of the playing surface and the bone mass in growing girls. Plaza-Carmona et al. (2014) assessed the association between the bone mass in boys and the surface in soccer. The present research provides a broader view because of its inclusion of different sports as well as a wide range of surfaces. The main finding of the present study was the significant association between the playing surface and the bone mass in pubertal girls. However, no significant differences in prepubertal girls was found, probably because most of the significant changes in bone mass take place during puberty (Maïmoun et al., 2013).

Despite the fact that the genetic basis has an important influence on the variability of bone mass, the bones adapt to the mechanical load to which they are regularly exposed (Bailey & Brooke-Wavell, 2008). There is consensus that physical activity of high impact improves bone health in contrast to the low impact physical activity such as swimming or cycling, which has been demonstrated not only in longitudinal studies (Czeczelewski, Długołęcka, Czeczelewska, & Raczyńska, 2013) but also supported by cross-sectional studies (Ubago-Guisado, Gómez-Cabello, Sánchez-Sánchez, García-Unanue, & Gallardo, 2015). Thus, cross-sectional studies such as Bellew and Gehrig (2006) and Nilsson, Ohlsson, Mellström, and Lorentzon (2013) in soccer, Carbuhn, Fernandez, Bragg, Green, and Crouse (2010) in basketball, and Vicente-Rodríguez, Ara, et al. (2004) and Hinrichs, Eun-Heui, Lehmann, Allolio, and Platen (2010) in handball; as well as longitudinal studies such as Creighton, Morgan, Boardley, and Brolinson (2001) in soccer and Rebai et al. (2012) in basketball have shown improvements in bone mass when comparing high impact activity with physical inactivity.

Thus, most of the intervention studies that analyse children who play soccer report osteogenic effect on hard surfaces (Vicente-Rodríguez, Ara, et al. 2004) when compared with soft surfaces. These researchers support the results found in the present study as the soccer practise on a surface with lower vertical deformation and force reduction and higher energy return (ground) is associated with higher levels of BMC and BMD in hip than on a surface with a higher vertical deformation and force reduction and lower energy return (artificial turf). This is because artificial turf is a softer surface than ground; therefore, it causes a higher force reduction and a higher vertical deformation. Thus, sport practise on hard surfaces provides a higher osteogenic stimulus.

In basketball, the practise of sport on synthetic surface is associated with higher BMC in legs in the intertrochanteric region than on parquet. In addition, handball players practising on concrete have higher BMC and BMD in hip than players practising on synthetic. This may be because the parquet and the synthetic surface have lower energy return although they have bigger force reduction and vertical deformation when compared with the basketball synthetic surface and smooth concrete, respectively. Thus, the present study is in agreement with Creighton et al. (2001) who distinguish between hard and soft surfaces, to conclude that athletes who practise sport on hard surfaces have a higher BMD in total than those who practise sport on softer surfaces. This may be due to the impact and mechanical loads that play a role in the bone modelling and remodelling resulting in increase of the BMC and the BMD (Wolff et al., 1999).

Table 3. Bone mineral content (g) and bone mineral density (g · cm^{-2}) at different sites in prepubertal and pubertal girls playing ball games.

BMC – Prepubertal (g)	Whole body	Mean legs	Pelvis	Hip	Femoral neck	Trochanter	Intertrochanteric region	Ward's triangle
Soccer – ground	1199.9 ± 174.9	223.8 ± 43.9	144.4 ± 30.0	21.7 ± 1.1	3.1 ± 0.4	5.6 ± 1.44	13.8 ± 2.1	0.9 ± 0.1
Soccer – artificial turf	1137.3 ± 204.8	207.6 ± 41.4	125.8 ± 27.5	21.4 ± 1.2	3.0 ± 0.5	5.0 ± 0.68	14.2 ± 3.3	1.0 ± 0.2
Basketball – synthetic	1261.4 ± 283.2	226.7 ± 55.1	156.5 ± 52.8	25.4 ± 2.0	2.9 ± 0.8	4.9 ± 1.63	19.9 ± 3.1	0.8 ± 0.2
Basketball – parquet	1399.0 ± 296.7	270.7 ± 68.2	160.3 ± 46.8	24.6 ± 1.4	3.4 ± 0.6	6.0 ± 1.43	19.0 ± 4.4	0.9 ± 0.1
Handball – synthetic	1142.1 ± 174.9	195.2 ± 34.3	154.2 ± 27.8	25.2 ± 1.3	2.8 ± 0.7	5.8 ± 1.07	21.0 ± 4.5	0.9 ± 0.1
Handball – smooth concrete	1202.6 ± 232.0	203.0 ± 46.0	149.7 ± 34.6	23.1 ± 3.2	2.9 ± 0.7	5.0 ± 1.35	19.2 ± 3.7	0.8 ± 0.1
BMD – prepubertal (g · cm^{-2})	**Whole body**	**Mean legs**	**Pelvis**	**Hip**	**Femoral neck**	**Trochanter**	**Intertrochanteric region**	**Ward's triangle**
Soccer – ground	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.9 ± 0.1	0.7 ± 0.1
Soccer – artificial turf	0.9 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.0	0.7 ± 0.1	0.7 ± 0.0	0.9 ± 0.1	0.8 ± 0.2
Basketball – synthetic	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.7 ± 1.1	0.9 ± 0.2	0.7 ± 0.2
Basketball – parquet	0.9 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	0.8 ± 0.0	0.8 ± 0.1	0.7 ± 0.1	0.9 ± 0.1	0.7 ± 0.1
Handball – synthetic	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.8 ± 0.0	1.0 ± 0.1	0.7 ± 0.1
Handball – smooth concrete	0.8 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	1.0 ± 0.1	0.7 ± 0.1
BMC – pubertal (g)	**Whole body**	**Mean legs**	**Pelvis**	**Hip**	**Femoral neck**	**Trochanter**	**Intertrochanteric region**	**Ward's triangle**
Soccer – ground	1600.9 ± 173.3	312.4 ± 38.7	194.0 ± 26.4	33.4 ± 4.4#	3.8 ± 0.4	7.2 ± 1.4	15.9 ± 3.1	0.9 ± 0.1
Soccer – artificial turf	1350.3 ± 230.8	259.00 ± 36.5	163.7 ± 32.5	26.6 ± 2.7	3.3 ± 0.5	7.3 ± 1.5	13.3 ± 2.2	0.9 ± 0.2
Basketball – synthetic	1776.4 ± 448.0	412.9 ± 45.5*	222.7 ± 68.3	37.9 ± 0.8	4.0 ± 0.8	6.6 ± 1.7	24.2 ± 7.0*	0.8 ± 0.1
Basketball – parquet	1753.7 ± 406.4	313.3 ± 64.9	219.8 ± 70.7	38.3 ± 5.4	4.1 ± 0.7	6.5 ± 1.7	16.8 ± 4.1	1.0 ± 0.2
Handball – synthetic	1898.8 ± 405.2	362.5 ± 82.7	274.5 ± 82.5	31.6 ± 4.3	4.4 ± 1.0	7.8 ± 1.5	24.8 ± 5.0	1.0 ± 0.1
Handball – smooth concrete	1708.1 ± 414.0	306.9 ± 85.2	250.6 ± 79.2	38.5 ± 4.7†	3.8 ± 0.9	7.1 ± 1.5	24.6 ± 4.7	1.0 ± 0.2
BMD – pubertal (g · cm^{-2})	**Whole body**	**Mean legs**	**Pelvis**	**Hip**	**Femoral neck**	**Trochanter**	**Intertrochanteric region**	**Ward's triangle**
Soccer – ground	1.0 ± 0.1	1.0 ± 0.1	1.1 ± 0.1	1.0 ± 0.1#	0.8 ± 0.1	0.8 ± 0.1	1.0 ± 0.1	0.8 ± 0.1
Soccer – artificial turf	0.9 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	1.0 ± 0.1	0.8 ± 0.1
Basketball – synthetic	1.0 ± 0.2	1.1 ± 0.2	1.1 ± 0.2	1.0 ± 0.001	0.8 ± 0.1	0.7 ± 0.1	1.1 ± 0.2	0.8 ± 0.1
Basketball – parquet	1.0 ± 0.1	1.1 ± 0.2	1.1 ± 0.2	1.0 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	1.0 ± 0.2	0.8 ± 0.2
Handball – synthetic	1.1 ± 0.1	1.2 ± 0.1	1.2 ± 0.2	0.9 ± 0.04	0.9 ± 0.1	0.8 ± 0.1	1.2 ± 0.1	0.9 ± 0.1
Handball – smooth concrete	1.0 ± 0.1	1.1 ± 0.1	1.1 ± 0.2	1.0 ± 0.1†	0.9 ± 0.1	0.8 ± 0.1	1.1 ± 0.2	0.8 ± 0.1

