

Archivos de medicina del deporte

Órgano de expresión de la Sociedad Española de Medicina del Deporte



ORIGINALES

Ankle Active Range of Motion as an Essential Factor of Footwork Technique in the Prevention of Overuse Injuries in Flamenco Dancers

Allometric scaling for normalizing maximal oxygen uptake in elite rugby union players

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Prevención de accidentes en deportes extremos

Accident prevention in extreme sports

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La práctica de actividad física, así como el deporte de competición, incluyendo el máximo nivel, presenta grandes beneficios para la salud. Sin embargo, estos deportistas también pueden tener un riesgo de lesiones y enfermedades más o menos graves, incluida la muerte súbita del deportista o los accidentes mortales.

Existen algunos deportes de competición donde las lesiones graves que pueden afectar al SNC son relativamente frecuentes entre los que se podría mencionar el fútbol americano, rugby, hockey sobre hielo, boxeo o lucha libre.

Todos estos deportes se encuentran regulados por unas normativas que incluyen reglas de juego, materiales deportivos, protecciones de seguridad de los terrenos de juego o accesorios específicos encaminados a la prevención de lesiones como cascos, protectores bucales, protectores oculares, guantes, muñequeras, coderas, tobilleras o calzados especiales. Además, todos los equipos deben de estar supervisados por un médico que vigilará el estado de salud de los deportistas, controlará las lesiones, la duración de las bajas deportivas y el momento de la reincorporación de los deportistas a entrenamientos y competiciones.

Estos deportes tienen un riesgo de lesiones y accidentes conocido y controlado y las reglas de juego se van modificando para garantizar la seguridad de los deportistas.

Sin embargo, existen otras modalidades deportivas en auge que se agrupan bajo el término de *deportes extremos* o *de aventura* que presentan diferencias importantes con los deportes tradicionales. Entre estos deportes se incluyen modalidades terrestres como snowboard, esquí alpino, escalada deportiva, monopatín, ciclismo de montaña o carreras de ultraresistencia, deportes aéreos como puenting, paracaidismo, ala delta o salto base y deportes acuáticos como buceo, remo en aguas bravas o surf.

Se consideran como deportes de alto riesgo porque se practican en entornos inhóspitos y tienen un nivel de peligrosidad alto por las condiciones en las que se practican. Aunque algunos ya están organizados, la mayoría se llevan a cabo en condiciones ambientales adversas sin ninguna reglamentación ni control médico, a pesar del elevado riesgo de lesiones graves e incluso la muerte.

Para estos deportistas el riesgo supone un desafío físico y mental que se traduce en placer y satisfacción e implica una liberación tanto física como psíquica. Todos estos deportes tienen un impacto social muy importante y el número de participantes está aumentando en los últimos años.

La mayor parte de estas actividades se practican a alta velocidad, altura o temperaturas extremas, lo que supone un peligro real o percibido y requieren un alto nivel de esfuerzo físico, con una sobrecarga de muchos órganos y sistemas. El nivel de concentración de estos deportistas ha de ser máximo ya que un solo error en algunas actividades, que puede ocurrir en centésimas de segundo, puede ser fatal.

La tipología y gravedad de lesiones y accidentes en deportes extremos varía mucho en función del tipo de deporte y de otras muchas circunstancias poco analizadas científicamente hasta estos momentos. Es frecuente que practicando estos deportes se produzcan lesiones leves, aunque el riesgo de lesiones más graves existe. Las fracturas, esguinces o lesiones musculares por caídas, impactos directos... son más frecuentes que practicando deportes tradicionales.

Las lesiones de cabeza y cuello, que con frecuencia se traducen en traumatismos craneoencefálicos (TCE) o lesiones medulares son las más preocupantes por las consecuencias a corto y largo plazo. Si analizamos los estudios existentes, el riesgo de lesiones de cabeza y cuello, así como el % de accidentes mortales es bajo pero, según va

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umentando la participación, las cifras de lesiones graves sufridas al practicar deportes extremos están creciendo en las últimas décadas. Los mecanismos de lesión de todos estos deportes son menos conocidos que los de los deportes tradicionales debido a que no existen registros fiables. Las lesiones se suelen producir por errores humanos en practicantes inexpertos o en expertos extremadamente arriesgados.

Muchos de estos deportistas dependen de patrocinios para ganarse la vida con su deporte y eso tiene mucho que ver con el incremento de riesgos para obtener imágenes impresionantes. Si fuera posible eliminar esto disminuiría el riesgo de accidentes graves.

¿Qué se puede hacer para disminuir el riesgo de accidentes en deportes extremos?

Desde un punto de vista médico todos estos deportes tienen un riesgo de lesiones graves mayor que los deportes tradicionales ya que los deportistas se pueden ver afectados por el calor, el frío, las aguas profundas o las alturas y, aunque existen pocos estudios científicos serios que lo puedan corroborar, se sabe que en muchos de ellos los TCE son más frecuentes que en los deportes tradicionales.

Hasta estos momentos los servicios médicos no han prestado la atención adecuada a todos estos deportes y existen muy pocas investigaciones científicas bien diseñadas sobre las lesiones relacionadas con ellos. Los especialistas en medicina del deporte tienen muy poca formación sobre los riesgos que conlleva la práctica de deportes extremos y de aventuras, aunque en algunos países existe una formación específica. Para poder prestar una buena asistencia hay que conocer los riesgos que tienen estos deportes para la salud de los practicantes.

En el rescate de estos deportistas donde en muchas ocasiones puede peligrar seriamente la salud, el médico que asiste in situ al lesionado debe estar preparado para atender este tipo de acontecimientos.

Los factores que causan lesiones en los deportes extremos dependen de muchas variables y sólo es posible intervenir sobre las controlables. Así, introducir dentro de estos deportes una serie de medidas de seguridad evitaría muchas lesiones y accidentes.

Mientras que en otras modalidades deportivas un accidente o un error puede causar una lesión, en los deportes extremos puede provocar la muerte del deportista.

Para mejorar la prevención de lesiones provocadas por la práctica de estos deportes, los médicos que controlan a estas personas deben de tener un conocimiento sólido de estas modalidades deportivas, el entorno donde se practican, los factores ambientales, los materiales utilizados, la metodología de entrenamiento y otros muchos aspectos como los psicológicos y los posibles mecanismos traumáticos. También es muy importante comprender las motivaciones de estos deportistas y tener una formación específica para poder prestarles asistencia médica individualizada.

Es necesario implementar programas de prevención efectivos para todos estos deportes. Entre las medidas preventivas de accidentes en deportes extremos habría que considerar:

- Reconocimiento médico deportivo obligatorio para todos los que practican deportes extremos evaluando la aptitud de los deportistas para cada deporte específico.
- También es importante mejorar la calidad de evaluación de los riesgos de cada deporte y realizar evaluaciones individuales.
- Controlar la nutrición y suplementos nutricionales en función de las necesidades energéticas de estos deportistas.
- Establecer unas limitaciones de edad para practicar estos deportes.
- Vigilar los síntomas de fatiga y sobreentrenamiento ya que aumentan los riesgos de accidentes.
- Los participantes en deportes extremos deben de tener una preparación física y entrenamiento adecuados.
- Realizar trabajos psicológicos con los obsesionados por la necesidad del riesgo.
- En la estrategia de prevención de accidentes graves o mortales en deportes de riesgo es esencial tener en cuenta la indumentaria así como el uso de equipos de protección como cascos, guantes o protecciones articulares ya que los márgenes de error en todos estos deportes son muy pequeños.
- En los deportes de montaña y nieve es muy importante controlar las variables ambientales (condiciones climáticas) y tenerlas en cuenta a la hora de realizar la planificación.
- Mejorar la difusión a través de las redes sociales de los mecanismos de prevención de lesiones para que los deportistas sean más conscientes del riesgo y de cómo prevenir los accidentes.
- También mejoraría mucho la prevención de accidente y los primeros auxilios el establecimiento de ubicaciones y espacios específicos para practicar las diferentes modalidades de deportes extremos teniendo en cuenta las posibilidades de evacuación y actuación de los servicios médicos.

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Ankle Active Range of Motion as an Essential Factor of Footwork Technique in the Prevention of Overuse Injuries in Flamenco Dancers

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Summary

Flamenco dance is a performing art which is based on footwork technique where the foot and ankle play an important role. The objective of this study was to investigate the effect of ankle active range of motion on external load and its efficacy as a predictor during a flamenco footwork technique, with consideration of accelerometer positions and dance proficiency. Twelve flamenco dancers composed of 6 professional and 6 amateurs participated voluntarily in this study for whom no significant differences were detected regarding age, mass or height. Participants completed a 15-second Zap-3 footwork test at a speed of 160 bpm (beats per minute), 180 bpm and as fast as they could. Triaxial accelerometers were positioned at the dominant ankle, 5th lumbar vertebrae and 7th cervical vertebrae to calculate accumulated PlayerLoad and uniaxial PlayerLoad of the 3 planes (anteroposterior, mediolateral and vertical) for each speed level. Percentage contributions were also calculated. The effect of dorsiflexion on the external load of the dominant ankle of both professional and amateur dancers existed only in the anteroposterior axis while dorsiflexion was related to the external load at the 7th cervical vertebrae and only amateurs were affected. Plantarflexion only affected the uniaxial contribution of the vertical-axis of professional dancers. These programs would be applied to develop a technique feedback system for the flamenco dancer to follow their own model with respect to the ideal. This would allow intervention in the prevention of overuse injuries in flamenco dance artists.

Key words:

Ankle active range of motion. External load. Playerload. Triaxial accelerometer. Overuse injuries.

Rango de movimiento activo del tobillo como factor esencial de la técnica de zapateado en la prevención de lesiones por sobreuso en bailarinas de flamenco

Resumen

El baile flamenco es un arte en el que el zapateado tiene un papel muy relevante. El objetivo de este estudio fue investigar el efecto del rango de movimiento activo del tobillo sobre la carga externa y su eficacia como predictor durante la realización de un zapateado flamenco, en función de las posiciones del acelerómetro y el dominio técnico de los participantes. Un total de doce bailarinas de flamenco, 6 profesionales y 6 amateurs, participaron voluntariamente en este estudio y en los que no se encontraron diferencias significativas respecto a edad, peso o estatura. Los participantes realizaron un test de zapateado denominado Zap-3 durante 15 segundos a una velocidad de 160 pulsos por minuto, 180 y tan rápido como pudieron. Se colocaron acelerómetros triaxiales en el tobillo del pie dominante, en la 5ª vértebra lumbar y en la 7ª vértebra cervical para calcular la PlayerLoad acumulada y la PlayerLoad uniaxial de los 3 planos (anteroposterior, medio-lateral y vertical) en función de cada nivel de velocidad, así como sus contribuciones porcentuales. Solamente se ha encontrado relación entre la flexión dorsal del tobillo dominante y la carga externa en el eje anteroposterior, tanto en profesionales como amateurs, mientras que a nivel de la 7ª vértebra cervical sólo se ha encontrado relación entre la dorsiflexión y la carga externa en el grupo de amateurs. Respecto a la flexión plantar solo se ha encontrado relación a nivel uniaxial con el eje vertical de los bailarinas profesionales. Estos programas podrían servir de ayuda a desarrollar un sistema de retroalimentación de la técnica para que el practicante de baile flamenco pueda seguir su propio modelo respecto al ideal. Esto permitiría intervenir en la prevención de las lesiones por sobreuso en los artistas de baile flamenco.

Palabras clave:

Rango de movimiento activo del tobillo. Carga externa. Carga de jugadores. Acelerómetro triaxial. Lesiones por sobrecarga.

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Introduction

Dance performance is a combination of physical movement and aesthetics, it demands a high level of physical conditioning, excellent artistic, and proficient techniques and dancers are also required to reach a similar demand for training and rehearsal, which could contribute to potential injury risk¹⁻³. Injuries have been reported in various styles of dance⁴⁻⁸, including flamenco dance and a high incidence of injuries is prevalent in the lower limbs, lumbar and cervical vertebrae⁹⁻¹¹. Injuries can have serious consequences for a dancer's career and can impact on their daily life^{12,13}, and result in psychological suffering^{14,15}. Injury can be caused by various factors including demographic characteristics, such as the body mass index, gender, age, and the level of proficiency of dancers⁷. Previous studies have demonstrated that the injury frequency suffered by professional dancers or athletes is greater than student or amateurs^{11,12,16-18}. Furthermore, the correlation between external load and injury risk has been proven in different sports and highlighted the importance of monitoring external workload metrics routinely for reducing injury risks¹⁹⁻²¹.

Previous studies indicated that range of motion (ROM) is an important contributor to dance performance²². Efficient ankle function is fundamental to success in dance and is an important factor in establishing low extremity stability between the leg and the foot²³ and can improve dance performance²⁴. Ankle ROM is related to the injury development²⁵⁻²⁷, and research has suggested that reduced right ankle plantarflexion is a risk factor for injury between injured and non-injured pre-professional dancers²⁸ and hyper ankle plantarflexion is related to increased injury rate^{15,26,29}. Dancers with decreased hip and ankle/foot joint ROM are less prone to developing patellofemoral pain syndrome³⁰.

Research investigating injury risk factors in contemporary dance students demonstrated that limited ankle dorsiflexion during a single-leg squat was significantly associated with the occurrence of substantial lower extremity injury³¹. These injuries may occur due to the aesthetic requirement of dance which require dancers to increase the ROM to sometimes excessive levels and can relate to injury^{26,32}. Ankle ROM could also affect joint stability and static balance performance³³, which could also be a potential injury risk. Currently the majority of research investigating the effect of ROM on dance performance and injury involves ballet or contemporary dancers with some research failing to specify dance genre.

There is a high loading demand of flamenco dancers on the foot and ankle joints¹⁰. The footwork technique requires dancers to use different foot locations to strike the floor and produce a rhythmic and loud sound³⁴, and the huge vibration produced during this time¹¹, the impact of the shoe is transmitted by vibrational waves from the joints of the lower body to the spine, which can trigger pains and overuse injuries⁹. For instance, the Zapateado-3 (Zap-3) flamenco footwork technique, utilized in this study requires striking the floor and quickly alternating the heel and tip of the toes. The heel striking occurs with the foot in dorsiflexion in front of the base of support and toes striking with the foot in plantarflexion by tapping the floor behind the supporting base³⁵. Furthermore, the frequency of this step can reach 11.8 steps for each second³⁴. This requirement of ankle active ROM (AAROM) and frequency for floor tapping may increase external load and reduce body stability.

Consideration of potential factors that may contribute to over-injury risk in dance and specifically the relationship between ankle active ROM and external load is required. The aims of this study were to investigate the effect of AAROM on external load and the efficacy of the AAROM as a predictor of external loading during the flamenco footwork technique with consideration of accelerometer positions and dance proficiency. We hypothesized that the ankle active range of motion significantly affects the external load and its efficacy as a predictor could be proved during a flamenco footwork technique, the effects may show difference between different dance proficiency and body positions.

Material and method

Participants

Twelve flamenco dancers were recruited by asking for volunteers via posters in three flamenco dancing training institutions or performance company. Participants were composed of a professional group (PRO group, 6 participants, age: 38.83 ± 7.96 years; height: 1.67 ± 0.10 m; mass: 63.33 ± 6.38 kg; BMI: 22.79 ± 1.95 kg/m²; flamenco dance experience: 7.67 ± 4.89 years) and an amateur group (AM group, 6 participants, age: 34.50 ± 10.67 years; height: 1.62 ± 0.03 m; mass: 56.17 ± 15.99 kg; BMI: 21.36 ± 6.00 kg/m²; flamenco dance experience: 1.83 ± 1.17 years). Only flamenco dance experience years shows significant difference between groups ($p = 0.09$). The inclusion criteria for the PRO group were that participants were professional flamenco dancers who received paid work for teaching, rehearsing or performing in the flamenco dance field and who primarily considered themselves as a professional flamenco dancer. For the AM group, participants were amateur flamenco dancers who engaged in dance for recreational purposes only and attended flamenco dance training at least 3 hours per week. Participants completed a self-reported questionnaire before the study, and those who under 18 years of age and had a minimum of 1-year flamenco dance experience and/or reported heart disease and/or were pregnant and/or had musculoskeletal injuries in the 6 months preceding the study were excluded. No participants reported they had been diagnosed with either Ehlers-Danlos syndrome, Marfan syndrome, or osteogenesis imperfecta. The dancers provided informed consent in writing before commencing the study. Ethical approval was granted by the Faculty Ethics Committee at Beijing Sport University (2022037H), and the study was conducted in accordance with the Declaration of Helsinki.

General Procedures

Participants were informed regarding the experimental methods and procedures. Firstly, AAROM was measured, and then accelerometer data was recorded during performing the Zap-3 footwork. The order of progress was fixed for each participant. One professional dance teacher who experienced at 12-years flamenco dance teaching demonstrated the Zap-3 footwork technique. Laboratory technicians who have at least 5-year of lab experience and are trained were responsible for data collection.

Ankle active ROM measurement

AAROM were measured prior to the Zap-3 footwork test to prevent any potential warm-up effects. Participants adopted a sitting position with their feet off the ground and legs relaxed with their knee joints flexed at 90°. AAROM was measured for dorsiflexion and plantarflexion using a goniometer (Mitutoyo, Jiangsu, China) by a physiotherapist with 5 years' experience. The angle was measured at the maximum extent^{15,30,36,37} with the measurement axis set to the lateral malleolus. While measuring, the fixed arm was parallel to the lateral aspect of the gastrocnemius and the moving arm was parallel to the lateral aspect of the 5th metatarsal bone³³.

Flamenco zapateado-3 footwork technique

Participants were asked to perform the Zap-3 composed of a sequence of 6 footwork steps with the right and the left foot (figure 1). When one sequence was completed, participants repeated the next sequence with the other foot and then repeated alternately with each foot^{35,38}. Participants were required to start with the dominant foot which was defined as that the foot they would kick a ball with³⁹⁻⁴¹. During the entire footwork movement, participants were required to keep their upper limbs and trunk stable, with maintaining in akimbo, and to perform smooth and coherent movements. The six Zap-3 steps were included and followed in this order: Zapateado de planta (P); Zapateado de Tacón-planta (TP); Zapateado de Tacón (T); Zapateado de Tacón-planta (TP); Zapateado de Punta (PNT); and Zapateado de Tacón-planta (TP).

Subsequently, for the flamenco footwork test, each participant was asked to complete Zap-3 footwork at 3 different speed levels on the same portable flamenco dancing wood floor (92×100 cm), respectively at 160 bpm (beats per minute), 180 bpm, and at their own the fastest speed possible (F speed level) in sequence. The sequence was performed in a dance studio and each speed was completed 3 times for a duration of 15 seconds. At 160 bpm and 180 bpm participants were required to dance while listening to an earphone which was linked to a metronome and had to strike the floor twice on each beat. At the fastest speed level (F), participants were required to perform every footwork step of Zap-3 as quickly as possible and maintain a rhythmic sound^{34,35}. During the test, PRO and AM groups performed the 160 bpm and 180 bpm at the same frequency, 5.33 and 6.00 res-

pectively. At F speed level, dancers tapped at 8.99 ± 0.78 Hz and 7.08 ± 0.50 Hz respectively which demonstrated a significant difference ($P < 0.05$). Participants were able to practice 5 minutes before each section testing commenced and rested for 5 minutes between sessions. Participants were instructed to wear flamenco footwear similar to that worn during training/performance (Figure 1).

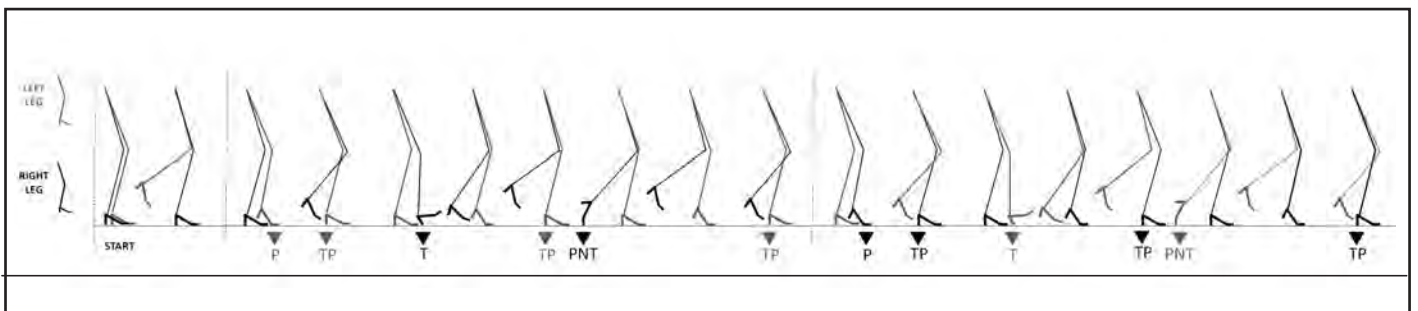
External load measurement during footwork: Playerload

Trigno Avanti™ Sensors (Trigno Wireless EMG System, Delsys, USA), were used to record acceleration data with data sampling at a frequency of 150 Hz and have a built-in nine degree of freedom inertial measurement unit which can relay acceleration, rotation, and earth magnetic field information. The sensors were attached directly to the skin using medical tape and secured using elastic bandage at the position of the 7th cervical vertebrae (C7), 5th lumbar vertebrae (L5), and superior to the lateral malleolus of the dominant ankle (DA). The locations were determined by palpation. Uniaxial PlayerLoad (PLuni) was calculated as the square root of the instantaneous rate of change in acceleration in each of the medial-lateral (PLml), anterior-posterior (PLap) and vertical (PLv) planes divided by 100. Accumulated total PlayerLoad (PLtotal) defined as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three planes and divided by 100 was calculated at C7, L5 and the DA. The uniaxial contributions (PL%) defined as the percentage contribution of the PLuni: medial-lateral (PLml%), anterior-posterior (PLap%) and vertical (PLv%) planes were quantified by dividing the individual PLuni value by PLtotal and by multiplying that value by 100^{42,43}.

Statistical analysis

SPSS statistical software package (SPSS IBM Statistics V21.0) was used for data analysis with descriptive statistics presented as mean \pm standard deviation. The descriptive characteristics of age, height, mass, BMI and flamenco dance experience and the frequency of the F speed level was analysed between PRO group and AM group using a Mann-Whitney U test since the dependent variable was not normally distributed. AAROM differences between PRO group and AM group were analysed with an independent sample t-test. A Pearson correlation coefficient (r) was used to examine the correlation between active

Figure 1. Elaboration of the graphic sequence of the ZAP-3 Test.



plantarflexion and PLtotal, PLuin and PL% respectively, and between active dorsiflexion and PLtotal, PLuin, PL%. Simple linear regression analysis was used to examine the effect of active dorsiflexion and plantarflexion as a predictor of PLtotal, PLuni, PL%. This analysis was performed using only variables that had a significant correlation with active dorsiflexion or plantarflexion. Independence of observations was assessed by Durbin-Watson test. Outliers were checked by casewise diagnostics and a scatterplot was used to assess linearity between AAROM and PLtotal, PLuni, PL%. The scatterplots of standardized residuals against predicted values were used to check for the assumption of homoscedasticity. Normal P-P plots were used to assess the normal distribution. The effect size for r were calculated as follows: 0.90 to 1.00 (-0.90 to -1.00) very high correlation; 0.70 to 0.90 (-0.70 to -0.90) high correlation; 0.50-0.70 (-0.50 to -0.70) moderate correlation; 0.30 to 0.50 (-0.30 to -0.50) low correlation; 0.00-0.30 (0.00 to -0.30) negligible correlation⁴⁴. Statistical significance level was set at $P < 0.05$.

Results

One participant in AM group was considered left foot dominant and the other 11 participants were right foot dominant. For PRO group, dorsiflexion was 15.33 ± 6.44 degrees, Plantarflexion was 50.50 ± 5.61 degrees; for AM group dorsiflexion was 19.50 ± 5.24 degrees, Plantar-

flexion was 50.50 ± 5.61 degrees. Statistical analysis via an independent sample t-test. There was no significant difference between the groups for dorsiflexion or plantarflexion ROM ($P > 0.05$).

The effect of ankle active rom on the external load in the dominant ankle

For the PRO group, Table 1 demonstrates that both DA-PLap at F speed level ($P = 0.041$) and DA-PLap% at 160 bpm ($P = 0.019$) had a high positive correlation with dorsiflexion. DA-PLv% had a very high negative correlation with plantarflexion at the F speed level ($P = 0.001$). For the AM group, table 1 demonstrates, DA-PLap had a very high positive correlation with dorsiflexion at 160 bpm ($P = 0.01$) and high positive correlation at 180 bpm ($P = 0.044$), and F speed level ($P = 0.039$). DA-PLap% had a high positive correlation with dorsiflexion at 160 bpm ($P = 0.035$) and very high positive correlation at 180 bpm ($P = 0.008$) and F speed level ($P = 0.003$). There was no correlation between DA-PL or DA-PL % and plantarflexion in the AM group.

Simple linear regression analysis was performed using only DA-PL or DA-PL% values that had a significant correlation with active dorsiflexion or plantarflexion. For the PRO group, Table 2 demonstrates that DA-PLap at the F speed level and DA-PLap% at 160 bpm were significantly related to dorsiflexion, DA-PLv% at F speed level was significantly related to plantarflexion. For AM group, Table 3 demonstrates that DA-PLap

Table 1. Correlation between AAROM and PLtotal, PLuni, PL% in the dominant ankle (n=12).

		Dorsiflexion (degrees)		Plantarflexion (degrees)	
		Group PRO	Group AM	Group PRO	Group AM
DA-PLtotal au	160	0.357	0.809	0.099	-0.378
	180	0.347	0.71	-0.003	-0.383
	F	0.417	0.684	-0.01	-0.006
DA-PLml au	160	0.177	0.77	0.355	-0.419
	180	0.233	0.74	0.27	-0.413
	F	0.146	0.682	0.171	0.041
DA-PLv au	160	0.478	0.783	-0.227	-0.372
	180	0.36	0.626	-0.238	-0.381
	F	0.505	0.579	-0.17	-0.021
DA-PLap au	160	0.634	0.916*	-0.115	-0.294
	180	0.603	0.824*	-0.232	-0.274
	F	0.829*	0.833*	-0.494	-0.004
DA-PLml%	160	-0.329	0.135	0.804	-0.288
	180	-0.246	0.247	0.79	-0.107
	F	-0.559	0.212	0.54	0.303
DA-PLv %	160	0.083	-0.519	-0.704	0.31
	180	0.024	-0.607	-0.748	0.331
	F	0.578	-0.788	-0.971**	0.012
DA-PLap%	160	0.884*	0.843*	-0.51	-0.241
	180	0.743	0.924**	-0.619	-0.33
	F	0.708	0.958**	-0.737	-0.158

* Correlation is significant at the 0.05 level (2-tailed). $P < 0.05$

** Correlation is significant at the 0.01 level (2-tailed). $P < 0.01$

Ankle active range of motion (AAROM); Total Playerload (PLtotal); uniaxial PlayerLoad (PLuni), uniaxial contribution (PL%); Total Playerload of the dominant ankle (DA-PLtotal); Playerload of the dominant ankle in three planes: medial-lateral planes (DA-PLml), vertical planes (DA-PLv), anterior-posterior planes (DA-PLap); uniaxial contribution of the dominant ankle in the three planes: medial-lateral planes (DA-PLml%), vertical planes (DA-PLv%), anterior-posterior planes (DA-PLap%); the professional group (Group PRO), the amateur group (Group AM). Performed Zap-3 at 160 beats per minute (160), 180 beats per minute (180) and at the fastest speed level (F).

Table 2. Simple linear regression analysis of AAROM of PLuni or PL% in the dominant ankle position of professional dancers (n=6).

AAROM	PLuni/PL%	r and P value	adjusted r ² value	β coefficient
Dorsiflexion	DA-PLap F	0.829 (0.041)	0.609	1.874
	DA-PLap% 160	0.884 (0.019)	0.726	0.45
Plantarflexion	DA-PLv% F	0.971 (0.001)	0.929	-0.224

Ankle active range of motion (AAROM); uniaxial PlayerLoad (PLuni), uniaxial contribution (PL%); Playerload of the dominant ankle in anterior–posterior planes at the fastest speed level (DA-PLap F); uniaxial contribution of the dominant ankle in anterior–posterior planes at 160 beats per minute (DA-PLap% 160) and in vertical planes at the fastest speed level (DA-PLv% F).

at 160 bpm, 180 bpm and F speed level were significantly related to dorsiflexion. DA-PLap% at 160 bpm, 180b pm, and F speed level were significantly related to dorsiflexion.

The effect of ankle active rom on the external load at the 7th cervical vertebrae

For the PRO group, table 4 demonstrates that C7-PLv% had a high positive correlation with plantarflexion at 180 bpm (P = 0.016) and F speed level (P = 0.017). For the AM group, Table 4 demonstrates, C7-PLv (P = 0.029) had a high positive correlation with dorsiflexion at

Table 3. Simple linear regression analysis of AAROM of PLuni or PL% in the dominant ankle position of amateur dancers (n=6).

AAROM	PLuni/PL%	r and P value	adjusted r ² value	β coefficient
Dorsiflexion	DA-PLap 160	0.916 (0.01)	0.798	5.055
	DA-PLap 180	0.824 (0.044)	0.599	5.527
Plantarflexion	DA-PLap F	0.833 (0.039)	0.618	6.877
	DA-PLap% 160	0.843 (0.035)	0.638	0.868
	DA-PLap% 180	0.924 (0.008)	0.818	0.917
	DA-PLap% F	0.958 (0.003)	0.897	0.955

Ankle active range of motion (AAROM); uniaxial PlayerLoad (PLuni), uniaxial contribution (PL%); Playerload of the dominant ankle in anterior–posterior planes at 160 beats per minute (DA-PLap 160), at 180 beats per minute (DA-PLap 180) and the fastest speed level (DA-PLap F); uniaxial contribution of the dominant ankle in anterior–posterior planes at 160 beats per minute (DA-PLap% 160), at 180 beats per minute (DA-PLap% 180) and the fastest speed level (DA-PLap% F).

160 bpm, C7-PLml% (P = 0.048) and C7-PLv% (P = 0.033) had a high positive correlation with dorsiflexion at 180 bpm. C7-PLap% had a high negative correlation with dorsiflexion at 180 bpm (P = 0.019) and F speed level (P = 0.03).

Simple linear regression analysis was performed using only C7-PL or C7-PL% that had a significant correlation with active dorsiflexion or plantarflexion. For PRO group, Table 5 demonstrates that C7-PLv% at

Table 4. Correlation between AAROM and PLtotal, PLuni, PL% in the seventh cervical vertebrae (n=12).

		AAROM Dorsiflexion (degrees)		AAROM Plantarflexion (degrees)	
		Group PRO	Group AM	Group PRO	Group AM
C7-PLtotal au	160	0.394	0.777	-0.023	-0.345
	180	0.289	0.713	0.087	-0.305
	F	0.05	0.654	0.021	0.321
C7-PLml au	160	0.472	0.812	-0.129	-0.365
	180	0.449	0.757	-0.092	-0.304
	F	0.07	0.763	-0.027	0.164
C7-PLv au	160	0.352	0.857*	0.197	-0.186
	180	0.16	0.788	0.452	-0.212
	F	-0.137	0.668	0.476	0.334
C7-PLap au	160	0.206	0.448	0.234	-0.225
	180	0.033	0.351	0.374	-0.325
	F	0.13	-0.083	0.067	0.808
C7-PLml%	160	-0.663	0.779	-0.731	-0.603
	180	0.637	0.816*	-0.728	-0.527
	F	0.182	0.835	-0.318	-0.544
C7-PLv %	160	-0.15	0.347	0.787	0.286
	180	-0.225	0.849*	0.896*	0.041
	F	-0.377	0.351	0.893*	0.462
C7-PLap%	160	-0.495	-0.811	0.792	0.592
	180	-0.445	-0.885*	0.753	0.478
	F	0.256	-0.854*	0.222	0.553

* Correlation is significant at the 0.05 level (2-tailed). P< 0.05

** Correlation is significant at the 0.01 level (2-tailed). P<.001

Ankle active range of motion (AAROM); Total Playerload (PLtotal); uniaxial PlayerLoad (PLuni), PL%(uniaxial contribution); Total Playerload of the seventh cervical vertebra (C7-PLtotal); Playerload of the seventh cervical vertebra in three planes: medial–lateral planes (C7-PLml), vertical planes (C7-PLv), anterior–posterior planes (C7-PLap); uniaxial contribution of the seventh cervical vertebra in the three planes: medial–lateral planes (C7-PLml%), vertical planes (C7-PLv%), anterior–posterior planes (C7-PLap%); the professional group (Group PRO), the amateur group (Group AM). Performed Zap-3 at 160 beats per minute (160), 180 beats per minute (180) and at the fastest speed level (F).

Table 5. Simple linear regression analysis of active plantarflexion of PL% and seventh cervical vertebra of professional dancers (n=6).

AAROM	PL%	r and P value	adjusted r ² value	β coefficient
Plantarflexion	C7-PLv% 180	0.896 (0.016)	0.755	0.637
	C7-PLv% F	0.893 (0.017)	0.746	0.612

Ankle active range of motion (AAROM); uniaxial contribution (PL%); uniaxial contribution of the seventh cervical vertebra in vertical planes at 180 beats per minute (C7-PLv% 180) and the fastest speed level (C7-PLv% F).

Table 6. Simple linear regression analysis of active dorsiflexion of PLuni or PL% and seventh cervical vertebra of amateur dancers (n=6).

AAROM	PLuni/PL%	r and P value	adjusted r ² value	β coefficient
Dorsiflexion	C7-PLv 160	0.857 (0.029)	0.667	0.418
	C7-PLml% 180	0.816 (0.048)	0.582	0.916
	C7-PLv % 180	0.849 (0.033)	0.651	0.334
	C7-PLap% 180	0.885 (0.019)	0.730	-1.261
	C7-PLap% F	0.854 (0.03)	0.662	-1.513

Ankle active range of motion (AAROM); uniaxial PlayerLoad (PLuni); uniaxial contribution (PL%); Playerload of the seventh cervical vertebra in vertical planes at 160 beats per minute (C7-PLv 160); uniaxial contribution of the seventh cervical vertebra in medial-lateral planes at 180 beats per minute (C7-PLml% 180), in vertical planes at 180 beats per minute (C7-PLv % 180), in anterior-posterior planes at 180 beats per minute (C7-PLap% 180) and in anterior-posterior planes at the fastest speed level (C7-PLap% F).

180 bpm and at the F speed level were significantly related to plantarflexion. For the AM group, Table 6 demonstrates that C7-PLv at 160 bpm, C7-PLml% and C7-PLv% at 180 bpm, C7-PLap% at 180 bpm and F speed level were significantly related to dorsiflexion.

The effect of ankle active ROM on the external load at the 5th lumbar vertebrae

There was no correlation between ankle AAROM and external load at L5 (P >0.05).

Discussion

Flamenco dance is characterized by the strong emotion and rhythmic sound made by footwork, which requires dancers to use different positions of the foot, such as heel, toe, ball and whole foot, to strike the floor³⁴. Some steps, such as Zap-3, requires quick alternating heel and toe strikes on the floor and dancers have to make unique adjustments to the ankle joint to fulfil the requirements of this dance style⁴⁵. Therefore, active dorsiflexion and plantarflexion may potentially affect the performance of this technical step⁴⁵. The objectives of this study were to investigate the effect of AAROM on external load and the efficacy of the AAROM as a predictor of external loading during a flamenco footwork technique with consideration of accelerometer positions and dance proficiency.

Regarding the effect of AAROM on external load and the percentage contribution, the results demonstrated dorsiflexion and plantarflexion were associated with PLtotal, PLuni and PL% dependent upon the position of the accelerometer. Dorsiflexion had a positive correlation with DA-PLap, DA- PLap% for both groups, and a negative correlation with C7-PLap% for the AM group. Therefore, during the footwork, a greater active dorsiflexion may produce greater external load in the anteroposterior plane of the DA, but less in the anteroposterior plane of C7. Dorsiflexion had a positive correlation with C7-PLv, C7-PLv% and C7-PLml%, but this correlation between dorsiflexion and PLtotal, PLuni or PL% did not exist in the DA positions in the vertical and mediolateral plane for both groups. Plantarflexion had a negative correlation with DA-PLv% and a positive correlation with C7-PLv %, in the PRO group only which may indicate that greater active plantarflexion may reduce external load on the vertical plane of the DA, but increase external load on the vertical plane of C7. The location of the accelerometer at the L5 position was not influenced by dorsiflexion or plantarflexion. This could potentially be due to L5 been located closer the centre of mass of the body and enhanced stability.

Results suggested AAROM was associated with different values of PLtotal, PLuni and PL% dependent upon the dance proficiency. The demographics of the two groups were similar and the only significant finding was for dance experience. There was no significant difference in the AAROM of the dominant ankle between groups, but the frequency of the F speed level was significantly different with PRO group significantly faster likely due to their professional status. Significant differences between amateur and professional dancers at maximum speed show that the ZAP-3 test is sensitive to the level of technical execution of the dancers. The AM group were only influenced by dorsiflexion with accelerometer position at the DA and C7. In contrast, the PRO group was only influenced by plantarflexion with accelerometer position at C7 and accelerometer position at DA was influenced by both dorsiflexion and plantarflexion. This may be due to differences in training duration, dance experience and dance proficiency, which might equate to greater injury risk due to cumulative load and the increased demands of training and rehearsal. The higher speeds in professionals at the fastest speed level when performing the test may also be a factor as normally professional dancers strike the floor harder to make a louder sound. These two reasons may lead to different mechanisms for completing the footwork technique between groups. The frequency of injuries suffered by professional dancers or athletes is greater than student or amateurs^{11,16-18}. Eileen M. Wanke's group (2018) found a higher asymmetric load in the highest national league group than in the regional or lower groups among latin dancers and they were more often injured⁴⁶.

In flamenco dance, professionals showed greater negative perception about pain and injuries than flamenco dance student¹⁴. In our study although AAROM did not significantly differ between the two groups, the mean dorsiflexion of amateurs was higher than professionals while the plantarflexion of professionals was higher than amateurs, and the external load values demonstrate that amateurs were only affected by dorsiflexion while professionals were affected by both. This may be due to the correlation between ankle stability and ROM⁴⁷ and reduced ankle stability may increase external load. Therefore, it is necessary to

consider if there is any difference between groups in ankle ligament strength and arch height which may be related to ankle stability. Ankle strength is influenced by postural balance in the single-leg quiet stance for athletes⁴⁸ and a lack of strength in the muscles around the joints often limit the active ROM, which may decrease joint stability⁴⁹. Ligament laxity may contribute to the high prevalence of lower limb injuries in dancers⁵⁰. Furthermore, increasing arch height is associated with decreased mediolateral control of single-limb stance⁵¹. Although joint hypermobility and associated ligament laxity is thought to be associated with reduced dynamic balance, postural control, and increased injury risk, it is possible that the required high-level proficiency of dance training may attenuate any potential reductions in dynamic balance⁵².

A high level of ROM is essential for optimal dance performance^{22,24,53}. The changes of ROM associated with adolescent dancers may cause an increase in injury incidence²⁷ and our study only used adult dancers to prevent such issues which would require a different study design with consideration of physical maturity. Dancers with decreased hip and ankle/foot joint ROM are less prone to develop patellofemoral pain syndrome³⁰. Pedersen⁴⁵ investigated AAROM in 23 female flamenco dancers who studied flamenco in intermediate and advanced classes by using the dynamometer. For plantarflexion, the mean ROM was 59.35° and 51.48° for the right and left ankle, and for dorsiflexion, the mean range of motion ROM was 6.57° and 12.87° for the right and left ankle, respectively. In contrast in our study, the plantarflexion DA ROM was lower for both the professional (50.50° ± 5.61°) and amateur (50.00° ± 3.58°) groups and the dorsiflexion ROM was higher (professional: 15.33 ± 6.44°; amateur: 19.50 ± 5.24°). Bejjani⁵⁴ reported that the mean of total ankle AAROM of 10 female flamenco dancers was 85° ± 11°. The values in our study for professional (66.83° ± 5.64°) and amateur (69.5° ± 6.16°) were lower. Castro-Méndez⁵⁵ measured the dorsiflexion of the ankle of professional flamenco dancer with the supine position and knees extended by goniometer (right foot: 11.92° ± 0.38°; left foot: 12.00° ± 0.43°), which was lower than this study. The difference in AAROM between groups may be due to the dance experience and proficiency^{49,56}. The AAROM difference of flamenco dancers between studies may be due to variations in the method of measurement, such as the participant position during measurement.

Two of the ZAP- 3 steps namely the Zapateado de Tacón (T) Zapateado de Punta (PNT) are always performed with the heel striking in dorsiflexion in front of the base of support and with the foot in the plantarflexion position by the toes tapping the floor behind the supporting base. The most mobile element of the locomotor unit is the ankle joint with a 42° entire ROM (plantarflexion through dorsiflexion ROM) during the footwork, however, in everyday activities, the ROM required in the sagittal plane is significantly reduced, with a maximum of 25° for walking³⁵ therefore highlighting the importance of ankle ROM for dance performance. Zap-3 was utilized for this study as firstly it is a representative step of flamenco technique, including the various factors of striking the floor with different parts of the foot, and it has a high choreographic correlation. Occasionally biomechanical research analyzes gestures that have no direct correlation with sports or scenic reality and in our study the authors desired a movement of practical importance. Secondly, some research has already pointed out the risks of overuse injuries for flamenco dancers during Zap-3 footwork tech-

nique and the factors are needed to be explored^{10,34,35,57}. Furthermore, since Zap-3 has been used in recent biomechanical studies and allows standardization for a comparison of results.