$P < 0.05$. Data adjusted by height and body mass.
BMC: bone mineral content; BMD: bone mineral density.
Soccer – ground vs. soccer – artificial turf.
* Basketball – synthetic vs. basketball – parquet.
† Handball – synthetic vs. handball – smooth concrete.

Table 4. Analyses of the regression of mechanical properties on BMC and BMD variables (Standard error in brackets).

BMC (g)	Whole body	Mean legs	Pelvis	Hip	Femoral neck	Trochanter	Intertrochanteric region	Ward's triangle
Force reduction	−17.17**	−4.20**	1.70	−0.49***	−0.033*	0.015	−0.110	−0.00
	(6.11)	(1.28)	(1.03)	(0.10)	(0.013)	(0.027)	(0.077)	(0.003)
Vertical deformation	−99.82*	−21.57*	−12.31	−3.42***	−0.155	0.079	−0.946	0.00
	(39.83)	(8.33)	(6.69)	(0.64)	(0.087)	(0.179)	(0.502)	(0.02)
Energy return	13.87*	3.17**	1.88*	0.43***	0.025*	0.018	−0.022	−0.001
	(5.56)	(1.16)	(0.94)	(0.09)	(0.012)	(0.025)	(0.070)	(0.002)
Constant	336.61	3.63	53.73	−3.29	1.302	4.430*	25.830***	0.98***
	(464.69)	(97.17)	(78.06)	(7.50)	(1.021)	(2.091)	(5.855)	(0.20)
R^2	0.079	0.088	0.097	0.314	0.049	0.013	0.375	0.007
N	120	120	120	120	120	120	120	120
BMD ($g \cdot cm^{-2}$)	**Whole body**	**Mean legs**	**Pelvis**	**Hip**	**Femoral neck**	**Trochanter**	**Intertrochanteric region**	**Ward's triangle**
Force reduction	−0.004*	−0.007**	−0.007*	−0.004*	0.002	0.001	0.000	0.001
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Vertical deformation	−0.023	−0.045**	−0.044*	−0.025*	−0.014	−0.015	−0.018	−0.003
	(0.012)	(0.015)	(0.018)	(0.011)	(0.013)	(0.013)	(0.015)	(0.015)
Energy return	0.003	0.005*	0.005*	0.004*	0.002	0.001	0.001	0.001
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Constant	0.658***	0.558**	0.570**	0.597***	0.629***	0.666***	0.973***	0.712***
	(0.140)	(0.175)	(0.214)	(0.133)	(0.147)	(0.147)	(0.179)	(0.171)
R^2	0.046	0.099	0.063	0.114	0.016	0.047	0.076	0.001
N	120	120	120	120	120	120	120	120

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.001$.
BMC: bone mineral content; BMD: bone mineral density.

Regarding the regression analysis, it is found that the values of R^2 are very low in all cases. This is due to the mechanical properties are only included as explicative variables and also there are many other factors which can influence on bone mass. The objective of these regressions were merely to complete the comparison of the previous mean, going in depth to the association of the sport surface with the bone mass variables, taking it into account not only the type of surface but also the mechanical properties which characterise them.

So, the present study shows a significant association between the bone mass variables (BMC and BMD) and the mechanical properties of the playing surfaces (force reduction, vertical deformation, and energy return). The main strength of the present research is the wide variety of sports and surfaces selected, which provide different mechanical loads on the bone. Furthermore, the broad age range spanning the period between prepuberty and puberty allows one to discover if the bone adaptations may depend on the degree of sexual maturity.

This research might be limited in terms of participants not being investigated longitudinal. For this reason, it is not possible to see a cause–effect relationship on the bone mass and therefore, producing interindividual variations that limit the conclusions. However, participants were carefully separated into 2 groups (prepubertal and pubertal) according to their sexual maturation, and in every group (soccer – ground, soccer – artificial turf, basketball – synthetic, basketball – parquet, handball – synthetic, and handball – smooth concrete) there were no significant differences regarding the baseline data. Sexual maturation was self-reported by the participants who might have some accuracy issues as previously shown (Desmangles, Lappe, Lipaczewski, & Haynatzki, 2006). Another possible limitation might be that the nutritional profile of participants was not recorded during the research. On the other hand, the practice of a sport of high osteogenic impact for at least 3 h per week at early ages is associated to bigger accumulation of bone mass than a sport of low osteogenic impact or physical inactivity (Ubago-Guisado et al., 2015). However, we only recommend a more rigid playing surface during puberty since in later stages the potential risk of injury shall be also taken into account.

In conclusion, the results found in the present study suggest that the playing surface has an association with the osteogenic effect of ball games during puberty. A hard playing surface, which has lower vertical deformation and force reduction, and higher energy return, gives a boost to acquiring higher levels of BMD and BMC in growing girls, regardless of the sport they practice.

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5.2. DISCUSIÓN GENERAL

El propósito principal de la presente Tesis Doctoral fue analizar la composición corporal y su relación con la práctica deportiva, la superficie de juego y la condición física en edad pediátrica. Para ello, se llevaron a cabo 5 estudios, cuyos objetivos específicos fueron: **1)** Analizar el efecto de la práctica deportiva en la masa grasa y masa muscular en niñas; **2)** Comparar las diferencias en masa ósea en niñas en función del tipo de deporte practicado; **3)** Estudiar la influencia de la masa grasa, la masa muscular, el consumo máximo de oxígeno, las horas de entrenamiento semanales y los años de práctica deportiva sobre la masa ósea en niñas; **4)** Examinar la asociación entre la condición física muscular y cardiorrespiratoria con la DMO y la geometría de cadera en niños; y **5)** Comparar las diferencias en la masa ósea en niñas en función del pavimento utilizado durante su práctica deportiva.

5.2.1. Asociación entre la práctica deportiva y composición corporal

Tejidos blandos: masa muscular y masa grasa

El principal hallazgo de nuestro **estudio 1** fue que las niñas que practican deporte regular de alto impacto (fútbol, baloncesto y balonmano) y de bajo impacto (natación) tienen menor masa grasa y mayor masa muscular, en comparación con aquellas que no practican deporte durante la etapa prepuberal y puberal.

En el estudio de Ara et al. (2004), los niños que no practicaban actividad física tenían más masa grasa total y masa grasa regional (tronco, brazos y piernas), que aquellos que practicaban al menos 3 horas de actividad física por semana. Esto coindice con nuestros resultados, donde las niñas del grupo control tenían mayor masa grasa, que las niñas que practicaban natación y balonmano durante más de 3 horas a la semana. Con respecto a la masa muscular, las niñas del grupo control tenían menos masa muscular que las físicamente activas (nadadoras, futbolistas, jugadoras de baloncesto y jugadoras de balonmano). Nuestros resultados coinciden con estudios previos, en los que la actividad física aumentó los niveles de masa muscular en niñas prepúberes (Morris, Naughton, Gibbs, Carlson, & Wark, 1997) y durante la adolescencia (Baxter-Jones, Kontulainen, et al., 2008).

De acuerdo con el análisis entre deportes, las jugadoras de fútbol en la etapa prepuberal tenían menos masa grasa en los brazos y en el tronco respecto a las jugadoras de baloncesto, coincidiendo con los estudios de Gil-Gómez y Juan (2011) y Pérez-Guisado (2009). Por otro lado, las jugadoras de baloncesto prepuberal tenían mayor masa muscular en el tronco y en las piernas que el grupo control. Nuestros resultados son similares a aquellos observados en un estudio previo, en el cual los jugadores de baloncesto mostraron mayor porcentaje de masa muscular que el grupo control (Koley & Singh, 2010). Sin embargo, las jugadoras de baloncesto puberal tenían mayor masa grasa que las niñas del grupo control. Esto puede deberse a que las jugadores de baloncesto eran significativamente más altas y más pesadas que las niñas del grupo control.

Además, las jugadoras de balonmano prepuberal y puberal tuvieron mayores niveles de masa muscular total, masa muscular en los brazos y masa muscular en el tronco respecto a las nadadoras y futbolistas. Esto puede deberse a que existe una clara tendencia de las jugadoras de balonmano a tener más masa muscular, especialmente en la parte superior del cuerpo, debido a los requerimientos físicos de este deporte (Milanese et al., 2011). Otras investigaciones recientes sugirieron que los jugadores de balonmano tenían mayor masa muscular en comparación con los futbolistas (Santos-Silva, Petroski, & Araujo-Gaya, 2013), resultados similares a nuestro estudio. En relación con las nadadoras puberales, estas tienen mayor masa muscular y menor porcentaje de masa grasa que las jugadoras de fútbol. Esto puede deberse a que las nadadoras entrenaban más horas a la semana y llevaban practicando deporte durante más años que las futbolistas.

Masa ósea

El principal hallazgo de nuestro **estudio 2** fue que las niñas que practican deportes de alto impacto (fútbol, baloncesto y balonmano) tienen una mayor masa ósea, frente a niñas que practican deportes de bajo impacto (natación) o la falta de actividad física en la pubertad.

Zouch et al. (2008) concluyeron que la masa ósea es mayor en aquellos huesos que soportan impactos, como sucede con la práctica de deportes como el fútbol. Las personas que hacen deporte y obligan a sus huesos a soportar impactos y carga mecánica, tienen mejor salud ósea que las personas sedentarias (Bedogni et al., 2002). Esto se ha demostrado en diversos estudios en niñas (Vicente-Rodriguez, Dorado, et al., 2004), adolescentes (Ermin, Owens, Ford, & Bass, 2012) y mujeres (Nikander, Sievänen, Heinonen, & Kannus, 2005), donde los ejercicios con alto impacto mejoran la DMO. Nuestros resultados sugieren que las niñas que practican deportes de alto impacto como el fútbol, el baloncesto y el balonmano, muestran valores más altos en el CMO y la DMO, en comparación con las niñas que practican deportes de bajo impacto (natación) y las que no practican deporte. La mayoría de diferencias significativas se encontraron en las niñas púberes, periodo en el cual el efecto del ejercicio puede apreciarse mejor, ya que la mayoría de los cambios en el esqueleto óseo debido al crecimiento tienen lugar durante la pubertad (Maïmoun et al., 2013).

Por otro lado, la práctica de deportes como el fútbol y el baloncesto se asocia con mayores niveles de CMO y DMO, en comparación con la natación o la ausencia de práctica deportiva en mujeres y hombres jóvenes (Carbuhn, Fernandez, Bragg, Green, & Crouse, 2010; Creighton, Morgan, Boardley, & Brolinson, 2001; Morel, Combe, Francisco, & Bernard, 2001), en adolescentes (Bellew & Gehrig, 2006; Ferry et al., 2011; Seabra et al., 2012; Vlachopoulos et al., 2016) y en niños/as (Agostinete et al., 2016; Vicente-Rodriguez et al., 2003).

En relación al balonmano, existen pocos estudios que analicen su asociación con la masa ósea. Es un deporte caracterizado por acciones intermitentes de alta intensidad como saltos y esprines, que causan una gran carga mecánica en los huesos de las extremidades inferiores, debido a las fuerzas de reacción producidas durante las carreras y saltos (Freychat et al., 1996). Vicente-Rodriguez, Dorado, et al. (2004) mostraron una mayor DMO y CMO en variables como la pelvis y el cuello del fémur en niños jugadores de balonmano, en comparación con el grupo de control.

En nuestro estudio, las nadadoras son las que tienen los valores más bajos de masa ósea tras el grupo control. Los resultados demuestran que debido a la situación de ingravidez del medio acuático, los huesos obtienen menos estímulos que cuando se practica deporte fuera de ella, debido a la falta de impactos (Derman et al., 2008; Nikander, Sievanen, Uusi-Rasi, Heinonen, & Kannus, 2006). La literatura reciente ha demostrado que los deportes de alto impacto, parecen ser más osteogénicos que los deportes sin impacto, como la natación o el ciclismo en niños (Karlsson et al., 2008; Maïmoun et al., 2013), y en adolescentes de ambos sexos (Ferry et al., 2013; Gómez-Bruton et al., 2015; Olmedillas et al., 2011). Así pues, nuestros resultados coinciden con todos estos estudios, ya que mostramos que la práctica de deportes de alto impacto como el fútbol, el balonmano y el baloncesto, mejoran los niveles de CMO y DMO en comparación con la práctica de la natación, especialmente durante la etapa puberal en niñas.

5.2.2. Asociación entre los tejidos blandos y la masa ósea

El principal hallazgo de nuestro **estudio 3** fue que durante la pubertad, la masa ósea de las niñas está relacionada con la masa muscular, la condición física cardiorrespiratoria y las horas semanales de práctica deportiva.

Aunque el peso corporal ha sido identificado como un determinante del desarrollo de la DMO, existe controversia sobre el efecto independiente de la masa muscular y la masa grasa (Lohman et al., 1995). El desarrollo de la **masa muscular** ha demostrado estar relacionado con la mejora de la masa ósea (Andreoli et al., 2001). De hecho, estudios anteriores en niños han concluido que la masa muscular es el mejor predictor de deposición de masa ósea (Faulkner et al., 1993; Rauch et al., 2004). Esto puede deberse a que los músculos más desarrollados son capaces de aplicar fuerzas superiores sobre los huesos donde se unen (Vicente-Rodriguez, Ara, et al., 2004).

Nuestros resultados en niñas confirman los hallazgos de estudios longitudinales anteriores, que asocian el crecimiento óseo en los niños de acuerdo con el desarrollo muscular (Rauch et al., 2004; Vicente-Rodriguez, Dorado, et al., 2004). Dichos resultados sugieren que la masa muscular es el mejor indicador para la acumulación de hueso durante la pubertad (Courteix et al., 1998; Vicente-Rodriguez et al., 2005). Además, no sólo ocurre durante la pubertad, sino también durante la adolescencia (Gracia-Marco, Moreno, et al., 2011). Esta relación entre la masa muscular y la masa ósea puede explicarse a través de la teoría del mecanostato, que establece que la resistencia ósea se regula mediante procesos de modelado y remodelación, dependiendo de las fuerzas mecánicas aplicadas sobre el esqueleto (Rauch et al., 2004; Schoenau & Frost, 2002). En nuestro estudio, existe una alta correlación entre la masa muscular y la masa ósea, siendo las chicas con mayor masa muscular las que presentan un mayor CMO y DMO.