Accelerometry was used to quantify external load as it has been widely utilized in the dance research to explore the physiological characterization of latin dance and physical activity levels during dancing^{58,59}. Researchers has also investigated the musculoskeletal demands of dynamic load on flamenco dancers and used accelerometer to record peak frequencies and amplitude at the tibial tuberosity and the anterior superior iliac spine^{54,60}. It was reported that urogenital disorders and back and neck pain may be related to the vibrations generated by flamenco dance form. Different dance genres and their varying demands limit comparison. PlayerLoad has sufficient sensitivity to quantify mechanical load during dance and can be used for injury prevention^{47,50,61} and has the benefit of been portable. Study limitations included the use of only the dominant ankle for ROM measurement and the relatively small sample size. Future studies could consider a larger sample and explore the effect of other dance genres. From an injury perspective the use of prospective injury surveillance would be beneficial to determine how mechanical loading might influence injury prospectively.

Conclusion

Our findings suggest that AAROM has a correlation with the external load at the DA and C7 during flamenco footwork techniques and the effect showed differences according to dancers' proficiency. Therefore, the external load of DA and C7 can be predicted by measuring AAROM of the DA to some extent in professional and amateur dancers. Furthermore, coaches, dancers, and practitioners with an understanding of the biomechanical characteristics of flamenco footwork can provide theoretical advice to develop technical training programs. These programs would be applied to develop a technique feedback system for the flamenco dancer to follow their own model with respect to the ideal. This would allow intervention in the prevention of overuse injuries in flamenco dance artists.

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Conflict of interest

The authors do not declare a conflict of interest.

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Allometric scaling for normalizing maximal oxygen uptake in elite rugby union players

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Summary

Introduction: The relation of a biological variable to body mass is typically characterized by an allometric scaling law. The purpose of this study was to evaluate the relationship between oxygen consumption (VO_{2max}), as a parameter of aerobic exercise performance, and body composition in rugby players.

Material and method: The sample included one hundred and seven males of the Spanish rugby team. Age: 25.1 ± 3.4 years; body mass (BM): 89.8 ± 11.7 kg, height: 182.4 ± 6.5 cm; 52 backs (BR) and 55 forwards (FR). Maximum oxygen consumption (VO_{2max} , $l \cdot min^{-1}$) was measured during treadmill exercise test with progressive workload. Anthropometrical measurements were performed to estimate the fat-free mass (FFM) and muscle mass (MM). The allometric exponent "b" was determined from equation $y = a * x^b$; where "y" is VO_{2max} and "x" is the corresponding mass (BM, FFM or MM) and "a" is one constant.

Results: The VO_{2max} was 4.87 ± 0.56 $l \cdot min^{-1}$, BR vs FR, 4.67 ± 0.48 $l \cdot min^{-1}$ vs 5.06 ± 0.06 $l \cdot min^{-1}$; FFM: 77.5 ± 7.7 kg, 73.5 ± 7 kg vs 81.3 ± 6.3 kg; and MM: 52.9 ± 6.5 kg, 49.6 ± 5.6 kg vs 56.1 ± 5.8 kg. The allometric exponents ($p < 0.0001$; $R^2 = 0.4$) were: 0.58 for BM (95% CI: 0.45 - 0.72); 0.71 for FFM (95% CI: 0.53 - 0.90); and 0.58 for MM (95% CI: 0.43 - 0.73). Significant differences ($p < 0.0001$) were found BR vs FR according to their anthropometric characteristics and VO_{2max} with respect to BM and MM without allometric scaling. While the VO_{2max} indexed by means of allometric scaling was similar between BR and FR.

Conclusions: In comparative studies, the VO_{2max} should be expressed proportional to the 0.58 power of body mass or related to FFM in order to take into account the variability in of body composition in rugby players.

Key words:

Allometric. Body size. Oxygen uptake.
Rugby union. Body composition.
Maximal aerobic capacity. Team sports.

Normalización del consumo de oxígeno máximo por escala alométrica en jugadores de rugby unión de élite

Resumen

Introducción: La relación de una variable biológica con la masa corporal se caracteriza típicamente por una ley de escala alométrica. El propósito del estudio fue evaluar la relación entre el consumo máximo de oxígeno (VO_{2max}), como parámetro de rendimiento aeróbico, y la composición corporal en jugadores de rugby.

Material y método: La muestra incluyó a 107 varones de la selección española de rugby. Edad: $25,1 \pm 3,4$ años; masa corporal (MC): $89,8 \pm 11,7$ kg, talla: $182,4 \pm 6,5$ cm; 52 defensas (DF) y 55 delanteros (DL). El VO_{2max} ($l \cdot min^{-1}$) se determinó en tapiz con carga progresiva hasta el máximo esfuerzo. Mediante técnica antropométrica se estimó la masa libre de grasa (MLG) y la masa muscular (MM). El exponente alométrico "b" se determinó por la ecuación $y = a * x^b$; donde "y" es VO_{2max} , "x" es la masa correspondiente (MC, MLG o MM) y "a" es una constante.

Resultados: El VO_{2max} fue $4,87 \pm 0,56$ $l \cdot min^{-1}$, DF vs DL, $4,67 \pm 0,48$ $l \cdot min^{-1}$ vs $5,06 \pm 0,06$ $l \cdot min^{-1}$; MLG: $77,5 \pm 7,7$ kg, $73,5 \pm 7$ kg vs $81,3 \pm 6,3$ kg; y MM: $52,9 \pm 6,5$ kg, $49,6 \pm 5,6$ kg vs $56,1 \pm 5,8$ kg. Los exponentes alométricos ($p < 0,0001$; $R^2 = 0,4$) fueron: 0,58 para MC (IC 95%: 0,45 - 0,72); 0,71 para MLG (IC del 95%: 0,53 - 0,90); y 0,58 para MM (IC del 95%: 0,43 - 0,73). Se encontraron diferencias significativas ($p < 0,0001$) DF vs DL según sus características antropométricas y VO_{2max} con respecto a BM y MM sin escalado alométrico. Mientras que el VO_{2max} indexado mediante escalado alométrico fue similar entre DF y DL.

Conclusiones: En estudios comparativos el VO_{2max} debería expresarse a la potencia de 0.58 de MC o con MLG debido a la variabilidad de la composición corporal en jugadores de rugby.

Palabras clave:

Alométrico. Tamaño corporal.
Consumo de oxígeno. Rugby unión.
Composición corporal.
Capacidad aeróbica máxima.
Deportes de equipo.

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Introduction

In the evaluation of the physiological variables influencing sports performance, such as maximal oxygen uptake (VO_{2max}), the interpretation may differ depending on whether it is expressed in absolute terms ($l \cdot min^{-1}$) or in comparison to body mass ($ml \cdot kg^{-1} \cdot min^{-1}$). The dependency between a biological variable such as VO_{2max} (y) and body mass (x) can be expressed through allometric scaling in the form $y = a \cdot x^b$, where b is the exponent or power of the scaling. When we express oxygen uptake as $ml \cdot kg^{-1} \cdot min^{-1}$, the exponent "b" is assumed to be equal to 1 with allometric scaling. However, most of the research conducted in this field suggests that "b" is less than 1, somewhere between 0.81 and 0.59 of body mass¹⁻⁴, as the rate at which oxygen uptake increases is less than the rate of increase in body mass. In an extensive sample of Danish athletes covering 25 different athletic activities, Jensen *et al.*, 2001⁵ estimated a power close to 0.73 between body mass and VO_{2max} determined in a maximum stress test. Because of this, depending on the normalization model or scaling we apply, we might have a bias according to the physical characteristics of the subject, potentially making this a factor affecting the comparisons made among individuals and also in longitudinal studies. On the other hand, body mass represents the sum of both fat mass and fat-free mass, in which the latter is the metabolically active one because of its muscular component. Athletes may have the same body mass with different proportions of fat mass and fat-free mass; and also the same VO_{2max} in absolute terms but different in relative value, so comparisons may be equivocal if the effect of these variables is not considered. In a recent review by Lee and Zhang, 2021⁶ they conclude that the most appropriate relationship between VO_{2max} and body weight is the power function and hypothesize that the b-value may not be a static value but a dynamic value ($\geq 2/3$ b < 1); they also suggest that lean weight is better for standardizing VO_{2max} . Regarding this, Lolli *et al.*, 2017 found an exponent of 0.90, with a 95% CI 0.68 to 1.12 by means of a meta-analysis based on fifteen previous fat-free mass studies⁷. The normalization of oxygen uptake in relation to fat-free mass has been called "aerobic muscle quality", indicating that it could be useful to make better comparisons of VO_{2max} among participants of varying fat and body mass^{8,9}.

Rugby is a contact team sport in which, in its 15-player version (rugby union, "RU"), players have quite distinct physical characteristics depending on their position on the field of play. They are divided into two large groups, the forwards (three lines making up the scrum of eight players) and the backs or three-quarters line (seven players). While the forwards are heavier, taller, with more subcutaneous adipose tissue, and require greater power and muscle strength, the backs are lighter, with less fat and need more speed and agility on the field¹⁰⁻¹⁶. Matches last for 80 minutes, divided into two halves with a 15 minute rest, so both groups must have good aerobic capacity. Rugby is an alternating aerobic-anaerobic activity with high demand of repeated-high intensity efforts and frequent collisions. Performance is associated with lower-body strength and power, high speed, high acceleration, and lower percent body fat¹⁷⁻¹⁹. Players can cover an average of 7 km during play; of this distance, 11% high intensity; the backs perform a greater number of sprints than forward. Mean game heart rate is around

88% HR_{max}²⁰. The training and physical preparation of rugby players will be aimed at improving their skills, including strength, by increasing the fat-free mass²¹. Also the contemporary rugby union player runs longer and harder. A relationship has been established between skinfolds and fat percentage to the performance of professional players¹⁶. Their body composition may undergo changes in the course of the season and the player's sporting life²²⁻²⁵. Currently there are few studies in rugby players in which the oxygen uptake values are determined directly by ergoespirometry, being estimation by test or physical tests the usual. On the other hand, the references of body composition are diverse when estimating body fat by different techniques and models^{26,27}.

The aim of this study was to determine the allometric ratio of VO_{2max} to body mass, fat-free mass and muscle mass in high-competition rugby players and to analyse which parameter would better discriminate the changes in performance monitoring.

Material and method

A retrospective study was carried out on the members of the male national rugby teams sent to the Sports Medicine Centre by their federation for a medical and sports examination during the period from 1994 to 2017. First of all, we selected for each player the stress test in which they obtained the highest VO_{2max} ($l \cdot min^{-1}$) in the period mentioned, for a cross-sectional study in order to obtain the reference values. This sample reached a total of 107 players, of whom 55 were forwards (FR) and 52 backs (BR), with a mean age of 25.1 ± 3.4 years, mass 89.8 ± 11.7 kg and height 182.4 ± 6.5 cm. In this group, we determined the allometric exponent for subsequent application to the VO_{2max} values relative to the different masses.

Secondly, for the longitudinal study, we selected the rugby players called up on two or more occasions, choosing for each one the two checks at which they achieved the highest (C1) and the lowest (C2) values for VO_{2max} in absolute figures for the stress test. This sample comprised 17 players, of whom twelve were BR and five FR.

The anthropometric protocol included the following variables: body mass (kg), height (cm), skinfolds (iliac crest, supraspinal, abdominal, subscapular, biceps, triceps, front thigh and medial calf, in mm) and girths of the forearm, middle thigh and maximum leg (cm). The material used was: Seca scales; Holtain stadiometer; Holtain skinfold caliper; and Rosscraft anthropometric tape. The person taking the measurements was accredited to level III by the ISAK (International Society for the Advance of Kinanthropometry), with the measurements being taken according to the recommendations of this society²⁸, except for the measurement of the perimeter of the medial thigh²⁹.

The study of body composition was carried out by the anthropometric technical, with body density being estimated using the equation of Withers *et al.* (1987) and subsequently the percentage of fat using the formula of Siri, (1961) both cited in Norton, 1996³⁰; fat masses (FM) and fat-free masses (FFM) were then derived. Muscle mass (MM) was estimated using the equation of Martin *et al.* (1990)²⁹.

The stress test was carried out on a treadmill (Jaeger, LE 600 C model), using Jaeger Oxycon Champion and Jaeger Oxycon Pro respiratory gas analysers depending on the year of each control. After two minutes

in the initial phase at 6 km/h, the first stage began at 8 km/h. The speed increases were 0.25 km/h every 15 seconds with a constant slope of 1% until exhaustion. The parameters evaluated include: heart rate (HR, bpm), absolute $\text{VO}_{2\text{max}}$ ($\text{l}\cdot\text{min}^{-1}$) and the $\text{VO}_{2\text{max}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) relative to body mass (BM), fat-free mass (FFM) and muscle mass (MM). The aerobic-anaerobic transition was determined from ventilation and gas exchange³¹. The ventilatory threshold 1 (VT1) was defined as the first non-linear increase in ventilation with an equivalent increase in oxygen (VE/VO_2) without any concomitant increase in the equivalent CO_2 (VE/VCO_2). Ventilatory threshold 2 (VT2) was considered to be the second non-linear increase in ventilation with a non-linear increase in the VE/VO_2 ratio and a simultaneous increase in the VE/VCO_2 ratio. The total duration of the test (FT, final time) and the time at which the VT2 was set (ANT, anaerobic threshold time) were considered as the comparative parameters for maximal power and sub-maximal capacity respectively in the longitudinal study as the same protocol was applied in all tests.

The sportsman signed an informed consent form in which they assigned the results of their tests for research purposes on condition of confidentiality for their personal details. The research work was carried out in accordance with the ethical standards of the Helsinki Declaration.

Descriptive statistical treatment (mean, standard deviation and percentiles) was carried out, with the normality of each of the variables being determined by the Shapiro-Wilk test. The difference between the FR and BR in the transversal sample was confirmed using the T test for independent samples or the Mann-Whitney U test in those that did not meet the criteria for normality. In the longitudinal study of the 17 players, Wilcoxon's non-parametric test was used between C1 and C2. Effect sizes can be evaluated using the *r* index and are classed as small (0.10-0.29), medium (0.30-0.49), or large (0.50 and greater)³². $\text{VO}_{2\text{max}}$ values were assessed according to the percentiles established.

The potential curvilinear regression model was developed according to the allometric model, $y = a \cdot x^b$, where absolute $\text{VO}_{2\text{max}}$ was the dependent variable "y"; the different masses (body mass, fat-free mass and muscle mass) were the independent variables "x"; "b" was the exponent

of power, and "a" the proportionality constant, using the Napierian logarithms of these variables for transformation to a linear adjustment. The $\text{VO}_{2\text{max}}$ were subsequently calculated relative to the powers obtained. By means of this correlation, it was possible to study the independence of the new indices with the corresponding masses.

Statistical significance was considered to exist above a *p* value of 0.05. Analyses were conducted using IBM SPSS Statistics version 19.

Results

The allometric exponents calculated in the regression study ($P < 0.0001$; $R^2 = 0.4$) were 0.58 (95% CI: 0.45-0.72) for BM; 0.71 (95% CI: 0.53-0.90) for FFM; and 0.58 (95% CI: 0.43-0.73) for MM. The regression curves are shown in Figure 1. The correlation of the relative $\text{VO}_{2\text{max}}$ calculated using allometric scaling with their corresponding masses turned out to be not significant (*p* between 1 and 0.94) and with an $R^2 = 0.0001$, confirming the independence of the new indices.

Table 1 shows the anthropometric characteristics and the $\text{VO}_{2\text{max}}$ of the entire cohort and grouped by playing positions (FR and BR). Significant differences were found between both groups in all the anthropometric variables, with the FR being heavier, taller, with a higher percentage of fat, fat-free mass and muscle mass than the BR. With respect to the maximal oxygen uptake, there is a significant difference between the two groups when their $\text{VO}_{2\text{max}}$ values are assessed in absolute terms, as well as by BM and MM, but not by FFM. FR players have higher $\text{VO}_{2\text{max}}$ values in absolute terms, whereas in relative terms, the BR have better $\text{VO}_{2\text{max}}$ values compared to BM and MM. When allometric scaling is applied to relative uptakes, the differences between the two groups disappears for BM, FFM and MM, with all of them giving similar values. The effect size in $\text{VO}_{2\text{max}}$ relative to masses using allometric scaling is virtually zero, while the effect size is medium with respect to body mass. The percentiles of $\text{VO}_{2\text{max}}$ obtained with the 107 players in absolute values and with respect to the various masses (BM, FFM and MM) using linear and allometric scaling are shown in Table 2.

Figure 1. Relationships between $\text{VO}_{2\text{max}}$ ($\text{l}\cdot\text{min}^{-1}$) and body mass (kg), fat-free mass (kg) and muscle mass (kg) for 107 male rugby players; $P < 0.0001$.

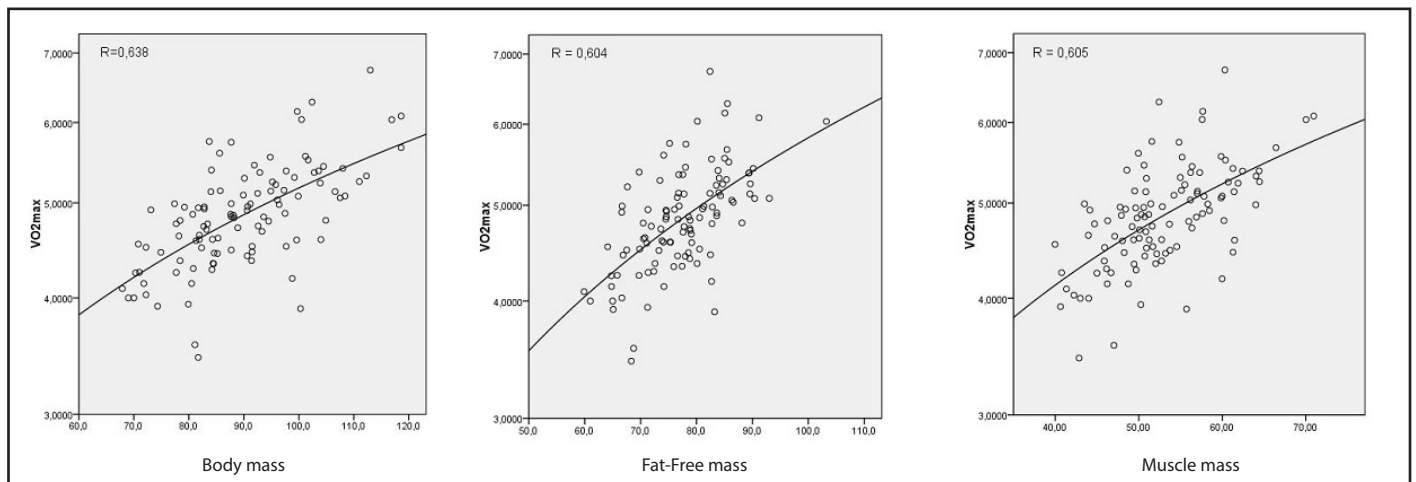


Table 1. Anthropometric and physiological characteristics of rugby union players (mean±SD).

	Total (n = 107)	BR (n = 52)	FR (n = 55)	P	r
Body mass (kg)	89.8±11.7	82.7±8.9	96.6±9.8	0.000	-0.66
Height (cm)	182.4±6.5	180±6.1	184.7±6.2	0.000	0.36
Body fat (%)	13.2±4.9	10.8±3.3	15.5±5.1	0.000	0.48
FFM (kg)	77.5±7.7	73.5±7	81.3±6.3	0.000	0.51
MM (kg)	52.9±6.5	49.6±5.6	56.1±5.8	0.000	0.50
VO _{2max} (l*min ⁻¹)	4.87±0.58	4.67±0.48	5.06±0.6	0.000	0.34
VO₂ isometric scaling					
VO _{2max} . ml*kgBM ⁻¹ *min ⁻¹	54.6±5.7	56.73±4.99	52.55±5.6	0.000	0.37
VO _{2max} . ml*kgFFM ⁻¹ *min ⁻¹	63.0±6.27	63.74±5.59	62.30±6.83	0.236	0.11
VO _{2max} . ml*kgMM ⁻¹ *min ⁻¹	92.58±9.99	94.65±9.12	90.61±10.46	0.036	0.20
VO₂ allometric scaling					
VO _{2max} . ml*kgBM ^{-0.58} *min ⁻¹	352.9±31.7	354.96±28.11	350.87±34.93	0.508	0.06
VO _{2max} . ml*kgFFM ^{-0.71} *min ⁻¹	218.3±20.8	217.53±17.87	218.95±23.36	0.726	0.03
VO _{2max} . ml*kgMM ^{-0.58} *min ⁻¹	486.2±46.1	484.17±40.27	488.14±51.36	0.659	0.04

BM: body mass; Body fat (%) estimated by Withers *et al.* 1987, in Norton, 1996²⁰; FFM: fat-free mass; MM: muscle mass, estimated by Martin *et al.* 1990²⁰, p, significantly different between BR (backs) and FR (forwards). r effect size: small, <30; medium, 0.30–0.49; and large, 0.50 and greater²¹.

Table 2. Percentiles of absolute and relative VO_{2max} for rugby union players (n = 107).