En cuanto a la relación entre **masa grasa** y masa ósea, Vicente-Rodriguez et al. (2005) mostraron que no existe correlación entre el aumento de la masa grasa, y la mejora de la masa ósea en los niños. En nuestro estudio, la masa grasa no se asoció con la masa ósea en las niñas en crecimiento, apoyando investigaciones previas (Pietrobelli et al., 2002; Rodriguez-Martinez, Blay, Blay, Moreno, & Bueno, 2002). Esta evidencia posiciona la masa muscular como el parámetro de composición corporal, que está directamente relacionado con el desarrollo óseo independientemente de la masa grasa (Vicente-Rodriguez et al., 2005). Algunos autores han concluido que la masa ósea está determinada principalmente por las cargas dinámicas, asociadas con las contracciones musculares, en lugar de con las cargas estáticas, asociadas con el peso corporal (Janicka et al., 2007; Pietrobelli et al., 2002).

Sin embargo, otros autores han sugerido una relación indirecta entre la masa grasa y el desarrollo óseo en las extremidades superiores, en mujeres y hombres, debido a la elevada contribución de la masa grasa en la masa corporal total (Capozza, Cointry, Cure-Ramirez, Ferretti, & Cure-Cure, 2004). Así mismo, en adolescentes de ambos sexos, se ha observado que el motivo por el cual la grasa y el hueso pueden asociarse positivamente, es debido al efecto del músculo, ya que adolescentes con más grasa tienden a desarrollar una mayor masa muscular, y por ello, una mayor masa ósea (Gracia-Marco et al., 2012).

5.2.3. Asociación entre la condición física y la masa ósea

El principal hallazgo de nuestro **estudio 4** fue que la AFV no parece explicar la asociación entre la condición física (cardiorrespiratoria y muscular) y los parámetros óseos (DMO y geometría de cadera), mientras que la masa muscular juega un papel clave en dicha asociación en jóvenes varones.

En relación a la **condición física cardiorrespiratoria,** nuestros resultados muestran que está positivamente relacionada con la DMO en niñas y niños; y con las variables de geometría de la cadera en niños. Sin embargo, la mayoría de las asociaciones encontradas entre la condición física cardiorrespiratoria y los resultados óseos, se atenúan cuando la masa muscular se introduce como covariable. Sólo desaparecen por completo las asociaciones con la DMO de la columna lumbar y del cuello femoral. Nuestros resultados están en línea con los de Gracia-Marco, Moreno, et al. (2011), en los que un bajo rendimiento en la prueba de Course Navette, estaba relacionado con un inferior CMO de cuerpo entero en adolescentes activos, después de ajustar por sexo, altura, masa muscular, ingesta de calcio y estado puberal.

Del mismo modo, un estudio longitudinal en chicas adolescentes encontró que la condición física cardiorrespiratoria, estaba directamente relacionada con la formación y reabsorción de masa ósea (Schneider et al., 2007). Por último, los resultados de otro estudio longitudinal de 15 años, mostraron que las asociaciones entre condición física cardiorrespiratoria (directamente medida como $VO_{2máx}$) y DMO de la columna lumbar y de la cadera en adolescentes, desaparecieron después de ajustar por sexo, estatura, peso, pliegues cutáneos, edad biológica e ingesta de calcio. Estos hallazgos son comparables con los nuestros, ya que el efecto de la masa muscular está incluido en el efecto del peso corporal, y en nuestro estudio también observamos que la masa muscular jugaba un papel relevante en la DMO de la columna y del cuello del fémur.

Por otro lado, estudios previos han demostrado una asociación directa entre la **condición física muscular** y los resultados óseos en niños (Vicente-Rodriguez, Ara, et al., 2004). Sin embargo, hay discrepancias en la evaluación de las covariables. Un mal resultado en la prueba de salto horizontal y en la prueba de prensión manual, se relacionó con un menor CMO en el cuerpo entero y en las extremidades inferiores en adolescentes, después de ajustar por sexo, estatura, masa muscular, ingesta de calcio y el estado puberal (Gracia-Marco, Vicente-Rodríguez, et al., 2011).

Del mismo modo, el rendimiento en salto vertical se asoció positivamente con la acumulación de hueso en la cadera y la columna lumbar en chicos prepúberes, utilizando la altura, la masa corporal y la edad como covariables (Vicente-Rodriguez, Ara, et al., 2004). Otro estudio encontró una relación entre el CMO y la condición física muscular en adolescentes, independientemente del estado de maduración y la masa muscular (Vicente-Rodriguez et al., 2008). Los hallazgos del presente estudio indican, que la condición física muscular está positivamente relacionada con la DMO y las variables de geometría de cadera en niños, debido al efecto de la masa muscular.

En este sentido, seguimos apoyando la idea de que la masa muscular sea considerada como uno de los mejores predictores de masa ósea durante el crecimiento (Gracia-Marco, Moreno, et al., 2011). De acuerdo con esta teoría del mecanostato, las asociaciones significativas observadas en nuestro estudio, entre la condición física muscular con la DMO y las variables de geometría de cadera, desaparecieron en la mayoría de los sitios, una vez que se consideró la masa muscular. Los presentes hallazgos apoyan los observados por Torres-Costoso et al. (2015) en escolares, quienes recientemente sugirieron que la masa muscular podría ser un mediador de la asociación entre la condición física muscular y la masa ósea.

5.2.4. Asociación entre la actividad física vigorosa (AFV) y la masa ósea

Estudios previos han sugerido que la AFV medida objetivamente, es un determinante clave de la masa ósea y la geometría (Tobias et al., 2007). En niños, se han sugerido al menos 25 minutos de AFV por día, para mejorar la masa ósea y la geometría de cadera (Sardinha et al., 2008); mientras que más de 28 minutos de AFV por día, parece asociarse a una mayor DMO en el cuello femoral en los adolescentes (Gracia-Marco, Moreno, et al., 2011).

Sin embargo, otros han sugerido que la asociación entre AFV y las variables óseas está mediada por otros factores. El estudio de Janz et al. (2004) en niños, demostró que la AFV explicó el 6,9% de la variabilidad en las variables relacionadas con la geometría de cadera. Sin embargo, la asociación se debilitó al 3,7% una vez que la masa muscular se añadió en el modelo de regresión. También en otra investigación realizada en niños y niñas de 8 a 15 años de edad, se observó que la asociación entre AF y la masa ósea del cuello femoral, desapareció después de ajustar por masa muscular (Forwood et al., 2006). En nuestros resultados, la AFV medida objetivamente, no parece explicar las asociaciones de la condición física (muscular y cardiorrespiratoria) con la DMO y la geometría de cadera.

La AFV se ha relacionado con la condición física muscular (Leppänen et al., 2016), y la condición física cardiorrespiratoria (Gutin, Yin, Humphries, & Barbeau, 2005), demostrando estar más relacionada que la AFM. En nuestro estudio, la AFV se correlacionó sólo con la condición física cardiorrespiratoria, pero no con la condición física muscular. Un estudio realizado por Gracia-Marco, Vicente-Rodríguez, et al. (2011) en adolescentes, demostró que para el mismo nivel de condición física (muscular y cardiorrespiratorio), aquellos que cumplían con las recomendaciones de AF tenían mayor CMO que sus compañeros inactivos; y, para un mismo nivel de AF, aquellos con mayor condición física tenían mayor CMO, que aquellos con menor condición física. Estos hallazgos, podrían ser parcialmente extrapolados a nuestros resultados, donde encontramos asociaciones positivas entre la condición física (muscular y cardiorrespiratoria) y los resultados óseos (CMO y variables de geometría de cadera).