Percentile	VO _{2max}		VO _{2max} relative					
	l*min ⁻¹		BM	BM ^{as}	FFM	FFM ^{as}	MM	MM ^{as}
3	3.90		42.80	277.05	50.98	175.33	73.23	388.69
5	3.96		44.80	304.93	54.24	188.80	76.67	406.13
10	4.14		47.25	317.09	56.04	196.04	82.59	441.07
15	4.28		48.76	323.71	57.07	199.01	83.52	444.15
20	4.40		50.13	329.74	58.12	202.80	84.51	450.90
25	4.48		51.10	334.49	58.75	205.25	85.22	457.95
30	4.56		51.54	336.58	60.13	208.49	86.15	462.68
35	4.61		52.11	342.06	60.28	210.04	87.38	468.31
40	4.72		52.94	345.14	60.94	212.41	88.89	470.65
45	4.80		54.18	350.33	61.24	213.79	90.63	476.36
50	4.86		54.69	353.50	61.96	216.13	92.07	482.74
55	4.92		55.07	355.43	62.84	218.25	93.45	487.98
60	4.98		55.71	358.17	64.42	220.28	93.98	494.51
65	5.06		56.63	360.16	65.00	221.84	95.38	499.00
70	5.13		57.50	366.41	65.56	224.75	96.48	506.19
75	5.23		59.21	373.87	66.33	228.99	98.24	511.64
80	5.33		59.84	375.26	66.86	232.18	101.12	516.91
85	5.41		60.39	381.49	69.37	239.38	103.89	523.99
90	5.57		61.40	389.84	72.52	246.62	106.63	547.39
95	6.04		64.35	417.67	75.48	259.67	111.66	575.59
97	6.13		65.44	420.86	76.94	262.86	113.33	582.82

VO_{2max} relative: BM, body mass: ml * BM⁻¹ * min⁻¹; BM^{as}: ml * BM^{-0.58} * min⁻¹; FFM, fat-free mass: ml * FFM⁻¹ * min⁻¹; FFM^{as}: ml * FFM^{-0.71} * min⁻¹; MM, muscle mass: ml * MM⁻¹ * min⁻¹; MM^{as}: ml * MM^{-0.58} * min⁻¹. Superscript "as": allometry scale. BM, FFM and MM in kg.

Table 3 shows the mean values for the anthropometric and ergospirometric readings of the 17 players selected to take part in the longitudinal study. There are significant differences in BM but not in the percentage of fat, FFM and MM. The VO_{2max} values show differences in both the absolute and the relative values, with or without allometric scaling. The FT and ANT times gave a similar mean in both controls. The effect size is large in BM and in VO_{2max} , confirming the differences mentioned. Table 4 shows the same data individually for each player in the two controls, ranked by larger to lower VO_{2max} ($l \cdot \text{min}^{-1}$) (C1 and C2). Taking a difference of more than or equal to 5% as the criterion, eight players (47%) were found to have changes in their VO_{2max} ($l \cdot \text{min}^{-1}$), of whom five also showed variation with respect to body mass ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). Two players (11.8%) had variations in their VO_{2max} ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) but not in VO_{2max} ($l \cdot \text{min}^{-1}$). Lastly, seven players (41.2%) showed no

change in their VO_{2max} values in either absolute terms nor in relation to their body mass.

If we analyse the trend in the variables of those subjects with the greatest variations in their body composition and/or in the oxygen uptakes, we can examine if there are differences in the valuation made with respect to the established references depending on whether we estimate it with or without an allometric scale. Four of these cases are reviewed below.

Subject n° 1 gained 3.5 kg of body mass, corresponding to an increase in the fat component, and raised the percentage of fat by 2.7; the fat-free and muscle mass components were similar in both controls. In the stress test, he produced a shorter time, achieving a lower VO_{2max} in both absolute terms (a decline of 20 p) and also relative to body mass (a decline of 15 p). If we see the change in VO_{2max} with respect to BM using allometric scaling, he goes from being on the upper limit to a low range (a decline of 70 p), the same as if we value it with respect to MM with or without scaling. As for VO_{2max} with respect to FFM, the valuation ranges from high to low (60-65 p) and from high to medium (55 p), respectively with or without scaling. With respect to the sub-maximal values, the anaerobic threshold represented by VT2 in the 2nd control was reached 1 min sooner, therefore at a lower speed. In this case, there is an unfavourable evolution in his physical condition (an increase in fat mass and lower values for maximal and sub-maximal oxygen uptake), which is discriminated better with allometric scaling or by relating it to FFM.

Subject n° 2 lost 4.1 kg of body mass, all corresponding to the fat component, reduced the percentage of fat by 3.6 and increased the non-fat component by 0.6 kg. In the stress test, the FT was similar and there were no significant changes in the absolute VO_{2max} (it fell by between 5 and 10 p) or with respect to BM without scaling (5 p) or with scaling (equal to p). With respect to the FFM with or without scaling, his values come down in a similar way (10 p), passing from the medium to low range in the valuation of allometric FFM. In comparison with MM, he remained in the low range at both controls, without scaling (5 p) and with scaling (10 p). As for the sub-maximal values, the anaerobic threshold in the second control was reached 1.15 min later, at a higher speed. In other words, the better body composition was only reflected in the stress test in the sub-maximal values, with the most evident changes being in related to FFM and MM.

Subject n° 4 lost 3.2 kg of body mass, of which 1.3 kg corresponded to the fat-free component and 1.9 kg to the fat component, lowering the fat percentage by 2.3. In the stress test he lowered his VO_{2max} in all variables: absolute (25 p) and relative to BM without (20 p) or with scaling (35/40 p); relative to FFM without (30 p) or with scaling, it comes down (40/45 p), and with respect to MM without scaling (10 p) and with scaling (30 p). With respect to the sub-maximal values the anaerobic threshold in the second control was reached at almost the same time, 0.45 min afterwards. In other words, the changes in body composition (both components came down) were associated with lower maximal values in the stress test, all of which were more evident in comparison with FFM and BM using scaling.

In Subject n° 15 the greatest variation in absolute VO_{2max} was obtained during the stress test. He had lost 2.6 kg in mass, with 2.2 kg corresponding to fat mass, lowering the fat percentage by 2. This

Table 3. Longitudinal study of body composition and VO_{2max} (n=17).

		mean	SD	P	r
Body mass kg	C1	90.65	14.88	0.039	-0.50
	C2	88.79	14.62		
Body fat %	C1	12.99	5.01	0.121	-0.39
	C2	11.99	4.80		
FFM kg	C1	78.34	9.60	0.287	-0.26
	C2	77.70	10.21		
MM kg	C1	54.19	9.83	0.068	-0.42
	C2	53.34	9.38		
VO_{2max} $l \cdot \text{min}^{-1}$	C1	4.93	0.54	0.000	-0.88
	C2	4.59	0.51		
VO_{2max} $\text{ml} \cdot \text{kgBM}^{-1} \cdot \text{min}^{-1}$	C1	54.86	4.39	0.010	-0.63
	C2	52.24	5.00		
VO_{2max} $\text{ml} \cdot \text{kgFFM}^{-1} \cdot \text{min}^{-1}$	C1	63.05	3.40	0.003	-0.73
	C2	59.36	4.72		
VO_{2max} $\text{ml} \cdot \text{kgMM}^{-1} \cdot \text{min}^{-1}$	C1	92.16	8.89	0.006	-0.67
	C2	87.21	9.35		
VO_{2max} $\text{ml} \cdot \text{kgBM}^{-0.58} \cdot \text{min}^{-1}$	C1	355.25	18.08	0.001	-0.80
	C2	335.19	22.83		
VO_{2max} $\text{ml} \cdot \text{kgFFM}^{-0.71} \cdot \text{min}^{-1}$	C1	218.97	10.96	0.001	-0.80
	C2	205.50	14.19		
VO_{2max} $\text{ml} \cdot \text{kgMM}^{-0.58} \cdot \text{min}^{-1}$	C1	486.37	26.67	0.001	-0.80
	C2	457.35	33.31		
Final time min	C1	9.60	0.93	0.365	0.19
	C2	9.79	1.12		
VT2 time min	C1	6.76	0.97	0.602	0.07
	C2	6.84	1.01		

The two checks where they achieved the highest (C1) and the lowest (C2) VO_{2max} in absolute values. BM: Body mass; FFM: fat-free mass; MM: muscle mass; VT2: ventilatory threshold 2; p: statistically significant; r: (z/\sqrt{n}); effect size: small, <0.30; medium, 0.30–0.49; and large, 0.50 and greater²¹. % body fat estimated by Withers *et al.* 1987, in Norton 1996³⁰ and MM by Martin *et al.* 1990³².

Table 4. Longitudinal study: individually data for each player in the two controls.

Subjects		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
BM kg	C1	118.6	108	117.6	73.3	74.1	86	104	85.3	88.8	90.7	97.7	71	72.2	83.7	97.8	84	88.2
	C2	122.1	103.9	109.7	70.1	68.9	88.2	98.8	84.3	84.9	92	97.1	73.5	71.8	82.8	95.2	84.2	82.8
Body fat %	C1	23.1	23.2	18	11.2	12.6	10.9	18.4	13.5	10.7	10.6	8.5	7.3	7.7	8.1	12	15.2	9.7
	C2	25.8	19.6	10.1	8.9	11.1	10.1	16.7	12.1	10.6	10.7	8.4	8.6	8.8	8.1	10	15.3	9.9
FFM kg	C1	91.2	82.9	96.4	65.1	64.8	76.6	84.9	73.8	79.3	81.1	89.4	65.8	66.6	76.9	86	71.3	79.7
	C2	90.6	83.5	98.7	63.8	61.3	79.3	82.3	74.1	75.9	82.1	89	67.2	65.5	76.1	85.7	71.4	74.6
MM kg	C1	70.96	64.11	71.28	43.82	44.76	50.01	67.02	50.05	51.41	52.82	62.43	40.76	42.23	49.11	59.27	49.76	51.47
	C2	70.91	61.9	68.27	41.25	42.55	53.25	62.99	50.47	49.81	55.18	61.91	42.03	41.31	47.76	58.38	49.67	48.43
VO _{2max} l*min ⁻¹	C1	6.09	5.37	5.35	4.59	4.12	5.02	5.22	4.61	4.89	4.96	5.38	4.25	4.03	5.18	5.32	4.39	4.98
	C2	5.24	5.23	4.76	4.09	4.01	4.84	4.9	4.42	4.36	4.8	5.23	3.69	3.82	4.95	4.57	4.28	4.93
VO _{2max} BM ml*min ⁻¹ *kg ⁻¹	C1	51.32	49.7	45.47	62.59	55.59	58.38	50.14	54.02	55.09	54.66	55.05	59.87	55.82	61.9	54.36	52.27	56.47
	C2	42.91	50.36	43.38	58.4	58.13	54.82	49.64	52.37	51.38	52.19	53.85	50.26	53.2	59.82	47.97	50.82	59.54
VO _{2max} FFM ml*min ⁻¹ *kg ⁻¹	C1	66.76	64.75	55.45	70.49	63.6	65.54	61.46	62.42	61.67	61.13	60.19	64.6	60.47	67.38	61.79	61.63	62.52
	C2	57.83	62.64	48.24	64.13	65.39	60.99	59.58	59.57	57.45	58.46	58.77	54.99	58.34	65.12	53.32	59.97	66.05
VO _{2max} MM ml*min ⁻¹ *kg ⁻¹	C1	85.78	83.74	75.01	104.71	92.02	100.41	77.82	92.07	95.16	93.86	86.14	104.3	95.43	105.5	89.69	88.25	96.77
	C2	73.88	84.53	69.71	99.26	94.13	90.8	77.85	87.48	87.57	87.01	84.46	88.02	92.47	103.7	78.23	86.16	101.8
VO _{2max} BMas ml*min ⁻¹ *kg ^{0.58}	C1	374.2	348.6	330.4	373.6	333.3	372.4	346.2	343.4	356.1	356.5	370.3	352.7	331.1	390.4	365.8	330.2	364.1
	C2	316.7	347.5	306.2	342.2	338.1	353.4	335.4	331.3	326	342.4	361.3	306	314.8	375.6	319.2	321.3	373.9
VO _{2max} FFMas ml*min ⁻¹ *kg ^{0.71}	C1	242.7	229.1	204.8	232.7	209.7	226.7	218.9	213.6	215.4	214.9	217.5	213.9	201	233.3	220.9	208.8	218.7
	C2	209.8	222.1	179.3	210.5	212.1	213	210.3	204.1	198.2	206.2	212.1	185.3	192.9	224.8	190.4	203.2	226.7
VO _{2max} MMas ml*min ⁻¹ *kg ^{0.58}	C1	511.6	478.6	448.3	510.3	452.5	517.2	453.2	474.4	495.9	494.7	486.9	493.1	458	539.3	496.1	453.6	504.5
	C2	440.5	476.1	409.1	471.6	453.1	480.2	441.7	452.3	450.3	467.1	475.8	423.1	439.7	524	430	442.5	517.4
Final time min	C1	8.30	8.58	8.04	10.05	9.05	11.02	8.01	9.01	10.05	10.57	9.59	10.09	10.54	10.24	10.03	10.03	10.04
	C2	7.02	9.01	9.07	11.47	9.05	11.43	10.02	10.00	10.03	10.29	9.58	9.04	10.03	10.13	11.03	10.05	10.10
VT2 time min	C1	6.45	6.00	5.30	8.00	7.15	8.30	5.45	7.30	7.00	8.45	7.15	6.30	7.00	6.45	7.00	5.15	6.45
	C2	5.45	7.15	5.00	8.45	6.00	7.15	7.15	7.45	7.30	8.15	6.45	6.15	6.30	7.00	8.45	6.45	7.00

Ranked by larger to lower VO_{2max} (l*min⁻¹) (C1 and C2). BM: body mass; % Fat estimated by Withers *et al.* 1987, in Norton 1996³⁰. FFM: fat-free mass; MM: muscle mass by Martin *et al.* 1990²⁹; Final time, duration of the stress test; time at which the VT2 was set (ventilatory threshold 2, anaerobic threshold). Superscript "as", allometry scale.

player achieved lower scores in all the VO_{2max} variables, moving from being in the high to the medium range in absolute terms (50 p), and lowering them in terms of BM without scaling (35) or with scaling (55 p); with regard to FFM, they were lowered without (40 p) or with scaling (50/55), and also for MM without scaling (35 p) and with scaling (50 p). With respect to the sub-maximal values, VT2 at the second control was reached 1.45 min later, at a higher speed. The improvement in body composition was accompanied by a worse stress test in comparison with the maximal values but with an improvement in sub-maximal capacity. The difference between the two controls in terms of the drop in VO_{2max} percentiles was greater with respect to BM and FFM with allometric scaling.

Discussion

In this study, we provide the percentiles of VO_{2max} for use in the assessment of RU players and recommend the use of VO_{2max} relative to fat-free mass or relative to body mass with application of scaling

depending on whether or not a body composition study is performed. The investigation carried out on a large sample of rugby players, who differ in their morphology according to playing position, has shown that when we value oxygen consumption by body weight with a linear scale, it is underestimated in those of greater weight, since if an allometric scale is applied or we assess the oxygen consumption in relation to the fat-free weight, the differences between these players disappear

The classic studies on allometric ratios between oxygen uptake and BM set the value at 0.67 or 0.75³³⁻³⁶. Exponents less than 1 were also found in athletes, indicating that this ratio does not increase in proportion to BM during physical activity. Bergh *et al.* (1991)³ obtained a power of 0.71 in VO_{2max} and 0.76 in VO_{2submax} in endurance athletes. Svedenhag, 1995³⁷ also proposed that, for the correct assessment of runners, the oxygen uptake during a race should be expressed as ml*kg^{-0.75}*min⁻¹. The most wide-ranging study among sports practitioners was carried out by Jensen *et al.*, 2001⁵, and the male group comprised 655 people engaging in 22 different types of sport subjected to stress tests with the corresponding specific ergometers. When the number of practitioners

was large ($n > 100$) as in the case of handball ($n = 142$, $b = 0.72$), cycling ($n = 157$; $b = 0.74$) and rowing ($n = 117$; $b = 0.73$), the allometric power came close to 0.73, so the authors set it at this value for the comparative studies between sports. Among Croatian athletes in different sports, Markovic *et al.*, 2009³⁸ obtained a power of 0.67. The mentioned researches did not include rugby, in which our power was lower (0.58). The potential reason is that rugby players are more robust, with a higher BM, entailing a higher fat and non-fat component than, for instance, among long-distance runners, cyclists or team sports players; on the other hand we consider the number of participants in our sample to be representative.

Secher, 1984³⁹ compared the relative oxygen consumption in rowers of different modalities (heavy and light) and therefore of different body size, with or without an allometric scale ($b = 0.67$), and also found that the differences disappeared with the allometric scale.

Our results are in agreement with von Döbeln⁴⁰ who already in 1957 had demonstrated, that VO_{2max} in 65 young men and women did not scale in direct ratio with body mass and should be expressed relative to FFM (body mass – fat mass), the exponent found to be 0.71 ± 0.082 . On the other hand, Batterham *et al.*² found that FFM models resulted in a larger coefficient of determination and a lower SE of the estimate in predicting VO_{2peak} . Their findings, like ours, suggest that FFM estimates should serve as an indicator of body size; both studies conducted in the general population.

Therefore, we should apply independent indices among sports practitioners with major differences in mass or body composition in order to be able to use them for comparisons. If these are not available, the assessment of the athlete should always be made according to their playing position which, although not taking into account their body composition, is generally similar in terms of general morphological characteristics of mass and height.

An athlete's maximum aerobic power fundamentally depends on age, gender, genetic burden and the level of physical activity. It may be affected by changes in training and/or in body composition. Allometric models have been developed for VO_{2max} that also include other variables apart from FFM such as gender, height or age⁴¹.

In an athlete, it may not be relevant how we express their absolute or relative oxygen uptake value over the course of a season or in successive years unless there are changes in mass or body composition. However, any modification of these parameters will influence their assessment. It has been found that among rugby players there has been an increase in BM in recent years, particularly among FRs, and this has been identified as one of the factors that determine improvement in sporting performance^{25,42,43}.

In the longitudinal study conducted, we have verified that when fat mass is lost and the percentage of body fat comes down, athletes improved their VT2 times. This coincides with the reports published by other authors^{44,45} stating that the fat mass has no effect on VO_{2max} (aerobic power), so an excess of body mass at the expense of the fat component would not imply a lower VO_{2max} , although it might have a negative influence on the sub-maximal aerobic capacity.

The values reported for VO_{2max} are between 53 - 62 $ml \cdot kg^{-1} \cdot min^{-1}$. By playing position, FR are between 58 - 48 $ml \cdot kg^{-1} \cdot min^{-1}$ and BR are between 60 - 55 $ml \cdot kg^{-1} \cdot min^{-1}$ ^{17,46-50}. Our values are within these ranges.

The anthropometric characteristics are also similar to those reported by other authors^{51,17,52,50,53}, with a body mass of between

115-98 kg for FR and between 95-84 kg for BR and a height of between 190-183 cm among FR and between 182-178 cm for BR. When comparing the percentage of fat, attention must be paid to the technique and formula applied. Lundy *et al.*, 2006⁵⁴, in a sample of 74 Australian players, obtained an average estimated fat percentage, starting from different equations, of 11% among BR and 13.5% in the FR, percentages respectively similar to and slightly lower than those in the present study. Also similar to those reported by Carlson *et al.*, 1994⁵⁵ in BR (10%) and FR (13%) for the US team; and, also in the USA, Maud y Shultz, 1984⁵⁶ in BR (7.8%) and FR (10.5%). Similar values were obtained by Brewer *et al.*, 1994⁵⁷ and by Scott *et al.*, 2003⁵⁸ in BF (12.6 and 12.1%) and FR (15.2 and 16.1%) with British subjects, obtained by Durnin-Womersley, 1974. In 36 elite Spanish players, Suarez-Moreno and Nuñez, 2011⁵⁹ obtained by Yuhasz's E. a fat percentage of 12% in BR and 16.4% in FR. In Australia, Zemski *et al.*, 2015¹² used a DXA scanner (Hologic Discovery A, Hologic, Bedford, MA) and obtained 10,7% in BR and 14,2% in FR. La Monica *et al.* (2016)⁵⁰ in USA University students obtained an average of 8.8 vs 12.6% (BE vs FR) using Jackson-Pollock's E. Lastly, Posthumus *et al.*, 2020¹⁶ in 39 players of New Zealand using DXA obtained the greatest fat percentage, 14.8% BR and 17.8% FR.

For rugby players, strength and muscle power are major components in their physical condition. Allometric studies have also been carried out⁶⁰⁻⁶² to assess performance in various tests of the upper body (bench pressing) and the lower body (vertical jumping) with respect to BM, FR and BR, and it was found that the players were better characterized by the normalization using the corresponding power. Moreover, it was useful in the comparisons between those of different body sizes.

The limitations of the study include the errors inherent to the techniques used, mainly in connection with the anthropometric estimation of muscle mass, since three perimeters are involved in the equation applied (forearm, thigh and leg), all involving limbs, and this may under-estimate the calculation as it does not take into account the muscle development at trunk level that occurs in this form of sport. On the other hand, other factors implicated in VO_{2max} , such as central cardiovascular adaptation (cardiac volumes) blood parameters (haemoglobin) have not been assessed.

Among the practical applications of this work is the use of VO_{2max} percentiles provided for the assessment of RU players, advising the use of VO_{2max} relative to fat-free mass or scaled body weight according to assessment of body composition or not. Likewise, the data of fat percentage, lean mass and muscle mass can serve for the control and fixing of the objectives that the athlete can reach according to position and time of the season.