No obstante, en nuestros estudios el tiempo empleado en AFV, no desempeñó ningún papel significativo en relación con la masa ósea, ni la geometría de cadera. Nuestros participantes superaron las recomendaciones actuales de AF de 60 minutos de AFMV al día (media ± DE: 101.3 ± 33.8 min). Sin embargo, el valor medio de AFV al día fue tan solo de 16,4 ± 10,4 min. Estos valores de AFV, están por debajo de los recomendados por estudios previos para aumentar variables de masa ósea y geometría (>25 min/día en niños y >28 min/día en adolescentes), lo cual podría explicar el rol no significativo de la AFV en nuestro estudio. Es importante considerar estos resultados con cautela, ya que es probable que la AFV esté subestimada, especialmente en los adolescentes que participaban en deportes de bajo impacto, limitación común en los estudios que utilizan acelerómetros.

5.2.5. Asociación entre las superficies deportivas y la masa ósea

El principal hallazgo de nuestro **estudio 5** fue que una superficie de juego dura, con menos deformación vertical y absorción de impactos, y una mayor energía de restitución, se asocia con niveles más altos de masa ósea en niñas, independientemente del deporte que practiquen.

La afinidad entre el jugador y la superficie de juego es importante para el rendimiento y la salud del mismo. La mayoría de las investigaciones con superficies deportivas, se han centrado en estudiar la influencia del pavimento en la incidencia de lesiones (Hershman et al., 2012; Iacovelli et al., 2013) y el rendimiento (Hughes et al., 2013; Sánchez-Sánchez et al., 2014) en superficies de exterior. Sin embargo, la asociación de diferentes superficies de juego de interior y exterior con la DMO y el CMO, todavía no ha sido estudiada.

En este sentido, nuestro estudio es el primero que analiza la asociación entre las propiedades mecánicas de la superficie de juego y la masa ósea en niñas. En un estudio previo de Plaza-Carmona et al. (2014) realizado en superficies de exterior con niños futbolistas, no se mostraron diferencias significativas en el desarrollo óseo entre la práctica de fútbol en tierra y en césped artificial. El principal hallazgo de nuestro estudio, fue la asociación significativa entre la superficie de juego y la masa ósea en las niñas puberales. Sin embargo, no se encontraron diferencias significativas en las niñas prepúberes, probablemente debido a que la mayoría de los cambios significativos en la masa ósea tienen lugar durante la pubertad (Maïmoun et al., 2013).

En nuestro estudio, en la comparación entre superficies dentro del mismo deporte, la práctica de fútbol en una superficie más dura, como la tierra, se asocia con mayores niveles de CMO y DMO en la cadera, respecto a una superficie más blanda, como el césped artificial. En baloncesto, su práctica en la superficie sintética se asocia con mayor CMO en las piernas y en la región intertrocantérica, respecto a su práctica en parquet.

Por último, los jugadores de balonmano que entrenan en hormigón, tienen mayor CMO y DMO en la cadera, que los jugadores que entrenan en superficie sintética. Esto puede deberse al impacto que sufren los huesos, y a las cargas mecánicas producidas durante la práctica deportiva, ya que juegan un papel importante en el modelado y remodelado óseo, resultando en un aumento del CMO y la DMO (Wolff, Van Croonenborg, Kemper, Kostense, & Twisk, 1999). Por ello, una superficie más dura (menor deformación vertical y absorción de impactos, y mayor energía de restitución) como la tierra, la superficie sintética y el hormigón, respecto a una superficie más blanda (mayor deformación vertical y absorción de impactos, y menor energía de restitución) como el césped artificial, el parquet y la superficie sintética, respectivamente, proporciona un mayor estímulo osteogénico.

Los resultados del presente estudio van en la línea con una investigación de Creighton et al. (2001) en mujeres jóvenes, donde concluye que las atletas que practican baloncesto y voleibol (fuerza de impacto alta), tienen una mayor DMO que las que realizan fútbol y carrera (fuerza de impacto media). Esta categorización no la realizaron midiendo directamente sus propiedades mecánicas, como en nuestro estudio, sino basándose en estudios anteriores que analizan las fuerzas de reacción de las superficies de diferentes deportes (Cavanagh & Lafortune, 1980; Steele & Milburn, 1987; Wielki & Dangre, 1985).

Capítulo 6

Conclusiones y Aportaciones Principales de la Tesis Doctoral [Conclusions and Main Contributions of the Doctoral Thesis]

6.1. CONCLUSIONES

A continuación, se enumeran las conclusiones de cada estudio de la presente Tesis Doctoral:

Estudio 1. Las niñas que practican deporte regular de alto impacto (fútbol, baloncesto y balonmano) y de bajo impacto (natación) tienen menor masa grasa y mayor masa muscular, en comparación con aquellas que no practican deporte durante la etapa prepuberal y puberal.

Estudio 2. Las niñas que practican deportes de alto impacto (fútbol, baloncesto y balonmano) tienen una mayor masa ósea, frente a niñas que practican deportes de bajo impacto (natación) y aquellas que no practican deporte.

Estudio 3. Durante la pubertad, la masa ósea de las niñas está relacionada con la masa muscular, la condición física cardiorrespiratoria y las horas semanales de práctica deportiva.

Estudio 4. La AFV no parece explicar la asociación entre la condición física (cardiorrespiratoria y muscular) y los parámetros óseos (DMO y geometría de cadera), mientras que la masa muscular juega un papel clave en la asociación entre la condición física muscular y los parámetros óseos en jóvenes varones.

Estudio 5. Una superficie de juego dura, con menos deformación vertical y absorción de impactos, y una mayor energía de restitución, se asocia con niveles más altos de CMO y DMO en niñas, independientemente del deporte que practiquen.

6.1. CONCLUSIONS

The conclusions of the present Doctoral Thesis are shown below:

Study 1. Pre-pubertal and pubertal girls engaged in both high impact (football, basketball and handball) and low impact sports (swimming) have lower fat mass and higher lean mass, compared to their inactive peers.

Study 2. Pubertal girls who practice high impact sports (football, basketball and handball) have higher bone mass, compared to those practicing low impact sports (swimming) and the inactive controls.

Study 3. During puberty, bone mass in girls is related to lean mass, cardiorespiratory fitness and weekly hours of sports practice.

Study 4. Vigorous physical activity does not seem to explain the association between fitness (cardiorespiratory and muscular) and bone parameters (bone mineral density and hip geometry), while lean mass plays a key role in this association in young males.

Study 5. A hard playing surface characterised by a low vertical deformation, low force reduction and high energy return is associated with higher levels of bone mass in girls, regardless of the sport they practice.

6.2. APORTACIONES PRINCIPALES DE LA TESIS DOCTORAL

Las aportaciones de esta Tesis Doctoral se detallan a continuación:

Estudio 1. Estos resultados pueden ser útiles para promover la práctica deportiva desde las primeras etapas de la vida, con el fin de prevenir futuras enfermedades. La participación regular en deportes durante la etapa de desarrollo, disminuye el riesgo de obesidad al reducir la masa grasa y el riesgo de sarcopenia al aumentar la masa muscular.

Estudio 2. El desarrollo óseo en las niñas durante la pubertad difiere según el deporte practicado. Los resultados de esta investigación pueden ser útiles para aumentar la adquisición de CMO y DMO durante el crecimiento, así como método de prevención de la osteoporosis en la edad adulta.

Estudio 3. En las niñas es importante un desarrollo adecuado de la masa muscular durante la pubertad, ya que la adquisición de masa ósea está más relacionado con la masa muscular que con la masa grasa. La promoción del ejercicio de alto impacto, intenso y que soporta el propio peso corporal es clave para desarrollar la masa muscular. Además, se debe fomentar en las niñas la práctica de actividad física que mejore su condición cardiorrespiratoria, debido a su asociación positiva con la masa ósea.

Estudio 4. Estos hallazgos contribuyen considerablemente a la evidencia que sugiere, que las asociaciones positivas de la condición física muscular y la masa ósea, son fruto de una mayor masa muscular. Además, es de los primeros estudios en combinar DXA y HSA, ofreciendo una visión más completa de la salud ósea.

Estudio 5. Una nueva perspectiva que propone que, además del tipo de deporte practicado, la superficie deportiva influye en el desarrollo de la masa ósea. Este estudio es el primero que analiza la asociación entre las propiedades mecánicas de la superficie de juego y la masa ósea en niñas. Así pues, se abre una nueva línea de investigación para futuros estudios en población pediátrica.

6.2. MAIN CONTRIBUTIONS OF THE DOCTORAL THESIS

The main contributions of the present Doctoral Thesis are shown below:

Study 1. These results may be useful to further promote sport participation from early life stages in order to prevent future diseases. Regular participation in sports during the developmental stage reduces the risk of obesity by reducing fat mass and the risk of sarcopenia by increasing lean mass.

Study 2. Bone development in girls during puberty differs according to the sport practised. The results of this research may be useful to improve the acquisition of bone mineral content and bone mineral density during growth as well as a strategy to reduce the risk of osteoporosis later in life.

Study 3. In girls, an adequate development of lean mass during puberty is important, as bone acquisition is more strongly related to lean mass than fat mass. The promotion of high impact, intense and weight bearing exercise is key in order to develop lean mass. In addition, girls must be encouraged to engage in physical activities that improve their cardiorespiratory fitness due to its positive association with bone mass.

Study 4. These findings significantly contribute to previous evidence suggesting that positive associations between muscular fitness and bone mass are a factor of lean mass. In addition, this is one of the first studies combining DXA and HSA in active boys offering an overall picture of bone health.

Study 5. A new perspective proposing that the sport surface influences the development of bone mass, in addition to the sport practised. This is the first study in girls analysing the association between the mechanical properties of the playing surface and bone mass. This study opens a new line of research for future studies in paediatric population.

Capítulo 7

Limitaciones y Futuras Líneas de Investigación [Limitations and Future Research]

LIMITACIONES Y FUTURAS LÍNEAS DE INVESTIGACIÓN

Estudio 1, 2, 3 y 5. Hay una serie de limitaciones que deben ser mencionadas. En primer lugar, no se recogieron datos sobre los hábitos alimenticios (por ejemplo, la ingesta de calcio), los cuáles pueden haber influido en algunos estudios. En segundo lugar, los marcadores bioquímicos de la sangre no se midieron, pudiendo haber proporcionado información adicional y útil sobre el proceso de mineralización ósea en poblaciones jóvenes. Finalmente, el $VO_{2máx}$ se estimó indirectamente, sin embargo, esto se ha realizado en numerosos estudios previos, considerándose un método válido. Asimismo, sería de gran interés analizar la asociación entre un mayor número de deportes y la composición corporal, porque hoy en día hay una amplia gama de actividades deportivas. Además, estos estudios se realizan exclusivamente en niñas, pero también se pueden replicar en niños y observar si las diferencias observadas permanecen o no. Esto es importante, ya que el número de hombres con osteopenia y osteoporosis está aumentando continuamente.

Estudio 4. La maduración sexual no se utilizó como covariable en nuestros análisis. Sin embargo, los análisis preliminares mostraron que la edad estaba más fuertemente asociada con las variables óseas y, por lo tanto, se utilizó en su lugar. Además, la metodología del acelerómetro que utilizamos para cuantificar la AFV, no detectó ninguna asociación con los resultados óseos. Los acelerómetros sólo registran las aceleraciones y, por lo tanto, podemos subestimar la intensidad de las actividades, donde los sujetos no soportan su propia carga corporal (por ejemplo, natación y ciclismo). Por ello, se necesitan más investigaciones para entender mejor cómo obtener datos más precisos en estos escenarios, utilizando la acelerometría.

Finalmente, los datos utilizados para estos análisis son transversales no pudiendo establecer relaciones causa-efecto, por lo que es importante desarrollar estudios longitudinales. Además, sería interesante analizar con más detalle la microarquitectura ósea mediante el uso de dispositivos tridimensionales, por ejemplo, con la tomografía computarizada cuantitativa periférica. Esto permitiría observar cambios que pueden ser imperceptibles con técnicas bidimensionales, como las que se utilizan en la presente Tesis Doctoral.

LIMITATIONS AND FUTURE RESEARCH

Studies 1, 2, 3 and 5. There are a number of limitations that have to be mentioned. Firstly, data on dietary habits (e.g. calcium intake) were not collected and these may have influenced some observations. Secondly, blood biochemical markers were not measured and they could have provided with additional and useful information about the process of bone mineralization in young populations. Finally, VO_{2max} was indirectly estimated. However, this has been performed in numerous previous studies and it has been considered a valid method. It would be of great interest to analyse the association between a greater number of sports and body composition, because nowadays there is a wide range of sport activities. In addition, these studies were carrying out exclusively in girls, but one could also replicate these studies in boys and observe whether the observed differences remain or not. This is importance since the number of men with osteopenia and osteoporosis is continuously rising.

Study 4. Sexual maturation was not used as a covariate in our analyses. However, preliminary analyses showed that age was more strongly associated with bone outcomes and therefore was used instead. In addition, the accelerometer methodology we used to quantify vigorous physical activity did not detect any association with bone outcomes. Accelerometers only record accelerations and therefore we could have underestimated the intensity of activities in which the subjects did not support their own body weight (e.g. swimming and cycling). Future studies should focus on how to obtain more accurate data in these scenarios using accelerometers.

Finally, all studies included in this Doctoral Thesis have a cross-sectional design and therefore we cannot establish cause-effect relationships. Future studies with a longitudinal design are required. In addition, it would be interesting to analyse in more detail the bone microarchitecture by using three-dimensional devices, i.e. peripheral quantitative computed tomography. This would allow observing changes that can be imperceptible with two-dimensional techniques, such as the one used in the present Doctoral Thesis.

Capítulo 8

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ANEXOS [ANNEX]

ANEXO 1. CUESTIONARIO HÁBITOS DE PRÁCTICA DEPORTIVA Y SALUD

UCLM
UNIVERSIDAD DE CASTILLA-LA MANCHA

GRUPO IGOID
Investigación en la Gestión de Organizaciones e Instalaciones Deportivas

Cuestionario

Nombre y apellidos: ____

Edad: ______________ **Código:**______________

1. ¿Cuántos años llevas practicando fútbol/baloncesto/balonmano/natación?
2. ¿Has tenido o tienes alguna lesión muscular u ósea?
3. ¿Has tenido o tienes alguna enfermedad?
4. ¿Cuantos días a la semana entrenas (incluida la competición del fin de semana)? ¿Cuántas horas semanales?
5. ¿Sobre qué superficie deportiva practicas fútbol/baloncesto/balonmano? ¿Cuánto tiempo en cada una de ellas?
6. ¿Practicas o has practicado otro deporte diferente? ¿Cuál? ¿Durante cuánto tiempo?

Anexo 2. Comité de Ética Investigación en España

COMPLEJO HOSPITALARIO UNIVERSITARIO DE ALBACETE

Hnos. Falcó, 37 - 02006 ALBACETE - Telf. 967 59...

REGISTRO GENERAL
15 DIC 2010
ENTRADA Nº | SALIDA Nº
4520

sescam

Albacete, 13de diciembre de 2010

FACULTAD CIENCIAS DEL DEPORTE
LEONOR GALLARDO GUERRERO
Avda Carlos III S/n
45071 TOLEDO

Titulo del Estudio: EFECTOS DE LA PRÁCTICA DEPORTIVA EN DIFERENTES CAMPOS DE CÉSPED ARTIFICIAL SOBRE LA SALUD ÓSEA Y EL DESARROLLO DEL ESQUELETO DE NIÑOS EN CRECIMIENTO. **Investigador Principal:** LEONOR GALLARDO GUERRERO.