Allometric scaling will be more useful to us to discriminate the changes in the maximum oxygen consumption in relation to the body composition. The increase in VO_{2max} may be due to a greater mass of metabolically active tissue and/or greater ability to extract and use oxygen within the muscle, reflecting the metabolic adaptation. We recommend the use of lean weight to relativize the maximum consumption due to the limitations mentioned in the estimation of muscle mass. In comparative studies among athletes, a higher maximum oxygen uptake relative to lean weight will therefore tell us who has better metabolic adaptation and the changes of this with training.

Conclusion

In all medical controls of athletes, it would be desirable to be able to include most of the variables involved in or affecting performance in order to determine the suitability of the training carried out. Allometric scaling may be useful for distinguishing the variations in aerobic power when body mass is taken into account. An alternative would be to use fat-free mass or lean mass instead of body mass to relativize $\dot{V}O_{2\max}$ since this takes into account biological variability in terms of body composition. The indices established with an allometric scale compensate for the effects of different body sizes and allow for comparative analysis between players.

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Conflict of interest

The authors do not declare a conflict of interest.

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La combinación de calentamiento activo y pasivo como método para incrementar la cantidad de repeticiones de sentadilla profunda

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Resumen

El objetivo del estudio fue determinar si la combinación del calentamiento activo (ejercicio) y pasivo (almohadilla térmica) genera un aumento en la cantidad de repeticiones de sentadilla profunda en comparación a realizar únicamente calentamiento activo. Para el estudio se reclutaron 10 sujetos físicamente activos y aparentemente sanos ($26,2 \pm 5,9$ años de edad). Se realizaron cuatro sesiones con intervalos de tres días por sesión. En la primera sesión se estimó el peso máximo, mediante repetición máxima, en sentadilla profunda (fórmula de Brzycki), la segunda, tercera y cuarta sesión realizaron la mayor cantidad de repeticiones de sentadilla profunda con el 85% de la repetición máxima (al fallo o hasta perder la técnica). Los sujetos fueron asignados de forma aleatoria a una de tres condiciones distintas: calentamiento activo (CA_{ct} , calentamiento tradicional más cinco minutos sentados), calentamiento activo más placebo (CA_{ct+p} , calentamiento tradicional más cinco minutos sentados con almohadilla térmica apagada sobre las piernas) y calentamiento combinado (CC_{om} , calentamiento tradicional más cinco minutos con la almohadilla térmica encendida sobre las piernas). No se hallaron diferencias ($p > 0,05$) entre la condición CA_{ct} ($8,6 \pm 1,8$ rep) y CA_{ct+p} ($8,7 \pm 1,6$ rep) en la cantidad de sentadillas realizadas. Sin embargo, la condición CC_{om} ($11,1 \pm 2,0$ rep; $p = 0,001$; $d = -2,107$) mostró ser más efectiva en comparación a CA_{ct} ($8,6 \pm 1,8$ rep) y CA_{ct+p} ($8,7 \pm 1,6$ rep). La combinación de calentamiento activo y pasivo (ejercicio y con almohadilla térmica) incrementa la cantidad de repeticiones de sentadilla profunda en personas jóvenes físicamente activas.

Palabras clave:

Almohadilla térmica. Tren inferior. Rendimiento físico.

Key words:

Heating pad. Lower body. Physical performance.

The combination of active and passive warm-up as a method to increase the number of deep squat repetitions

Summary

The aim of this study was to determine if the combination of active (exercise) and passive warm-up (thermal blanket) generates an increase in the number of deep squat repetitions compared to only active warm-up. Ten physically active and apparently healthy subjects (26.2 ± 5.9 years of age) were recruited for the study. Four sessions, with three-days intervals were performed. In the first session the maximum weight in deep squat was estimated (Brzycki's formula), the second, third and fourth sessions performed the greatest number of deep squat repetitions with 85% maximum repetition (to exhaustion or even losing the technique). Before each condition, subjects were randomly assigned to one of three different conditions: active warm-up (CA_{ct}) traditional warm-up plus five minutes sitting, active warm-up plus placebo (CA_{ct+p}) traditional warm-up plus five minutes sitting with thermal blanket placed on the legs and combined warm-up (CC_{om}) traditional warm-up plus five minutes with a thermal blanket placed on the legs. No differences ($p > 0.05$) were found between CA_{ct} (8.6 ± 1.8 reps) and CA_{ct+p} (8.7 ± 1.6 reps) conditions in the number of squats performed. However, the CC_{om} condition (11.1 ± 2.0 reps; $p = 0.001$; $d = -2.107$) was more effective compared to CA_{ct} (8.6 ± 1.8 reps) and CA_{ct+p} (8.7 ± 1.6 reps). A combination of active and passive heating (thermal blanket), increases the number of repetitions of deep squats in physically active young people.

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Introducción

En las diversas modalidades de ejercicio físico, así como en los distintos deportes, el calentamiento forma parte fundamental de las sesiones de entrenamiento o competencias, el cual, puede considerarse incluso como una actividad imprescindible al ejercitarse o en la competencia, sin embargo, su efecto sobre el rendimiento físico permanece en controversia¹⁻⁴.

Se le considera calentamiento a cualquier actividad que derive en el incremento de la temperatura corporal, pudiendo realizarse de forma activa y/o pasiva con el objetivo de mejorar la respuesta neuromuscular y disminuir la probabilidad de lesión⁵. El calentamiento activo es aquel que se ocasiona por el ejercicio físico (aeróbico y/o anaeróbico), mientras que el pasivo hace referencia al uso de instrumentos externos para elevar la temperatura corporal (sumersión en agua caliente, aumento de la temperatura ambiental, mangas de compresión, almohadilla térmica, entre otros)⁶.

En la actualidad, es muy recomendable realizar calentamiento activo previo a una práctica deportiva debido a la mejora en el desempeño físico ocasionada por el metabolismo muscular y la velocidad de conducción de las fibras musculares, además de generar una mayor estabilidad emocional, confianza y preparación mental^{4,6,7}. De la misma manera, el calentamiento pasivo ha demostrado ser beneficioso para mejorar el rango articular y para disminuir la probabilidad de lesión^{8,9}.

Se ha demostrado que el incremento de la temperatura corporal, a través de calentamiento pasivo, mejora el rendimiento físico en actividades de corta y larga duración a causa del aumento del metabolismo muscular y la degradación del glucógeno, producción de adenosín trifosfato y fosfocreatina. Además, aumenta la velocidad de conducción de la fibra muscular, es decir, genera un incremento en la potencia muscular, debido a la rápida liberación de calcio por el retículo sarcoplásmico y la hiperpolarización de la membrana como resultado del aumento de la actividad de la bomba sodio-potasio. Otro aspecto que incrementa el rendimiento físico es la relajación muscular, la cual mejora a temperaturas altas (25-37 °C) debido a la eficiencia de los mecanismos de la eliminación del calcio del sarcoplasma, la disociación calcio-troponina y a la separación de los puentes actina-miosina^{10,11}.

En el caso del calentamiento activo, además de los mecanismos antes mencionados, acciona la cinética del consumo de oxígeno debido a un mayor intercambio gaseoso, al cambio en la curva de la oxihemoglobina y a la activación de las enzimas oxidativas. También, mejora la potenciación posterior a la activación, es decir cuando se realiza un trabajo muscular intenso, el ejercicio subsecuente se genera con mayor potencia. Lo anterior como resultado de un aumento de la actividad eléctrica en la médula espinal, aumento de la sensibilidad del calcio en los filamentos de actina y el aumento de las concentraciones de calcio en esas fibras musculares⁴.

Debido a los beneficios en el desempeño físico, ocasionados por el calentamiento, el objetivo de este estudio fue determinar si la combinación del calentamiento activo y pasivo (almohadilla térmica) genera un aumento en la cantidad de repeticiones de sentadilla profunda (85% RM) en comparación a realizar únicamente calentamiento activo.

Material y método

Participantes

Se reclutaron 10 sujetos (5 hombres y 5 mujeres) físicamente activos y aparentemente sanos (edad $26,2 \pm 5,9$ años, peso $70,0 \pm 11,8$ kg, estatura $166,6 \pm 10,9$ cm), con $2,8 \pm 1,4$ años de experiencia realizando el ejercicio de sentadilla profunda. La selección de sujetos se hizo de manera no probabilística, por conveniencia. Todos los participantes fueron informados de manera detallada sobre los objetivos y procedimientos del estudio, haciendo énfasis en los riesgos implicados, lo que quedó establecido en una carta de consentimiento y participación voluntaria firmada por cada uno de ellos. El protocolo de investigación fue desarrollado con apego a los lineamientos para las investigaciones en seres humanos establecidos en la declaración de Helsinki¹².

Procedimiento

Se citó a los sujetos a un centro de acondicionamiento físico en cuatro ocasiones distintas. En la primera sesión se estimó el peso máximo en sentadilla profunda ($75,4 \pm 26,9$ kg) mediante la fórmula propuesta por Brzycki¹³, peso levantado en kg / $(1,0278 - (0,0278 * \text{número de repeticiones}))$. Para este test los sujetos realizaron un calentamiento tradicional enfocado en dos aspectos principales: actividad aeróbica de baja intensidad (15 segundos de movimientos laterales de cabeza, rotación de hombros, rotación de cadera, flexoextensión de rodilla, circunducción de tobillos sostenidos en el aire y trote por tres minutos) y estiramiento muscular dinámico (pectoral mayor, dorsal ancho, isquiosurales, cuádriceps y psoas ilíaco, 15 s cada uno)¹⁴.

Una vez estimado el peso máximo en sentadilla, se asignó de forma aleatoria el orden de las siguientes tres condiciones, las cuales consistían en realizar la mayor cantidad de repeticiones de sentadilla profunda a un 85% de su capacidad máxima estimada en la sesión uno ($64,1 \pm 22,9$ kg) (Figura 1). Cabe mencionar que cada sujeto asistió en el mismo horario (8:30 a 10:30 hrs) con tres días de intervalo entre sesión.

Calentamiento combinado (CC_{om})

Para esta condición, los sujetos realizaron el calentamiento activo de la sesión uno. Posteriormente, se sentaron y se les colocó una almohadilla térmica a 42°C sobre las piernas (GAON Innovación, Estado de México, México) (Figura 2) por un periodo de cinco minutos. La temperatura de la piel, al final de los cinco minutos, fue de $37,4 \pm 1,0$ °C.

Calentamiento activo (CA_{ct})

Los sujetos realizaron el calentamiento activo tradicional de la sesión uno, seguido, se sentaron por un periodo de cinco minutos sin la almohadilla térmica. Finalizando el tiempo que debía permanecer sentado, la temperatura de la piel en la zona de los cuádriceps fue de $32,0 \pm 1,0$ °C. La temperatura de la piel fue obtenida por medio de un termómetro infrarrojo Fluke 68 (Washington, EUA), el cual tiene una resolución de 0.1°C y una precisión de ± 1 °C.

Figura 1. Ejemplo de la ejecución de sentadilla profunda.

Figura 2. Ejemplo de la implementación de almohadilla térmica para la condición CC_{om} y CA_{ct+P} .

Calentamiento activo más placebo (CA_{ct+P})

Para esta condición, los sujetos realizaron el mismo calentamiento activo de la sesión uno. Posterior a eso, se sentaron un tiempo de cinco minutos y se les colocó sobre las piernas la almohadilla térmica desconectada y con la pantalla que controla la temperatura hacia abajo (para que no vieran que estaba apagada). Esta condición se propuso para determinar si el uso de la almohadilla térmica generaba un efecto placebo en el desempeño físico. La temperatura de la piel, al final de los cinco minutos, fue de $32,1 \pm 0,3^{\circ}\text{C}$.

La intensidad del calentamiento activo fue medida de forma subjetiva por medio de la escala de percepción de esfuerzo de Borg (0-10). Los sujetos calificaron el calentamiento como fuerte ($5,3 \pm 1,3$). Finalizado el periodo de sedestación, independientemente de la condición, se les dio la indicación de realizar la mayor cantidad de sentadillas posibles con el 85% del peso máximo. Para todas las sesiones, se informó a los sujetos que no realizaran ejercicio físico en las 24 horas previas, así como no consumir medicamentos, bebidas o alimentos considerados diuréticos.

Análisis estadístico

Se utilizó el paquete estadístico SPSS versión 23 para el análisis de los datos. Se aplicó estadística descriptiva para las variables edad, talla, peso y años de experiencia realizando sentadilla profunda. La prueba de normalidad de Shapiro-Wilk proporcionó una distribución normal de los datos ($p > 0,05$). Se realizó un ANOVA de un factor (condiciones) de muestras relacionadas para comparar la temperatura ambiente, humedad relativa, temperatura de la piel, cantidad de repeticiones realizadas y para la suma del peso levantado (peso por repeticiones) después de un calentamiento con almohadilla térmica encendida, apagada y sin almohadilla térmica.

Resultados

No se encontraron diferencias significativas en la temperatura ambiente (CC_{om} $20,0 \pm 2,3^{\circ}\text{C}$, CA_{ct} $19,2 \pm 5,3^{\circ}\text{C}$, CA_{ct+P} $20,4 \pm 5,5^{\circ}\text{C}$; $p = 0,91$) ni en la humedad relativa (CC_{om} $59,6 \pm 5,9\%$, CA_{ct} $54,0 \pm 5,6\%$, CA_{ct+P} $49,2 \pm 2,8\%$; $p = 0,41$) entre las distintas condiciones. Este resultado indica que los sujetos realizaron las evaluaciones en las mismas condiciones ambientales.

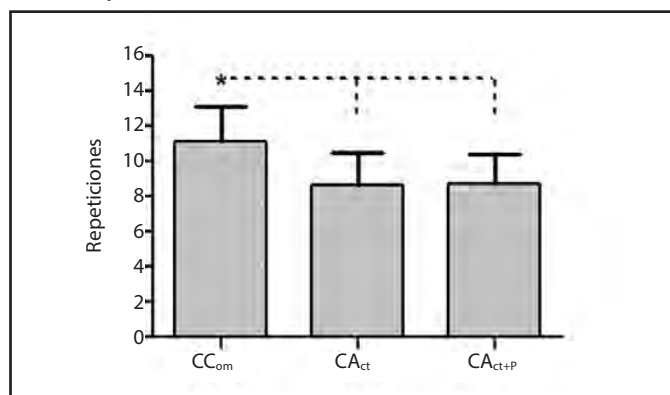
El ANOVA de una vía no mostró diferencias en la temperatura de la piel entre la condición CA_{ct} y CA_{ct+P} ($p > 0,05$). Sin embargo, se encontraron diferencias en la condición CC_{om} comparándola con las otras dos condiciones ($p = 0,001$). Estos resultados indican que la aplicación del calentamiento pasivo generó un aumento en la temperatura de la piel de $5,3^{\circ}\text{C}$ en comparación a las condiciones que no tenían este tipo de calentamiento (Tabla 1).

El análisis de varianza no mostró diferencias significativas ($p > 0,05$; IC95% $-1,294, 1,094$; $d = -0,079$) entre la condición CA_{ct} y CA_{ct+P} en la cantidad de repeticiones realizadas en sentadilla profunda. No obstante, sí se encontraron diferencias ($p = 0,001$; IC95% $-3,182, -1,618$; $d = -2,107$) entre CC_{om} y CA_{ct} y entre CC_{om} y CA_{ct+P} ($p = 0,001$; IC95% $1,407, 3,593$; $d = -2,683$) (Figura 3). Los datos sugieren que con el calentamiento

Tabla 1. Descripción de los datos obtenidos.

	Temperatura de la piel (°C)	Número de repeticiones	Suma del peso levantado (kg)
CC _{om}	37,4±1,1*	11,1±2,0*	681,9±167,5*
CA _{ct}	32,0±1,0	8,6±1,8	445,1±154,5
CA _{ct+P}	32,1±0,3	8,7±1,6	529,7±116,4

*Diferencias significativas en comparación a las otras dos condiciones ($p < 0,001$).

Figura 3. Cantidad de repeticiones realizadas en sentadilla profunda entre las condiciones calentamiento combinado (CC_{om}), calentamiento activo (CA_{ct}) y calentamiento activo más placebo (CA_{ct+P}). * $p = 0,001$ 

combinado (CC_{om}) se generan una mayor cantidad de repeticiones de sentadilla profunda (Tabla 1).

En cuanto a la suma total de peso levantado (peso por repeticiones), no se hallaron diferencias ($p > 0,079$; IC95% -178,329, 8,993; $d = -0,618$) entre la condición CA_{ct} y CA_{ct+P}. Por otra parte, se encontraron diferencias ($p = 0,001$; IC95% 137,497, 336,115; $d = 1,469$) entre CC_{om} y CA_{ct} y entre CC_{om} y CA_{ct+P} ($p = 0,001$; IC95% 91,215, 213,061; $d = 1,055$). Este resultado sugiere que el calentamiento combinado (CC_{om}) es el método más efectivo para levantar una mayor cantidad de peso (Tabla 1).

Discusión

El objetivo de este estudio fue determinar si la combinación del calentamiento activo y pasivo (almohadilla térmica) genera un aumento en la cantidad de repeticiones de sentadilla profunda (85% RM) en comparación a realizar únicamente calentamiento activo. El principal hallazgo fue que con el calentamiento combinado se observó un mayor número de repeticiones de sentadilla en comparación con el calentamiento activo y calentamiento activo con placebo, es decir, el calentamiento combinado genera un mejor desempeño físico en cuanto al número de repeticiones realizadas en sentadilla profunda.

Se ha demostrado que por sí solo el calentamiento pasivo no es suficiente para dirigir el cuerpo hacia un esfuerzo físico extenuante, por lo tanto, es necesario desarrollar un calentamiento activo para que las articulaciones y el tejido muscular se encuentren en óptimas condiciones para esfuerzos mayores.

Por décadas, se ha reportado que uno de los principales resultados del calentamiento es el aumento de la temperatura corporal y muscular. De acuerdo con distintos autores, el incremento de 1°C, en la temperatura muscular, es suficiente para observar mejoras del rendimiento en el ejercicio posterior en un 2-5%^{15,16}, lo cual, también fue observado en este estudio en la condición CC_{om}, donde, aunque no fue medida la temperatura muscular de manera directa, sí se propició su incremento a través de las contracciones musculares del calentamiento activo más el calentamiento pasivo, el cual aumentó 5,3 °C la temperatura de la piel.

El aumento de la temperatura corporal, a causa del calentamiento activo o pasivo, puede generar un aumento del metabolismo muscular, la velocidad de conducción de la fibra muscular y del rendimiento contráctil muscular⁵. Por su parte, McGowan *et al.*⁴, reportaron que el calentamiento activo y pasivo influyen notablemente en el rendimiento posterior a su implementación debido al incremento de adenosín trifosfato (un nucleótido fundamental en la obtención de energía celular), la tasa cíclica de los puentes actina-miosina y la cinética del consumo de oxígeno.

Recientes investigaciones reportan que la combinación entre calentamiento activo y pasivo mejora el rendimiento físico en comparación a cuando se utilizan de forma independiente, esto a pesar de que se utilicen distintos métodos y protocolos de aplicación del calentamiento pasivo. Por ejemplo, en el estudio de Baskaran, Seemathan y Sadhasivam¹⁷, utilizaron lámpara infrarroja para incrementar la temperatura corporal de manera pasiva en sujetos con características similares a las de este estudio; por otra parte, McGawley, Spencer, Olofsson y Andersson¹⁸, desarrollaron su estudio con protocolos de ejercicio a $-7,2 \pm 0,2^{\circ}\text{C}$ implementados con esquiadores alpinos, quienes vistieron una prenda térmica en el tren inferior como método de calentamiento pasivo. No obstante, cuando se habla sobre qué tipo de calentamiento (activo - pasivo) es mejor antes de la práctica deportiva, la evidencia señala el calentamiento activo como el adecuado para la mejora de fuerza, potencia anaeróbica y el rango de movimiento^{19,20}. Aun así, se puede observar una importante cantidad de literatura que indica que el calentamiento, ya sea activo, pasivo o combinado, no es un factor que mejore o deteriore el desempeño físico, lo cual no es consistente con los hallazgos del presente estudio. Ahsan y Mohammad²¹, reportaron que no hubo diferencia en la fuerza muscular en ninguna de las condiciones de calentamiento empleadas en su estudio (activo, pasivo y combinado), lo cual pudo deberse a que la fuerza fue medida mediante un dinamómetro isocinético que valora la fuerza en las extremidades del tren superior cuando su protocolo de calentamiento pasivo fue implementado en el tren inferior (glúteos, isquiotibiales, cuádriceps, gastrocnemius y soleos). Además, el estudio fue de muestras independientes analizando deportistas de voleibol, baloncesto y balonmano, deportes donde la fuerza prensil podría no cobrar la misma relevancia que la fuerza explosiva²²⁻²⁴. Por su parte, Gogte, Srivastav y Balhithilla²⁵, también reportaron no encontrar diferencias en los tres tipos de calentamiento, lo cual pudo deberse a que el calentamiento activo constó de actividades más intensas (ciclismo, prensa de piernas, sentadillas con salto y saltos con sentadilla) a las que comúnmente componen el calentamiento activo (carrera a baja intensidad, por ejemplo). Asimismo, el calentamiento pasivo fue implementado a través de toallas

húmedas en el tren inferior durante 20 minutos, un tiempo largo en el que no se explica si el calor se perdía durante ese tiempo o si era alimentado de alguna forma.