El C.E.I.C. del Complejo Hospitalario Universitario de Albacete, en su reunión del día 2 de diciembre de 2010 ha considerando que el mencionado proyecto se ajusta a las normas éticas esenciales utilizadas en este ámbito.

Fdo.: Consuelo Martínez
Unidad de Gestión de la Investigación

INVESTIGACIÓN

Cod. 025051

COMPLEJO HOSPITALARIO DE TOLEDO
HOSPITAL VIRGEN DE LA SALUD
Avda. Barber, 30. 45004. Toledo. Teléfono 925 269200

C.E.I.C. SALIDA
FECHA: 10/06/2015
N.º

sescam

DICTAMEN DEL COMITE ETICO DE INVESTIGACION CLINICA DEL AREA SANITARIA DE TOLEDO

D. Fernando Jiménez Torres, Secretario del Comité Ético de Investigación clínica del "Complejo Hospitalario de Toledo".

CERTIFICA:

Que este Comité, en su reunión del día 27 de mayo de 2015, ha evaluado el Proyecto de Investigación: "INFLUENCIA DE LA SUPERFICIE DE JUEGO EN LA SALUD Y EL RENDIMIENTO DE LA MUJER DEPORTISTA". In. Principal: **Dra. Leonor Gallardo Guerrero.** Facultad Ciencias del Deporte. Toledo. Universidad Castilla-La Mancha, y considera que:

Este CEIC emite Dictamen Favorable para la realización de dicho proyecto.

Lo que firmo en Toledo, 27 de mayo de 2015.

COMPLEJO HOSPITALARIO DE TOLEDO
COMITE ETICO DE INVESTIGACION CLINICA

Fdo: Fernando Jiménez Torres

ANEXO 3. COMITÉS DE ÉTICA INVESTIGACIÓN EN REINO UNIDO

Ethical Review in FP7

Ethics Review Report

for
Central Review

PROPOSAL PROGRAMME	PROPOSAL ID	ACRONYM
FP7-PEOPLE-2013-CIG	618496	PRO-BONE

REVIEW DATE
16 July 2013

---

1. Identification of the issues* raised by the project (panel's assessment)

- Healthy children/adolescents
- Human biological samples (peripheral blood samples)
- Data protection and privacy

* (e.g. the involvement of children, patients, vulnerable people, animals, non-human primates, human interventions and tissues, data protection and privacy, hESC, …)

---

2. Ethical issues

a) Were the **ethical*** aspects of the proposed research well described in relation to its objectives?

☒ Yes ☐ No

The objective of PRO-BONE is to compare the osteogenic (healthy bone formation and development) benefits of different forms of physical activity in male adolescents. This will provide a more comprehensive understanding of bone growth and may underpin new approaches in the prevention of osteoporosis. The objectives of the project therefore do not raise any ethical concerns.

618496_PRO-BONE 1/4

b) Were the **ethical*** aspects of the proposed research well described in relation to its methodology?

☒ Yes ☐ No

A number of cohorts of male children/adolescents will be studied. An intervention in the form of plyometric jump training (designed to replicate impact and weight-bearing physical activity) will be evaluated in one group of research participants, and their physical condition and progress measured against a 'less active' control group. Measurement of 25-dihydroxyvitamin D will be performed in blood samples from the cohorts.

In response to the ethics screening report, the applicant has provided comprehensive responses to all of the issues raised, although a number of issues still need to be addressed.

Human samples: No information is provided on whether the samples will be retained or destroyed at the end of the study period.

Consent: Written information leaflets and consent forms will be provided to potential participants and their parents. Copies of these consent forms and information sheets have been attached to the resubmission, although in certain cases, the language as presented may not be understandable for participants and their families e.g. phraseology such as *"The percentage of whole body fat mass will be calculated using the BodPod", "Cardiorespiratory fitness, lower leg muscle strength jump height will be measured using standard tests"* should be modified.

Indemnity insurance: While evidence of indemnity insurance is provided for the project, it does not cover the entire timeline of the project (Annex 2).

Incidental findings: A policy on incidental findings has not been provided.

Data Protection and Privacy: Data management and security procedures are outlined. The University of Exeter does not have a formal approval process for *"the technical data protection procedures"* but the applicant indicates that the Ethical Approval and application of the Data Protection Act and related University policies *"will help to identify problems"*. Nevertheless, approvals on the secondary use of data must be provided. No information is provided on whether data will be retained or destroyed at the end of the study period.

---

c) Were the **ethical*** aspects of the proposed research well described in relation to the possible implications of its results?

☒ Yes ☐ No

The benefits associated with this research project include early detection of low bone mineral density and the potential for improved bone mineralization development during growth via selected forms of physical activity. As osteoporosis has now been recognized as a disease that is dramatically increasing in both developed countries and emerging economies, this project may have a strong societal impact.

618496_PRO-BONE 2/4

d) Do the applicants clearly indicate how the proposal meets the national legal and ethical requirements of the country where the research will be performed?

☒ Yes ☐ No

Approval from the host institution's research ethics committee is to be sought subsequent to the European Commission's approval of the proposal. However, the national/European ethical/legal frameworks pertaining to the research to be conducted are not presented in sufficient detail.

---

e) Does the applicant include a timeframe for approval of the proposed study by a relevant authority at national level (local ethics committee and/or competent national authority?)

☐ Yes ☒ No

The applicant indicates that ethical approvals will be obtained and submitted prior to the commencement of the research, but no precise timeframe has been given.

---

3. Overall Assessment

a) The proposal adequately identifies and addresses the relevant ethical issues. Specific requirements, if any, are provided in the 'Requirements' section

☒

b) The proposal addresses the ethical issues only in general terms but there are aspects which require substantial clarification. These are highlighted in the 'Requirements' section

☐

c) The proposal fails to identify and to address the relevant ethical issues. A supplementary Ethics Review is recommended.

☐

---

4. Requirements
(Requirements become contractual obligations)

In implementing the following requirements, the analysis and comments made in the sections above must be taken into account. They are considered as an integral part of the requirements.

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1. Copies of ethical approvals by the competent local/national Ethics Committees must be submitted to the European Commission prior to the commencement of the research. These must include ethics approval for the secondary use of data.

2. All the information forms and consent forms must be written in terms that are understandable to the participants. These forms must indicate if destruction or retention of data/human material collected is proposed following the completion of the study.

3. The insurance certificate must be extended to cover the whole study period. A copy of the renewed certificate must be forwarded to the European Commission when available.

4. A policy must be set up to handle any incidental findings. A copy of the policy must be provided to the European Commission.

The progress of compliance with the Requirements should be described in the periodic/final Reports under the Section 3.2.2 ('*Work progress and achievements during the period'* - Guidance Notes on Project Reporting*)*

---

5. Would you recommend an Ethics Audit?

(The Ethics Review Sector of DG RTD will undertake an Ethics Audit of selected project(s) in order to ensure compliance with the contractual requirements detailed above)

☐ **Yes** ☒ **No**

---

6. Recommendations

(Recommendations are suggestions and advice provided to the applicants. Recommendations do not become contractual obligations)

- Full details of what is entailed in the biological and physiological tests to be conducted and samples taken should be provided in the oral presentation during the recruitment phase as best practice.

- Given the involvement of children/adolescents, it is recommended that an Ethics Advisor be involved, particularly in the recruitment phase of the project.

- During the life-time of this project the revised Directive 95/46/EC on Data Protection and Privacy may come into force, and the applicant(s) may need to take this into account to ensure continuing compliance.