Gray y Nimmo², al igual que los anteriores investigadores, no hallaron diferencias entre el calentamiento activo y pasivo. Este resultado pudo generarse debido a que, en la sesión de calentamiento pasivo, los investigadores introdujeron a los sujetos a un cuarto con clima controlado (45°C-70%) hasta que alcanzaran la misma temperatura corporal obtenida en el calentamiento activo (36,9±0,2°C). No obstante, en el calentamiento pasivo los sujetos permanecieron sentados, sin generar un desgaste físico como en el calentamiento activo. Otra de las limitaciones de los estudios es que no reportan la temperatura muscular, corporal o de la piel después de implementar el calentamiento pasivo²¹⁻²⁵, siendo esta variable un factor importante para la efectividad del calentamiento. A diferencia del calentamiento activo, el pasivo puede aumentar tanto la temperatura corporal como muscular sin la necesidad de perder sustratos energéticos. Se ha documentado que el aumento de 1°C en la temperatura muscular mejora entre un 2 a 5% el desempeño físico⁴. En este estudio los sujetos aumentaron 5,3°C la temperatura de la piel en las piernas con la almohadilla térmica, mejoraron el desempeño físico un 27% con el calentamiento combinado.

Conclusión

Los resultados de este estudio demuestran que la combinación de calentamiento activo y pasivo (almohadilla térmica) aumentan la cantidad de repeticiones realizadas de sentadilla profunda. Sin embargo, para lograr esta mejoría, es necesario que la temperatura de la piel ronde los 37,5°C.

Conflicto de interés

Los autores no declaran conflicto de interés alguno.

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El deporte como condicionante en la elección del tipo de plastia en la reconstrucción del ligamento cruzado anterior. Encuesta epidemiológica y análisis de la situación actual

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Resumen

Objetivos: Conocer la toma de decisiones del cirujano en la elección de la plastia en la cirugía de reconstrucción del ligamento cruzado anterior (LCA) en función al deporte practicado por el paciente.

Material y método: Se realizó una encuesta online, dirigida a través de la Sociedad Española de Traumatología del Deporte (SETRADE) y la European Society for Sports Traumatology, Knee Surgery and Arthroscopy (ESSKA). Se realizó un análisis descriptivo de la muestra, y un análisis del motivo principal de la elección de la plastia estratificando la muestra en distintos grupos.

Resultados: 83 cirujanos respondieron la encuesta, 71 miembros de SETRADE y 12 de ESSKA. La media de plastias realizadas al año por cada encuestado fue de 56 (1-220). Para el 86,7% de los encuestados el deporte influyó a la hora de tomar la decisión del tipo de injerto a utilizar, siendo la principal razón las propiedades biomecánicas de la plastia (49,4%). La coincidencia media en la plastia utilizar en cada deporte estudiado fue del 58,29% (71,1%-38,6%). Las mayores concordancias en la plastia de elección se produjeron en ciclismo, utilizando los encuestados isquiotibiales en el 71,1% de los casos. Los deportes con menos concordancia fueron la lucha y el esquí. No hubo diferencias estadísticamente significativas en la razón para elegir la plastia.

Conclusiones: La encuesta fue realizada por un número significativo de cirujanos con experiencia en plastias del LCA, siendo las propiedades biomecánicas el principal motivo a la hora de elegir el injerto a utilizar. A la mayor parte de ellos les influyó el tipo de deporte practicado en esta decisión. Los autores recomendamos el dominio de al menos 2 plastias para las reconstrucciones primarias del LCA e individualizar cada caso considerando el tipo de deporte en la selección del injerto.

Palabras clave:

Ligamento cruzado anterior.
Reconstrucción. Selección de injerto.
Deporte. Encuesta.

Sport as a conditioning factor in the choice of the type of plasty in anterior cruciate ligament reconstruction. Epidemiological survey and analysis of the current situation

Summary

Objective: To know the surgeon's decision making on the choice of graft in anterior cruciate ligament (ACL) reconstruction surgery according to the sport practiced by the patient.

Material and method: An online survey was conducted through the Spanish Society of Sports Traumatology (SETRADE) and the European Society for Sports Traumatology, Knee Surgery and Arthroscopy (ESSKA). A descriptive analysis of the sample was performed, and an analysis of the main reason for the choice of plasty was carried out stratifying the sample into different groups.

Results: 83 surgeons responded to the survey, 71 members of SETRADE and 12 of ESSKA. The mean number of ACL reconstruction performed per year per respondent was 56 (1-220). For 86.7% of the respondents, sport influenced the decision on the type of graft to be used, the main reason being the biomechanical properties of the plasty (49.4%). The mean agreement in the type of graft to be used in each sport studied was 58.29% (71.1%-38.6%). The highest concordance in the plasty of choice occurred in cycling, with respondents using hamstrings in 71.1% of cases. The sports with the least concordance were wrestling and skiing. There were no statistically significant differences in the reason for choosing plasty.

Conclusions: The survey was conducted by a significant number of surgeons with experience in ACL surgery, with biomechanical properties being the main reason for choosing which graft to use. Most of them were influenced in this decision by the type of sport practiced. The authors recommend the handling of at least 2 plasties for primary ACL reconstructions and to individualize each case considering the type of sport in the selection of the graft.

Key words:

Anterior cruciate ligament.
Reconstruction. Graft selection.
Sport. Survey.

ACCÉSIT premios SEMED a la investigación 2022

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Introducción

La lesión del ligamento cruzado anterior (LCA) de la rodilla es una de las patologías más limitantes para los deportistas en la actualidad¹. La inestabilidad que produce en la rodilla no permite la práctica deportiva en la mayoría de los casos y por ello se requiere una cirugía de reconstrucción de dicho ligamento con un injerto que lo sustituye.

Desde hace más de un siglo, el tipo de reconstrucciones ha ido variando. En primer lugar, se intentó la reparación del LCA, con resultados no favorables, por lo que actualmente no está recomendada en deportistas². Si bien, en la actualidad existen grupos de trabajo que están realizando técnicas de reparación con resultados comparables a las técnicas de reconstrucción³. Aun así, se ha establecido que la reconstrucción es el tratamiento más recomendable hoy en día en deportistas de alto rendimiento.

Disponemos de distintos tipos de injertos para la sustitución del LCA. Dentro de estos tipos, existen distintas clases de injertos, y los factores para elegir uno u otro son múltiples: el tipo de deporte practicado, el nivel y actividad del paciente, la disponibilidad de los mismos, la presencia de lesiones múltiples, la presencia de cirugías previas, la filosofía y experiencia del cirujano, la preferencia del paciente, la estética y las posibilidades económicas^{4,5}. Los principales problemas de estos injertos se relacionan en primer lugar con la zona donante, que es la zona de donde se extraen, siendo el más frecuente el dolor residual⁶.

El éxito de esta cirugía del LCA se basa en la capacidad de conseguir que el paciente vuelva a realizar las actividades tanto deportivas como laborales recuperando el nivel deportivo o laboral previo a su lesión.

El objetivo general del estudio es conocer las indicaciones específicas de cada injerto en nuestro medio en la elección de la plastia para la reconstrucción primaria del LCA en deportistas profesionales en edad madura en función al deporte practicado por los pacientes, los motivos de dicha elección y observar si nuestros resultados se corresponden con las recomendaciones obtenidas en la bibliografía consultada.

Material y método

Se realizó una encuesta online anónima e inédita, compuesta de 5 preguntas: 3 preguntas de elección libre y 2 preguntas de elección obligatoria (Anexo 1). La encuesta fue difundida a través de la Sociedad Española de Traumatología del Deporte (SETRADE) y de la *European Society for Sports Traumatology, Knee Surgery and Arthroscopy* (ESSKA) a todos aquellos traumatólogos españoles y europeos que realizan reconstrucción del LCA en su práctica clínica habitual.

Todas las preguntas hacen referencia al contexto de la rotura completa del LCA en un deportista profesional en edad madura sin antecedentes, lesiones ni cirugías previas.

Primero se recopiló información sobre cantidad de cirugías de reconstrucción del LCA anuales que realizaban anualmente, el número y tipo de plastias que dominaban para dicha reconstrucción, pudiendo elegir entre las más frecuentemente utilizadas (Autoinjerto HTH, IT, QT, aloinjerto, reconstrucción LCA + plastia extraarticular u otra), pudiendo elegir más de una opción.

Posteriormente, se consultó cuál es el principal motivo que tiene el cirujano en cuenta a la hora de elegir la plastia a utilizar (complicaciones

de la zona donante, mayor estabilidad/rigidez de la plastia, osteointegración más rápida, propiedades biomecánicas, tasa de re-rotura, etc) y si tiene en cuenta el tipo de deporte que practica el paciente para elegir entre una plastia y otra.

Finalmente se plantearon distintos escenarios con la intención de ver cómo varían las preferencias en el injerto a utilizar según el deporte y nivel de actividad y necesidades funcionales del paciente: se les solicitó a los participantes que eligieran un tipo de injerto para cada escenario y se analizaron los resultados.

Todos los datos obtenidos se registraron en una base de datos diseñada para este estudio.

Se realizó un análisis descriptivo de la muestra. Se analizó la variable "razón para la elección de la plastia" estratificando la muestra en distintos grupos analizándolos por separado: aquellos cirujanos que realizaron un número mayor o menor de 40 plastias al año, aquellos cirujanos pertenecientes a SETRADE y ESSKA, y aquellos para los que el deporte influyó a la hora de elegir la plastia y los que no.

Análisis estadístico

El análisis estadístico se realizó mediante el programa informático SPSS, versión 18.0 (SPSS Inc., Chicago, USA). Para determinar si los datos se ajustaban a la distribución normal, se utilizó la prueba de Kolmogorov-Smirnov. Las variables cuantitativas se presentan con medias y desviación estándar, y las cualitativas con porcentajes. Para comparar las características entre los grupos se construyeron tablas 2x2 para las variables categóricas. Para las variables cualitativas se utilizó la prueba de chí cuadrado con corrección de Yates según procediera o la no paramétrica de Mantel-Haenszel.

Resultados

La encuesta fue respondida por 83 cirujanos (n=83) miembros de SETRADE (n=71) y ESSKA (n=12).

La media de plastias realizadas al año por cada encuestado fue de 55,93 (rango 1-220, desviación típica 47,82) y la mediana fue de 40. En este rango, el percentil 25 fue 20, el percentil 50 fue de 40, y el percentil 75 fue 100. El 26,5% de los encuestados realizó más de 100 cirugías de reconstrucción del LCA al año.

El 89,1% (n=74) dominaba al menos 2 plastias a la hora de realizar esta cirugía. Del total, 60 de ellos (72,2%) conocía la técnica con injerto HTH, y 75 (90%) dominaba la técnica con ST-RI. Únicamente 21 cirujanos conocían la técnica con tendón QT (25,3%) mientras que 55 (66,2%) manejaba la técnica con aloinjerto. La plastia extraarticular era utilizada por el 50,6% de los cirujanos encuestados (n=42) (Figura 1).

Para el 86,7% de los encuestados el deporte influye a la hora de tomar la decisión del tipo de injerto a utilizar, siendo la principal razón las propiedades biomecánicas de la plastia (49,4%), seguida de las complicaciones de la zona donante (19,3%) y en tercer lugar el tipo de deporte practicado por el paciente (12%) (Figura 2).

Al enfrentar a los cirujanos a diferentes escenarios, sus elecciones de injerto variaron de la siguiente forma. Puede consultarse de forma más detallada en la Tabla 1:

Figura 1. Conocimiento de las plastias por los encuestados.

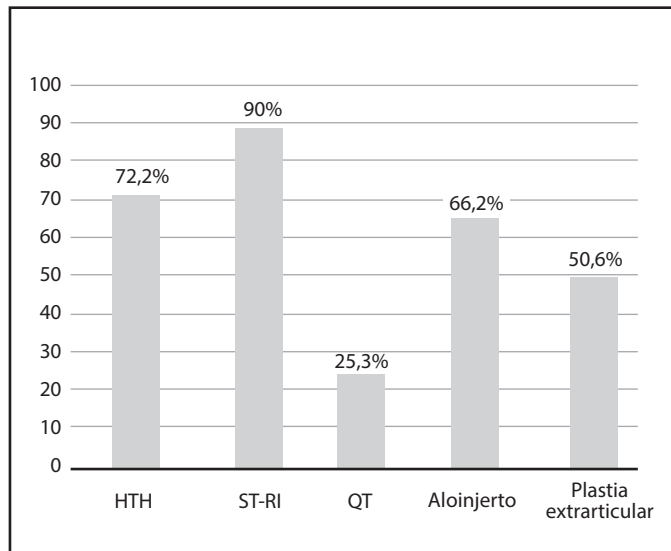


Figura 2. Razones para la elección de la plastia.

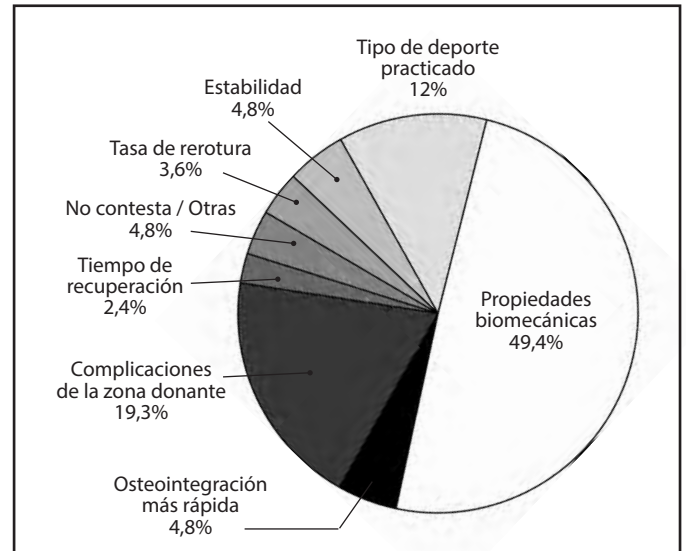
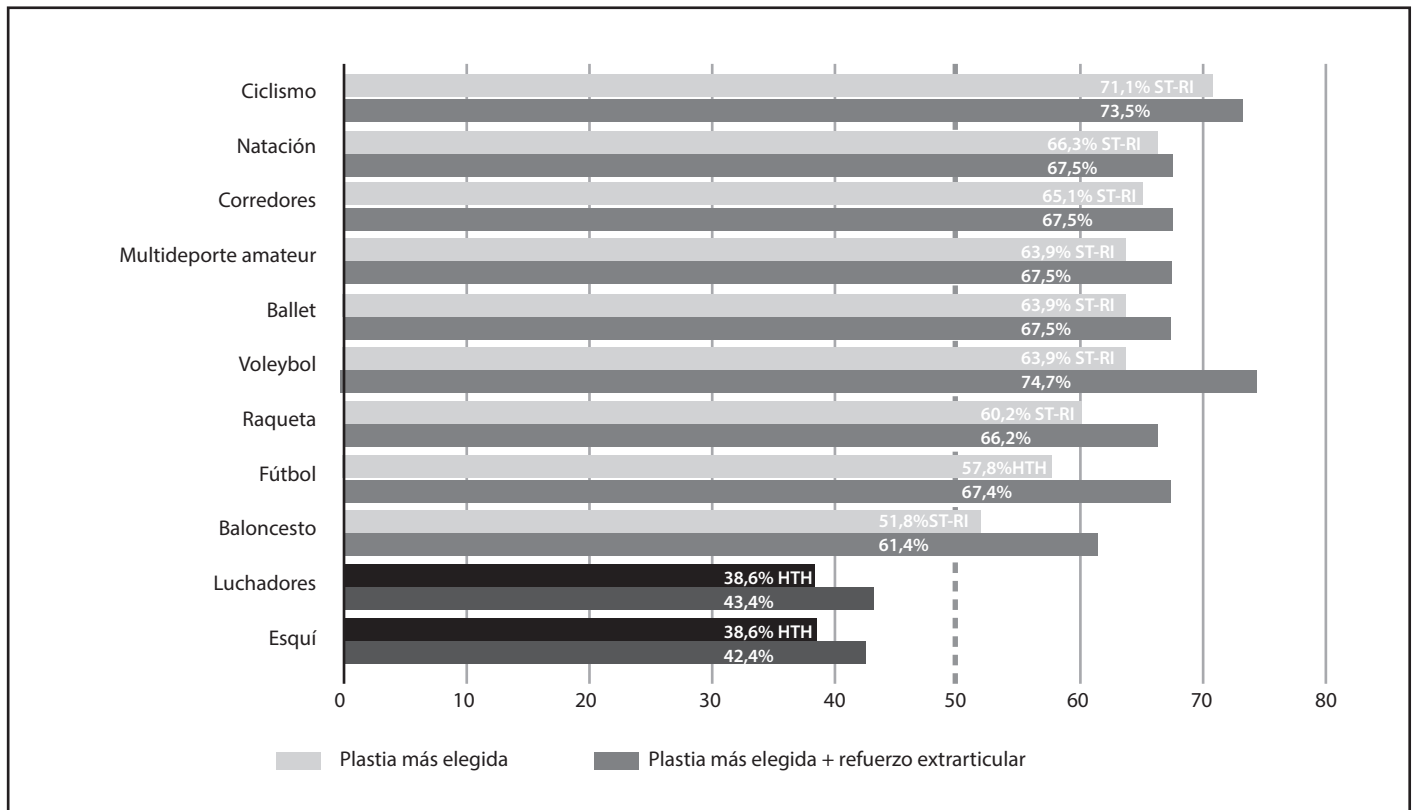


Tabla 1. Distribución de la elección de plastia según deporte.

Deporte	HTH (%)	ST-RI (%)	QT (%)	HTH + Plastia extraarticular (%)	ST-RI + Plastia extraarticular (%)	Aloinjerto (%)	No contesta (%)
Futbol	57,8	21,7	4,8	9,6	2,4	3,6	-
Baloncesto - saltadores	27,7	51,8	2,4	-	9,6	7,2	1,2
Raqueta	22,9	60,2	2,4	-	6	6	2,4
Luchadores	38,6	38,6	4,8	4,8	2,4	7,2	3,6
Voleibol	18,1	63,9	1,2	-	10,8	3,6	2,4
Ciclismo	14,5	71,1	1,2	-	2,4	8,4	2,4
Esquí	38,6	37,3	4,8	3,6	3,6	8,4	3,6
Ballet	15,7	63,9	2,4	-	3,6	10,8	3,6
Corredores	14,5	65,1	2,4	-	2,4	12	3,6
Natación	18,1	66,3	-	-	1,2	10,8	3,6
Multideporte	24,1	63,9	-	-	3,6	7,2	1,2

- En el fútbol encontramos que el 57,8% de los encuestados tiene preferencia por el autoinjerto HTH, seguido del ST-RI (21,7%) y del HTH + plastia extraarticular (9,6%). El 4,8% de los encuestados utiliza como primera opción el QT, el 3,6% el aloinjerto y por último el 2,4% utiliza la plastia con ST-RI + plastia extraarticular.
- En el baloncesto y saltadores, 51,8% de los encuestados tiene preferencia por el autoinjerto ST-RI, seguido del HTH (27,7%) y del ST-RI + plastia extraarticular (9,6%). El 7,2% de los encuestados utiliza aloinjerto en este tipo de deportistas.
- En los deportes de raqueta, la plastia más utilizada es el ST-RI (60,2%), seguida del autoinjerto HTH (22,9%) y del ST-RI + plastia extraarticular y aloinjerto, ambas utilizadas como primera opción por un 6% de los cirujanos encuestados.
- En los luchadores, el 38,6% de los encuestados eligió tanto HTH como ST-RI como primera opción. En tercer lugar, el 7,2% de los cirujanos utiliza el aloinjerto como opción principal en estos pacientes.
- En el voleibol el 63,9% de los encuestados tiene preferencia por el autoinjerto ST-RI, seguido del HTH (18,1%) y del ST-RI + plastia extraarticular (10,8%).
- En ciclismo el 71,1% de los encuestados tiene preferencia por el autoinjerto ST-RI, seguido del HTH (14,5%) y aloinjerto (8,4%).
- En el esquí, el 38,6% de los encuestados eligió el HTH y el 37,3% el ST-RI como primera opción. En tercer lugar, el 8,4% de los cirujanos utiliza el aloinjerto como opción principal en estos pacientes.
- En ballet el 63,9% de los encuestados tiene preferencia por el autoinjerto ST-RI, seguido del HTH (15,7%) y del aloinjerto (10,8%).
- En corredores el 65,1% de los encuestados tiene preferencia por el autoinjerto ST-RI, seguido del HTH (14,5%) y del aloinjerto (12%).
- En natación el 66,3% de los encuestados tiene preferencia por el autoinjerto ST-RI, seguido del HTH (18,1%) y del aloinjerto (10,8%).

Figura 3. Elección de la plastia en función al deporte practicado por el paciente.



- En pacientes multideporte amateur, el 63,9% de los encuestados tiene preferencia por el autoinjerto ST-RI, seguido del HTH (24,1%) y del aloinjerto (7,2%).

La plastia más elegida coincidió o fue la misma en un 58,29% de media (rango 71,1 – 38,6%) en cada deporte en los distintos deportes estudiados (Figura 3).

Al analizar los resultados, se obtuvo que 43 encuestados (51,8%) realizaron 40 o más plastias al año, mientras que 40 (48,2%) realizaron menos de 40 plastias. Al comparar estos grupos, no hubo diferencias estadísticamente significativas en las razones al elegir la plastia (Test de Fisher $p=1$) (Tabla 2).

Al comparar los grupos de cirujanos procedentes de las sociedades SETRADE y ESSKA, no hubo diferencias estadísticamente significativas en las razones al elegir la plastia (Test de Fisher $p=0,22$) (Tabla 3).

Al comparar aquellos cirujanos para los que el deporte influyó a la hora de elegir la plastia, no hubo diferencias estadísticamente significativas en las razones al elegir la plastia (Test de Fisher $p=0,734$) (Tabla 4).

Discusión

Nuestra encuesta fue realizada por 83 cirujanos o jefes de equipos quirúrgicos. A la luz de los resultados, observamos que la mayoría se trataba de cirujanos con amplia experiencia, con una media de plastias realizadas al año por cada cirujano o equipo de 55,93. Además la mayoría

de los cirujanos encuestados dominaba al menos 2 plastias, hallazgos que evidencian la idoneidad de los encuestados para este trabajo. El rango de plastias realizadas al año fue de 1 a 220, siendo 220 las plastias realizadas por uno de los equipos quirúrgicos españoles. Estas cifras son similares a otras encuestas publicadas⁷. La plastia más conocida entre los cirujanos que rellenaron la encuesta fueron los IT, manejados por el 90% de los encuestados. Estos hallazgos se corresponden con los de Arnold y su equipo [8] que exponen en su artículo la evolución de las plastias para esta cirugía: En 1992, la elección de injerto más frecuente era el HTH, con casi un 90%. Los autoinjertos de IT han aumentado su popularidad, y actualmente superan el 50%, seguidos por algo menos del 40% de autoinjerto de HTH. Recientemente el autoinjerto QT ha aumentado su popularidad desde 2014.

Otro de los hallazgos a destacar es que el deporte tuvo influencia en la elección de la plastia para el 86,7% de los encuestados, y en cuanto a las razones a la hora de elegir la plastia fue la 3º razón más importante en la encuesta, siendo las propiedades biomecánicas el principal motivo a la hora de elegir el injerto a utilizar. No hubo diferencias estadísticamente significativas en la razón para elegir la plastia entre los cirujanos de las distintas sociedades, cirujanos más o menos experimentados y cirujanos que tuvieron o no el deporte en cuenta en dicha elección, lo que indica homogeneidad en la muestra.

Analizando cada deporte por separado, encontramos que la plastia más elegida coincidió o fue la misma en un 58,29% de media (rango

Tabla 2. Análisis estadístico. Grupos que realizan más o menos de 40 plastias al año.

			Razón elegir plastia		
			Propiedades	Otras	Total
Número de plastias	≥40	Recuento	22	21	43
		% dentro de número de plastias	51,2%	48,8%	100%
	<40	Recuento	19	18	37
		% dentro de número de plastias	51,4%	48,6%	100%
Total		Recuento	41	39	80
		% dentro de número de plastias	51,3%	48,8%	100%

Pruebas de chi-cuadrado

	Valor	GI	Sig. asintótica (bilateral)	Sig. exacta (bilateral)	Sig. exacta (unilateral)
Chi-cuadrado de Pearson	0,000*	1	0,987		
Corrección por continuidad**	0,000	1	1,000		
Razón de verosimilitudes	0,000	1	0,987		
Estadístico exacto de Fischer				1,000	0,582
Asociación lineal por lineal	0,000	1	0,987		
Nº de casos válidos	80				

*0 casillas (0,0%) tienen una frecuencia esperada inferior a 5. La frecuencia mínima esperada es 18,04.

**Calculado sólo para una tabla de 2x2.

Tabla 3. Análisis estadístico. Grupos Setrade y ESSKA.

			Razón elegir plastia		
			Propiedades	Otras	Total
Origen	Setrade	Recuento	37	31	68
		% dentro de origen	54,4%	45,6%	100%
	ESSKA	Recuento	4	8	12
		% dentro de origen	33,3%	66,7%	100%
Total		Recuento	41	39	80
		% dentro de origen	51,3%	48,8%	100%

Pruebas de chi-cuadrado

	Valor	GI	Sig. asintótica (bilateral)	Sig. exacta (bilateral)	Sig. exacta (unilateral)
Chi-cuadrado de Pearson	1,814*	1	0,178		
Corrección por continuidad**	1,068	1	0,301		
Razón de verosimilitudes	1,839	1	0,175		
Estadístico exacto de Fischer				0,220	0,151
Asociación lineal por lineal	1,791	1	0,181		
Nº de casos válidos	80				

*0 casillas (0,0%) tienen una frecuencia esperada inferior a 5. La frecuencia mínima esperada es 5,85.

**Calculado sólo para una tabla de 2x2.

71,1 – 38,6%) en cada deporte estudiado. Este dato se puede interpretar como que, en la mayor parte de los deportes estudiados, la mayoría coincide en la elección de la misma plastia. Además, en deportes como el fútbol o baloncesto, si tenemos en cuenta la suma de la plastia principal o más elegida, más el refuerzo extraarticular (la plastia principal es la

misma, pero se añade un gesto técnico accesorio) los porcentajes de elección de plastia se elevarían al 67,4% (sumando HTH aislado y HTH con plastia extraarticular) en el caso del fútbol, y al 61,4% en el caso del baloncesto (sumando IT y IT más refuerzo extraarticular). En el caso del voleibol, siendo el deporte en el que los cirujanos han escogido más la

Tabla 4. Análisis estadístico. Grupos en los que influye o no el deporte en la decisión de la plastia en la reconstrucción del LCA.

			Razón elegir plastia		
			Propiedades	Otras	Total
¿Deporte influye?	Sí	Recuento	37	34	71
		% dentro de deporte, ¿Deporte influye?	52,1%	47,9%	100%
	No	Recuento	4	5	9
		% dentro de deporte, ¿Deporte influye?	44,4%	55,6%	100%
Total		Recuento	41	39	80
		% dentro de deporte, ¿Deporte influye?	51,3%	48,8%	100%

Pruebas de chi-cuadrado

	Valor	Gl	Sig. asintótica (bilateral)	Sig. exacta (bilateral)	Sig. exacta (unilateral)
Chi-cuadrado de Pearson	0,188*	1	0,665		
Corrección por continuidad**	0,006	1	0,937		
Razón de verosimilitudes	0,188	1	0,664		
Estadístico exacto de Fischer				0,734	0,468
Asociación lineal por lineal	0,186	1	0,667		
Nº de casos válidos	80				

*2 casillas (50%) tienen una frecuencia esperada inferior a 5. La frecuencia mínima esperada es 4,39.

**Calculado sólo para una tabla de 2x2.

opción del refuerzo extraarticular, este porcentaje se elevaría al 74,7% sumando IT e IT más refuerzo extraarticular, encontrando aquí el mayor porcentaje de coincidencia en la respuesta elegida en nuestra encuesta.

En deportes como luchadores y esquí es donde existe más heterogeneidad hemos encontrado en nuestro estudio, no predominando ninguna elección por encima del 50%.

Al revisar la literatura, encontramos que en el marco de una reconstrucción primaria aislada del LCA, la mayoría de autores y revisiones realizan las recomendaciones del tipo de plastia dividiendo a los pacientes en 3 grupos⁹: En primer lugar, los atletas de élite, pacientes jóvenes y activos donde el injerto de elección preferido es el autoinjerto HTH, aunque el autoinjerto de tendón del cuádriceps puede ser una opción cada vez más viable en esta población. Dado que el autoinjerto de IT y el aloinjerto han mostrado mayores tasas de fracaso y mayor laxitud, aunque se puede utilizar si el paciente debe arrodillarse con frecuencia debido a su profesión. En segundo lugar, los pacientes moderadamente activos donde el injerto de elección es el autoinjerto de IT. Tiene una menor tasa de fracaso y revisión en comparación con los aloinjertos, y también evita la morbilidad de la zona donante asociada a la extracción de HTH. Aunque puede quedar algo de laxitud residual en comparación con un injerto de HTH, no está claro si esta diferencia es clínicamente relevante. Por último, los pacientes de mayor edad y menos activos en los que si el tratamiento no quirúrgico fracasa, el injerto de elección sigue siendo el autoinjerto de IT. Sin embargo, en pacientes dispuestos a aceptar un mayor riesgo de fracaso del injerto, se puede considerar el aloinjerto.

Otras indicaciones de HTH podrían ser deportistas con tendinopatía rotuliana, de tal manera que se puede tratar concomitantemente a la toma de injerto del tendón rotuliano, y pacientes con laxitud medial de rodilla por lesiones crónicas, pues los IT actúan de estabilizador medial y estaría desaconsejada su resección para toma de injerto⁵.

Vemos pues, que, en el grupo de atletas de élite, el HTH es la opción principal. Y es aquí donde queremos incidir. Para nosotros no existe injerto mejor sobre otro, sino qué indicación precisa de su utilización. No todos los deportes son iguales ni tienen los mismos requerimientos.

En otras revisiones, como la de Calvo y su grupo¹⁰ van un poco más allá en cuanto a las recomendaciones para la selección de injerto según las características del paciente y deporte practicado: se recomienda el uso del autoinjerto de tendón patelar en pacientes profesionales y de alta competencia (fútbol y rugby), pacientes que requieran retorno deportivo precoz, pacientes susceptibles de lesión de IT (velocidad, fútbol americano) y pacientes hiperlaxos; mientras que el uso de IT se recomienda para pacientes con fisis abiertas, mujeres (ventaja estética), pacientes que requieran arrodillarse y deportes susceptibles de daño al tendón patelar (baloncesto, voleibol, tenis). Por último, el aloinjerto se aconseja en casos de lesiones multiligamentosas, pacientes mayores de 40 años de baja demanda, revisiones.

Esta guía ya realiza recomendaciones según algunos tipos de deporte realizado y es lo que tratamos de analizar.

Recientes estudios prospectivos de cohortes han identificado factores de riesgo para el fracaso del injerto de reconstrucción del

LCA, como la edad más joven del paciente, el mayor nivel de actividad, la colocación de un túnel no anatómico y el uso de aloinjertos. Entre ellos, el factor de riesgo más fácilmente modificable es la elección del injerto por lo que hay que elegir el más adecuado para el paciente, por lo que también Buerba y equipo¹¹ recomiendan tener en cuenta estos factores de riesgo y el deporte practicado, aconsejando el HTH en deportes o profesiones que no implican arrodillarse; el IT en deportes que no dependen en gran medida de musculatura IT; y QT en atletas que dependen de sus IT, y en atletas o trabajadores que pasan tiempo de rodillas (luchadores, judo y carpinteros).

Arnold y Houck^{8,12} en nuestra línea también concluyen que la selección del injerto debe ser individualizada para cada paciente y entender las tendencias globales en la elección del injerto puede ayudar a los cirujanos ortopédicos a discutir las opciones de injerto con sus pacientes y determinar el injerto apropiado para cada caso. Por lo tanto, el cirujano debe estar familiarizado con todas las opciones de reconstrucción del LCA disponibles para optimizar el tratamiento y los resultados de cada paciente.

Algunas consideraciones sobre las posibles limitaciones de este trabajo podrían ser las derivadas de la utilización de datos de únicamente 2 sociedades a nivel Europeo como sesgo de selección. Se recibieron numerosas respuestas de la sociedad española (SETRADE), no así de la europea (ESSKA) pudiendo por ello no ser representativos de la sociedad. Además, el rango de plastias realizadas al año por los cirujanos es muy elevado, habiendo amplias diferencias entre los grupos con mucha experiencia y los cirujanos con poca experiencia.

Como aspectos a destacar, cirujanos y equipos con amplia experiencia realizaron la encuesta, tanto en volumen de cirugías al año como en plastias dominadas por los encuestados, lo que fortalece nuestros resultados.

Tras evaluar la situación y tener en cuenta todas las consideraciones, se podrían establecer las siguientes bases y consenso:

El rendimiento de deportistas que practican fútbol, el rugby, fútbol americano, levantamiento de pesas, velocidad, bailarinas, taekwondo, o karate, que comprometen IT, puede verse afectado si los utilizamos como injerto ya que se podría disminuir considerablemente la fuerza de flexión final. Además, existe una mayor incidencia de contracturas musculares y desgarras en la zona dadora y en deportistas mujeres si utilizamos IT; por lo que, en estos deportes, el HTH sería la plastia de elección.

Por otro lado, para deportes en los cuales el aparato extensor juega un rol importante, y el ponerse de rodillas es práctica habitual, como son artes marciales, esquí, voleibol y baloncesto optaríamos por IT, con el fin de no lesionar el aparato extensor.

En los deportes de raqueta, ciclismo, corredores, natación y en pacientes multideportistas amateur, donde la potencia isquiotibial o los requerimientos no son tan importantes se puede recomendar la plastia de IT dadas las ventajas e inconvenientes analizados previamente.

Para deportistas con cartílago de crecimiento abierto, se utilizan solo IT, independiente del deporte, ya que para evitar daño en el crecimiento epifisiario el túnel debe estar siempre relleno con tejidos blandos.

Los aloinjertos los recomendamos solo en lesiones multiligamentosas, deportistas amateurs sobre 35 años, ya que la incorporación y resistencia del injerto requieren el doble del tiempo que los autoinjertos,

y la tasa de re-rotura es mayor. También hay que tener en cuenta la elección las preferencias del paciente.

Actualmente vemos que para casi el 90% de los encuestados el deporte influye a la hora de tomar la decisión del tipo de injerto a utilizar. Si analizamos cada deporte por separado, en líneas generales y deportes más practicados se aprecia una coincidencia en la plastia utilizada, aunque para otros no existe tanta concordancia como cabría esperar. Con todo ello, los autores recomendamos el dominio de al menos 2 plastias para las reconstrucciones primarias del LCA e individualizar cada caso considerando el tipo de deporte en la selección del injerto teniendo en cuenta lo analizado en este trabajo y en la literatura.

Conclusiones

Nuestra encuesta fue realizada por un número significativo de cirujanos con experiencia en plastias del LCA, siendo las propiedades biomecánicas el principal motivo a la hora de elegir el injerto a utilizar. A la mayor parte de ellos les influye el tipo de deporte practicado en esta elección.

La plastia más elegida fue la misma en un 58,29% de media en cada deporte estudiado, coincidiendo la mayoría en la misma elección, aunque existen deportes en los que no predomina ninguna opción.

Los autores recomendamos el dominio de al menos 2 plastias para las reconstrucciones primarias del LCA e individualizar cada caso considerando el tipo de deporte en la selección del injerto.

Anexo 1. Encuesta

Todas las preguntas hacen referencia al contexto de la rotura completa del ligamento cruzado anterior de la rodilla (LCA) en un deportista profesional en edad madura sin antecedentes, lesiones ni cirugías previas.

1. ¿Cuántas cirugías de reconstrucción por rotura del LCA al año?
2. ¿Tienes en cuenta el tipo de deporte que practica el paciente para elegir la plastia en la cirugía del LCA?
3. ¿Cuál es el principal motivo que tienes en cuenta a la hora de elegir la plastia a utilizar? (Complicaciones de la zona donante, mayor estabilidad/rigidez de la plastia, osteointegración más rápida, propiedades biomecánicas, tasa de re-rotura, etc).
4. ¿Cuántas plastias para la reconstrucción del LCA y que tipo manejas con soltura? Elije las opciones que considere Autoinjerto de tendón rotuliano (HTH):
 - a) HTH-Tendón rotuliano.
 - b) Autoinjerto de tendones isquiotibiales (ST-RI).
 - c) Autoinjerto de tendón cuadriceps (QT).
 - d) Aloinjerto.
 - e) Reconstrucción LCA + plastia extraarticular.
 - f) Otra.
5. ¿Según el tipo de actividad siguiente, ¿qué plastia para la reconstrucción del LCA de entre las anteriores cree más adecuada? Es posible más de una respuesta:

- a) Deportista de fútbol y deportes de impacto – rugby, fútbol americano, balonmano.
- b) Deportista de baloncesto /atletismo – saltadores.
- c) Deportista de raqueta o similar: tenis, pádel, pin pon, bádminton, squash, baseball, criquet.
- d) Luchadores y artes marciales.
- e) Voleibol.
- f) Ciclismo.
- g) Esquí / snowboard, hockey sobre hielo o patines.
- h) Ballet y otros tipos de baile.
- i) Corredores de larga distancia.
- j) Natación.
- k) Pacientes multideportistas amateur.
- l) Pacientes con baja actividad.

Conflicto de interés

Los autores no declaran conflicto de interés alguno.

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Effect of tibial tunnel diameter on the outcome of ACL reconstruction

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Summary

The number of variables that influence the success of an anterior cruciate ligament (ACL) reconstruction is so high that an in-depth analysis of the problem can only be carried out through numerical tools. Once the diameter of the substitute plasty and the interference screw has been chosen for a given patient, one of the main concerns of the surgeon is to find the most suitable diameter of the tibial tunnel for its fixation. In this work, a finite element model was developed in order to simulate both the reconstruction and the subsequent rehabilitation of the ACL at its tibial insertion. For the simulation, the chosen tendon and screw diameters were 4 mm and 7 mm, respectively, while diameters of 7, 8, 9, and 10 mm were tested for the tibial tunnel. The parameters of the behavior models of the different materials (screw, bone and tendon) were obtained through experimental tests. The results obtained show that, as the diameter of the tunnel decreases, the compressive stress over the plasty will increase (theoretical objective of the fixation), but the deformation induced on the trabecular bone also increases, which can trigger its failure. For this reason, the maximum values of the interferential pressure must be limited to those strictly necessary to ensure that the reconstruction is properly done, that is, that it prevents the tendon from slipping in the tunnel during the rehabilitation process. The simulation of the rehabilitation process was done by pulling the already fixed tendon in the femoral direction in order to extract it. It was obtained that the most suitable diameter of the tibial tunnel for the chosen plasty-screw assembly is 8 mm, since it provides a suitable subjection without high values of deformation in trabecular bone, that is, no damage in this part of the bone.

Key words:

ACL. Tibiae. Trabecular bone.
Plasty. FEM.

Efecto del diámetro del túnel tibial en el resultado de la reconstrucción de LCA

Resumen

El número de variables que influyen en el éxito de una reconstrucción de ligamento cruzado anterior (LCA) es tan elevado que un análisis profundo del problema sólo puede realizarse a través de herramientas numéricas. Elegido el diámetro de la plastia sustituta y del tornillo interferencial para un determinado paciente, una de las principales preocupaciones del cirujano es dar con el diámetro de túnel tibial más adecuado para su fijación. En este trabajo se desarrolló un modelo de elementos finitos que simula tanto la reconstrucción como la posterior rehabilitación del LCA en su inserción tibial. Para la simulación, los diámetros del tendón y tornillo elegidos fueron 4 mm y 7 mm respectivamente mientras que para el túnel tibial se probó con diámetros de 7, 8, 9 y 10 mm. Los parámetros de los modelos de comportamiento de los diferentes materiales (tornillo, hueso y tendón) se obtuvieron mediante ensayos experimentales. Los resultados obtenidos muestran que, conforme disminuye el diámetro del túnel utilizado, crece la tensión de compresión ejercida sobre la plastia (objetivo teórico de la fijación), pero también crece la deformación inducida sobre el hueso trabecular, lo que puede desencadenar el fallo del mismo. Por esta razón, los valores máximos de la presión interferencial deben limitarse a los estrictamente necesarios para asegurar que la reconstrucción sea efectiva, es decir, que evite el deslizamiento del tendón en el túnel durante el proceso de rehabilitación. Simulado, también, el proceso de rehabilitación tirando del tendón en dirección femoral, se ha obtenido que el diámetro de túnel tibial más adecuado para el conjunto plastia-tornillo elegido, es el de 8 mm, ya que proporciona una fijación suficiente sin que los valores de deformación en el hueso trabecular lleguen a producir su daño.

Palabras clave:

LCA. Tibia. Hueso trabecular.
Plastia. FEM.

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Introduction

ACL tears are usually treated by rebuilding the damaged ligament or by replacing it with a tendon that can perform its function. To carry out this procedure, the surgeon must drill two bone tunnels, in the tibia and femur, remove the ligament and replace it with the graft.

The prevalence of this injury estimates that 60% of them have a sporting nature, that is, they happen to the young and active population¹. However, it also happens in people who are overweight and not very active or have motion limitations. Largely, the success of the reconstruction will depend on the chosen plasty, but also on the choice of the geometry of the tibial tunnel, the materials involved and the optimal size of each element depending on the patient. To date, the surgeon usually carries out the intervention in a standardized way, without being able to make great distinctions between patients. Through this work, it is intended that each patient can be treated individually. Moreover, this work try to find the optimal reconstruction parameters for each patient, that is, it will be performed for their type and size of tendon, as well as for their own bone characteristics.

Due to the large number of variables involved in the study, it seems clear that making the most appropriate decision for each patient is not easy, and in order to undertake the analysis, we must use numerical tools².