618496_PRO-BONE 4/4

UNIVERSITY OF EXETER

College of Life and Environmental Sciences
SPORT AND HEALTH SCIENCES

St. Luke's Campus
University of Exeter
Heavitree Road
Exeter
EX1 2LU
United Kingdom

Certificate of Ethical Approval

Proposal Ref No: 2014/766 (and AM141203-01 and AM151202-04)

Title: PRO-BONE: Effect of a program of short bouts of exercise on bone health in adolescents involved in different sports

Applicants: Dr Luis Gracia-Marco, Prof Craig Williams, Dr Alan Barker, Adrian Taylor, Brad Metcalf, Karen Knapp, Dimitris Vlachopoulos (PhD Student), Kelly Wilkinson (MSc Student), Rob Newman, Tom Murch, Sophie Edwards, Craig Willis, Roberta Burkin, Sam West (UG Students)

The proposal was reviewed by the Sport and Health Sciences Ethics Committee.

Decision: This proposal has been approved until November 2017

Signature: Date: 27/11/2013 (revised 4/11/2015)

Name/Title of Ethics Committee Reviewer: Dr Melvyn Hillsdon

Your attention is drawn to the attached paper which reminds the researcher of information that needs to be observed when Ethics Committee approval is given.

NHS
Health Research Authority

NRES Committee South West - Cornwall & Plymouth
Bristol Research Ethics Committee Centre
Level 3
Block B
Whitefriars
Lewins Mead
Bristol
BS1 2NT

Telephone: 01173421390
Facsimile: 01173420445

08 May 2014

Dr Luis Gracia-Marco
Chief Investigator- Lecturer
University of Exeter
Baring Court
University of Exeter St Luke's Campus
Heavitree Road
EX12LU

Dear Dr Gracia-Marco

Study title:	**PRO-BONE: Effect of a program of short bouts of exercise on bone health in adolescents involved in different sports**
REC reference:	**14/SW/0060**
Protocol number:	**151833**
IRAS project ID:	**151833**

Thank you for your letter of 1st May 2014. I can confirm the REC has received the documents listed below and that these comply with the approval conditions detailed in our letter dated 24 April 2014

Documents received

The documents received were as follows:

Document	*Version*	*Date*
Covering Letter		01 May 2014
Other: My Jump Diary	2	01 May 2014
Other: My jump Diary	2	01 May 2014
Participant Information Sheet: Parent/Guardian - Control Participant	3	01 May 2014
Participant Information Sheet: Parent/Guardian - Sport	3	01 May 2014
Participant Information Sheet: 12-14 years Control Participant	3	01 May 2014
Participant Information Sheet: 12-14 years Sport	3	01 May 2014

Approved documents

The final list of approved documentation for the study is therefore as follows:

Document	*Version*	*Date*
Covering Letter		28 February 2014
Covering Letter		01 May 2014
Evidence of insurance or indemnity		31 January 2014
Investigator CV	LG-M	23 January 2014
Letter from Sponsor		31 January 2014
Other: CV - AB		23 January 2014
Other: CV - CW		23 January 2014
Other: CV - DV		23 January 2020
Other: Ethics Screening Report	2	31 January 2014
Other: Ethics Screening Report	2	31 January 2014
Other: Incidental Findings	2	26 February 2014
Other: Hazard identification/Risk assessment form	1	26 July 2013
Other: Assent Form for 12-14 years	2	26 February 2014
Other: Attendance Register Form Footballers		
Other: My Jump Diary	2	01 May 2014
Other: My jump Diary	2	01 May 2014
Participant Consent Form: Parent/Guardian	2	26 February 2014
Participant Consent Form		
Participant Information Sheet: Parent/Guardian - Control Participant	3	01 May 2014
Participant Information Sheet: Parent/Guardian - Sport	3	01 May 2014
Participant Information Sheet: 12-14 years Control Participant	3	01 May 2014
Participant Information Sheet: 12-14 years Sport	3	01 May 2014
Protocol	2	28 February 2014
REC application	3.5	03 March 2014
Referees or other scientific critique report		31 January 2014

You should ensure that the sponsor has a copy of the final documentation for the study. It is the sponsor's responsibility to ensure that the documentation is made available to R&D offices at all participating sites.

14/SW/0060	**Please quote this number on all correspondence**

Yours sincerely

Miss Georgina Castledine
REC Assistant

E-mail: nrescommittee.southwest-cornwall-plymouth@nhs.net

A Research Ethics Committee established by the Health Research Authority

APÉNDICE [APPENDIX]

Factor de impacto de las revistas y ranking en ISI Journal Citation Reports (JCR) dentro de sus áreas temáticas correspondientes.

[Impact factor of the journals and ranking in ISI Journal Citation Reports (JCR) within their subject categories].

	Revista	***Factor de impacto***
Artículo I.	Journal of Sport and Health Science	1.712 (Q1)
	Ranking in 2014 ISI JCR: 10/43 (Hospitality, Leisure, Sport and Tourism)	
Artículo II.	Journal of Sports Sciences	2.246 (Q1)
	Ranking in 2014 ISI JCR: 19/81 (Sport Sciences)	
Artículo III.	European Journal of Sport Science	1.785 (Q2)
	Ranking in 2015 ISI JCR: 30/82 (Sport Sciences)	
Artículo IV.	European Journal of Sport Science	1.785 (Q2)
	Ranking in 2015 ISI JCR: 30/82 (Sport Sciences)	
Artículo V.	Journal of Sports Science	2.142 (Q2)
	Ranking in 2015 ISI JCR: 22/82 (Sport Sciences)	

En este documento se presenta una Tesis Doctoral donde se han llevado a cabo cinco estudios diferentes que analizan la composición corporal y su relación con la práctica deportiva, la superficie de juego y la condición física en edad pediátrica. Se midieron un total de 321 niños/as (121 niños y 200 niñas) españoles e ingleses con edades comprendidas entre los 9 y 14 años.

Los resultados que se presentan en este documento tienen una clara utilidad para el mundo científico y la sociedad. **En primer lugar**, pueden ser útiles para promover la práctica deportiva desde las primeras etapas de la vida, con el fin de prevenir futuras enfermedades. La participación regular en deportes durante la etapa de desarrollo, disminuye el riesgo de obesidad al reducir la masa grasa y el riesgo de sarcopenia al aumentar la masa muscular.

En segundo lugar, el desarrollo óseo en las niñas durante la pubertad difiere según el deporte practicado. Los resultados de esta investigación pueden ser útiles para aumentar la adquisición de CMO y DMO durante el crecimiento, así como método de prevención de la osteoporosis en la edad adulta.

En tercer lugar, en las niñas es importante un desarrollo adecuado de la masa muscular durante la pubertad, ya dicho desarrollo está más relacionado con la masa ósea que con la masa grasa. La promoción del ejercicio de alto impacto, intenso y que soporta el propio peso corporal es clave para desarrollar la masa muscular. Además, se debe fomentar en las niñas la práctica de actividad física que mejore su condición cardiorrespiratoria, debido a su asociación positiva con la masa ósea.

En cuarto lugar, estos hallazgos contribuyen considerablemente a la evidencia que sugiere, que las asociaciones positivas de la condición física muscular y la masa ósea, son fruto de una mayor masa muscular. Además, es de los primeros estudios en combinar DXA y HSA ofreciendo una visión más completa de la salud ósea.

Por último, se propone una nueva perspectiva que propone que, además del tipo de deporte practicado, la superficie deportiva influye en el desarrollo de la masa ósea. Este estudio es el primero que analiza la asociación entre las propiedades de la superficie de juego y la masa ósea en niñas. Así pues, se abre una nueva línea de investigación para futuros estudios en población pediátrica.

UNIVERSIDAD DE CASTILLA-LA MANCHA

FACTULTAD DE CIENCIAS DEL DEPORTE

DEPARTAMENTO DE ACTIVIDAD FÍSICA Y CIENCIAS DEL DEPORTE

TOLEDO, 2017