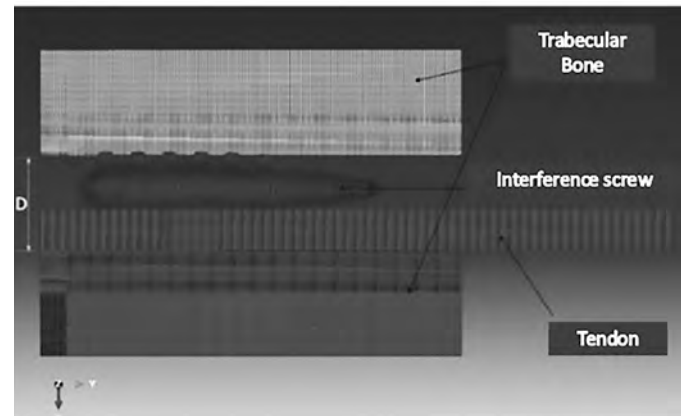
The objective of this work is, therefore, the analysis of the mechanical response of the tibia-plasty-screw assembly after the anterior cruciate ligament reconstruction, evaluating the influence of the different variables that come into play³. This would not be possible without the correct mechanical characterization, through laboratory tests, of the different materials involved. This need arises, in large part, due to the enormous variability in the existing bibliographic data⁴⁻¹⁰, derived both from the use of very diverse materials (different species, screws of different materials, etc.) as well as very different test methodologies. Thus, in order to develop and subsequently validate a correct numerical model, it is necessary to describe the most appropriate mechanical behavior models for each of the intervening elements, which would not be possible without their prior experimental characterization.

Once the most appropriate behavioral models for each material involved in the reconstruction have been defined, this paper presents the finite element model used to describe the fixation process of the plasty in the tibial tunnel by using an interference screw. The states of stress and strain are also analyzed once the surgery is finished, depending on the diameter of the tibial tunnel used. Finally, the stability of the reconstruction is checked when, at the end of the plasty fixation process, the assembly must respond to normal workloads that would try to move the graft (and even the screw) along the tunnel.

Material and method

The numerical simulation of the ACL reconstruction has been carried out using the finite element method (FEM) with the commercial program ABAQUS. Hence, a two-dimensional (2D) geometric model has been made. It consisted of the trabecular bone that surrounds the tibial tunnel, inside which the substitute plasty and the interference screw

Figure 1. Geometric model used in the analysis.



are located, as shown in Figure 1. Four different diameters of the tibial tunnel ($D = 7, 8, 9$ and 10 mm) were analyzed, while the diameters of the plasty and the interference screw were considered invariable, with values of 4 mm and 7 mm, respectively.

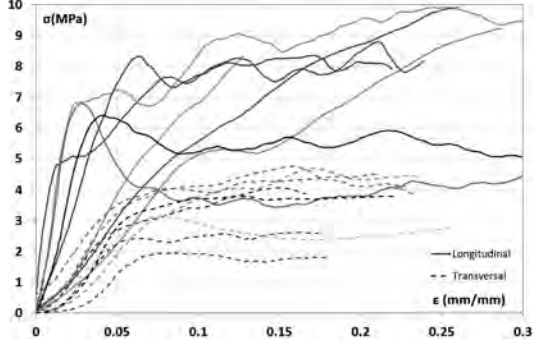
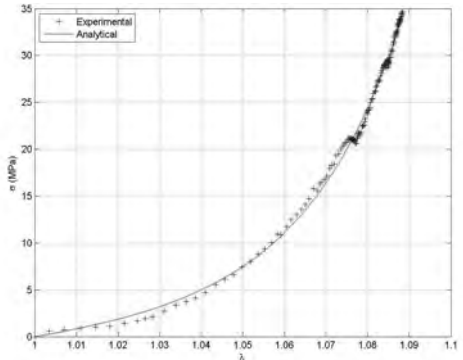
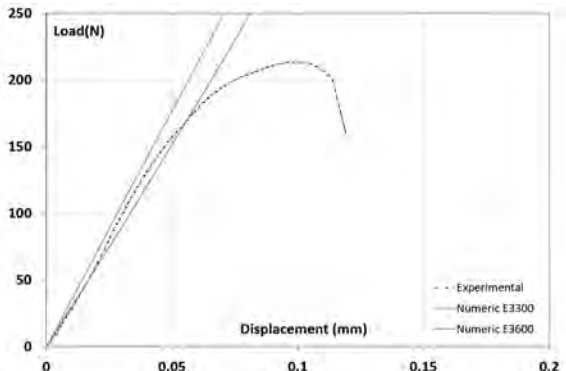
The material models used are a reflection of the results obtained after an extensive experimental work, which are collected in detail in previous publications^{11,12}.

Thus, trabecular bone, from porcine tibiae and characterized by compression tests^{11,12}, showed that once a certain level of load (σ_y) was reached, its resistant capacity remained constant until macroscopic failure due to collapse of the different trabeculae happened. It is an elastic-perfectly plastic behavior that is modeled by introducing the elastic parameters (elastic modulus, E and Poisson's ratio, ν) and the yield stress, σ_y , of the material. The trabecular bone also showed greater resistance and stiffness when it was loaded in the longitudinal direction (with respect to the axis of the tibia) than when it was loaded in the transverse direction, that is, it has an anisotropic mechanical behavior. However, taking into account that it is impossible to fix the position of the tibial tunnel with respect to the axis of the tibia in an exact way numerically, the best and safest option is to consider that the behavior of the bone is isotropic using the corresponding properties to the weakest direction (transversal). This also has greatly simplified the calculus¹¹.

The tendons had porcine origin (*flexor digitorum*), too. They were characterized using tensile loads and measuring the deformations with an ARAMIS 5M video correlation image equipment¹². The behavior of the tendons was clearly hyperelastic and anisotropic, typical of this type of material. It is adjustable to a material model defined by Calvo and Peña¹³, that describes the behavior of soft tissues being incorporated into the finite element program through a user subroutine (uanisohyper_inv^{2,3,13}), whose constants, C_{10} , C_3 and C_4 , collected in Table 1, are obtained after adjusting the model to the experimental results.

For its part, the interference screw used (with dimensions of 7 mm diameter and 25 mm length), was subjected to a compression test, loading the specimen perpendicularly to its principal axis. Its behavior was linear-elastic behavior up to very high loads. The elastic parameters obtained (E y ν), shown in Table 1, were consistent with those expected for the type of material analyzed, composed of a mixture of PLLA polymer (75%) and hydroxyapatite HA (25%)¹².

Table 1. Materials involved in the simulation: Properties and constitutive model chosen.

Material	Behavior	Constitutive model	Properties
Trabecular bone	 <p>A line graph showing stress σ (MPa) on the y-axis (0 to 10) versus strain ϵ (mm/mm) on the x-axis (0 to 0.3). Multiple curves represent different orientations: solid lines for longitudinal and dashed lines for transversal. The curves show an initial elastic region followed by a plastic region with varying degrees of strain hardening.</p>	Elastic-perfectly plastic	$E=73$ MPa $\nu = 0.27$ $\sigma_y 2.7$ MPa
Tendon	 <p>A line graph showing stress σ (MPa) on the y-axis (0 to 35) versus stretch ratio λ on the x-axis (1 to 1.1). The plot compares experimental data points (marked with '+') and an analytical curve (solid line). The curve shows a non-linear, hyperelastic behavior.</p>	uanisohyper_inv ¹³	$C_{10} = 7.98$ $C_3 = 0.374$ $C_4 = 19.24$
Interference screw	 <p>A line graph showing Load (N) on the y-axis (0 to 250) versus Displacement (mm) on the x-axis (0 to 0.2). It compares experimental data (dashed line) with two numerical models: E3300 (solid line) and E3600 (dotted line). The experimental curve shows a peak load around 0.1 mm displacement followed by a drop.</p>	Elastic	$E = 3600$ MPa $\nu = 0.3$

To carry out the simulation, it was assumed that both the screw and the tendon are located in their final position (the one they would have after the real threading process was carried out by the surgeon) inside the tunnel. In this way, the screw is not in contact with the surrounding materials (trabecular bone and tendon) because a sufficient radial compression pressure has been applied to it. In a second step, this pressure is deleted, allowing the screw to start the contact with the other components that will be pressed, to a greater or lesser extent, depending on the size of the tunnel analyzed. The interaction properties (contacts) between the different materials have been defined based on previous studies^{2,3,13,14,15}. A friction coefficient of 0.1 was used for the contact between the trabecular bone and the tendon or the screw while for the contact between the interferential screw and the tendon a much smaller coefficient (just 0.05) has been taken.

In this way, once the geometric model was generated (Figure 1), the materials (Table 1), contacts and the corresponding boundary conditions¹² were defined, the LCA reconstruction process was carried out in three calculation steps:

- *Step 1. Screw compression:* A uniform pressure is applied to the entire surface of the screw until its dimensions are reduced such that, once it is placed in the desired position within the tibial tunnel, there is no contact with any of the other elements of the model.
- *Step 2. Tendon pretension:* In the same way the surgeons act to ensure that the tendon does not roll or become lax during the screw entry process¹², a slight pretension is performed on it.
- *Step 3. Decompression of the screw:* Gradually, the pressure to which the screw had been subjected in step 1 is deleted. At the same time, the screw is allowed to recover little by little its initial

geometry and dimensions, starting the contact with the rest of the elements of the joint.

Once the reconstruction is complete, stress and strain values of the different elements are evaluated. However, the fundamental proof of the success of the intervention is that the substitute tendon is sufficiently fixed, so that, during the rehabilitation process, when it is subjected to a tensile load in the femoral direction, it does not experiment big displacements inside the tunnel. Thus, the following step is used.

- *Step 4. Rehabilitation:* After the surgery, the tendon is released from its initial pretension, and it is pulled from the opposite end, in the same direction, but towards the femur, trying to extract it from the tibial insertion. This simulates the natural movement of the knee. Based on the results obtained by other authors¹⁶ when they analyzed the relative displacement of the tendons during a normal rehabilitation process, the axial displacement applied to the tendon at its femoral insertion is about 3 mm, which would be equivalent to knee flexion of 30°, position of maximum load during rehabilitation¹⁷. After this step, the relative displacements between the tendon and the screw teeth in different positions are analyzed.

Results

Figure 2 compares the appearance of the different elements involved in the ACL reconstruction once it is completed (step 3 is finished), for different diameters of the tibial tunnel. The configurations corresponding to the tibial tunnels with diameters of 10 mm (Figure 2a), 9 mm (Figure 2b), 8 mm (Figure 2c) y 7 mm (Figure 2d), are represented keeping constant the geometric parameters of the other components. As can be seen, as the diameter of the tibial tunnel decreases, the points of contact between the surface of the screw and the adjacent elements increase.

Figure 3 shows the distribution of minimum principal stress (radial pressure) at the points of the tendon surfaces in contact with the screw (tendon_left) and in contact with the trabecular bone (tendon_right), for the four cases analyzed. The points of contact between the teeth of the screw and the tendon are reflected in the peaks of the stress profile (Figure 3.a), showing punctual values of high compressive stresses. However, the contact between the tendon and the trabecular bone (Figure 3.b) shows a much smoother and more homogeneous stress

Figure 2. Numerical results of the reconstruction. Arrangement of tibial tunnels of: (a) 10 mm; (b) 9 mm; (c) 8 mm; (d) 7 mm.

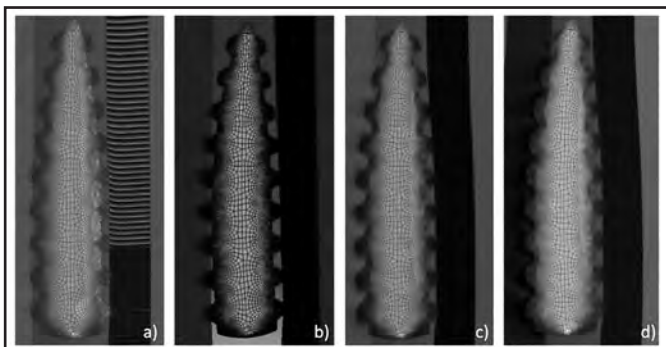
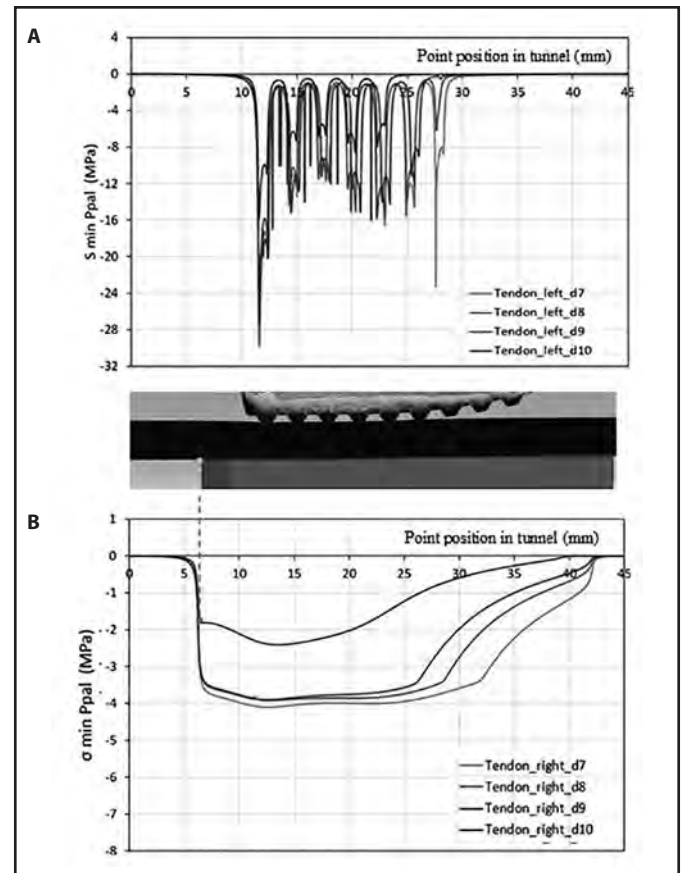


Figure 3. Influence of the tibial tunnel diameter on the Minimum Principal Stress in the tendon: (A) in contact with the screw; (B) in contact with trabecular bone.



distribution. It starts in the area corresponding to the beginning of the tibial tunnel, reaching its maximum value in the areas whose longitudinal coordinates match with the first or second tooth of the screw, the area with the largest diameter of the screw. Then, a progressively decrease of stress happens until its disappearance in an area close to the exit of the tibial tunnel towards the femur. These figures also show that as the diameter of the tunnel decreases, the stress levels on the tendon are higher as well as the area affected by these stresses, something that is beneficial in theory. However, the greatest variation in stress happens when the diameter of the tunnel decreases from 10 mm to 9 mm.

Furthermore, as can be seen in Figure 4, the decrease in the tibial tunnel diameter also affects to the values of strain strongly, especially in the trabecular bone. The strong increase in the radial deformation of the trabecular bone is especially relevant when the diameter of the tunnel decreases from 8 mm to 7 mm.

For its part, Figure 5 shows the displacements experienced by different points of the tendon when it is subjected to the rehabilitation process once the reconstruction is completed. The zones represented are those that are in contact with the different teeth of the screw after reconstruction. *Zone 1* is the one corresponding to the tooth furthest from the femur and *Zone 8* is the one closest to the femoral part of the tunnel.

Figure 4. Influence of the tibial tunnel diameter in the strain distribution of the trabecular bone in contact with the tendon.

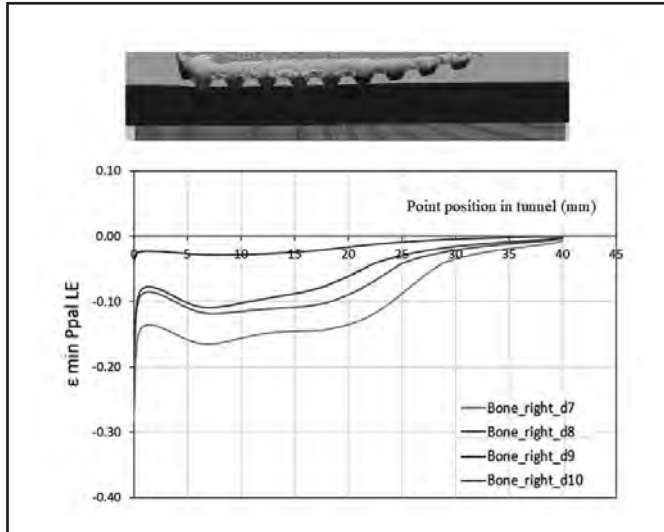
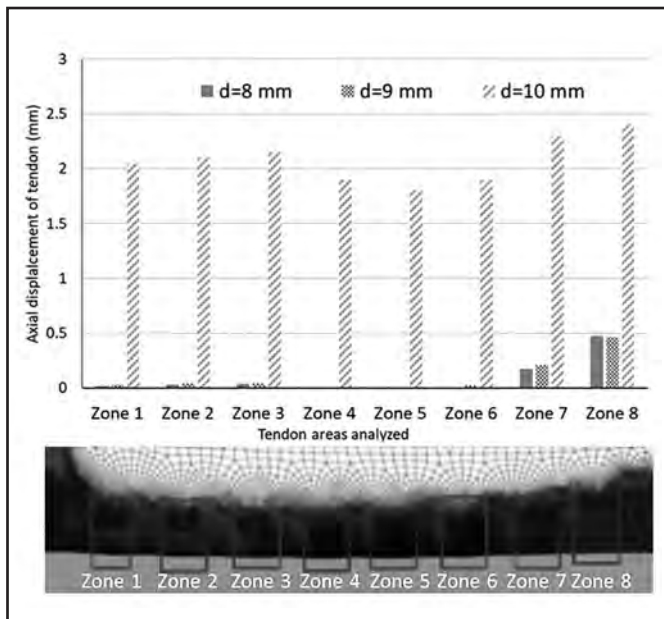


Figure 5. Displacement of the different points of the tendon along the tibial tunnel for different diameters of tunnel (d=10, 9 y 8 mm).



As can be seen, when the tunnel diameter used is 10 mm, all points of the tendon suffer longitudinal displacements close to or greater than 2 mm, which indicates that with this tunnel diameter, the tendon has not been sufficiently fixed. Thus, the reconstruction cannot be validate. However, when the diameter of the tibial tunnel becomes 9 mm, the displacements in the areas furthest from the femur are very small, being almost zero the one corresponding to the first tooth. With an 8 mm tibial tunnel diameter, all tendon displacement is zero, except to the ones that are near the femur.

Discussion and Conclusions

First, it should be noted that this work collects the results obtained after developing and applying a finite element model that simulates ACL reconstruction in the tibial area when a single interference screw with a diameter of 7 mm and a length of 25 mm is used to fix the position of a single 4 mm diameter substitute plasty. The variable that will change its value is the diameter of the tibial tunnel (between 7 mm and 10 mm). The geometric model, made in two dimensions, has been modeled in the most reliable way possible, and the behavior models of the materials involved (trabecular bone, tendon and interference screw) come from results obtained from an extensive experimental work collected in previous publications^{11,12}. Due to the large number of contacts established between the elements involved, the problem to solve is very complex in numerical terms, so a strategy consisting of using three steps to simulate the actual reconstruction and one more step to simulate the rehabilitation process has been used. This early rehabilitation therapy lies in the application of a longitudinal displacement of 3 mm to the tendon, already located in the proper position inside the tibial tunnel, but trying to extract it in the femoral direction.

Simulating the ACL reconstruction process with four different diameters of the tibial tunnel (10, 9, 8 and 7 mm), the stress and strain values in the contact surfaces of the tendon with the trabecular bone and with the screw have been presented (Figures 3 and 4). The results have revealed that the diametrical pressure exerted by the screw against the tendon (Figure 3.a), with peaks and valleys -depending on whether the contact area is the teeth or the area between them-, increases as the diameter of the tunnel decreases. Practically, the maximum value of diametrical pressure is reached when the tunnel passes from a 10 to 9 mm diameter. It also happens with the contact pressure between the tendon and the trabecular bone (Figure 3.b), which, although with a much smoother profile, goes from a value of about 2.5 MPa to 4 MPa when the diameter of the tunnel is reduced from 10 to 9 mm.

Subsequent reductions in diameter of the tunnel (8 mm and 7 mm) have more influence in expanding the area subjected to maximum stress (by increasing the area of contact between the screw and the rest of the materials surrounding it) than in increasing the value of this stress distribution. These results are not far from those obtained by other authors¹⁸, who used a much simpler model, without the presence of a tendon. This author used an interference screw with a diameter of 8 mm and a length of 20 mm that perfectly adjusted to the tibial tunnel and in which the material bone was simplified to only cortical bone behavior, as linear elastic material ($E=13.4$ GPa, $\nu=0.28$). They obtained that the pressures exerted on the bone tunnel did not exceed 3 MPa, a value well below the yield limit of the cortical bone used in said study (182 MPa).

Although the decrease in the diameter of the tunnel barely affects the stress values from 9 mm diameter of tunnel, it does not occur with the strain in the trabecular bone (Figure 4), which grows very noticeably, especially when going from a tunnel diameter of 8 mm to one of 7 mm. When the results of these two tunnel diameters (8 and 7 mm) are compared, although the stresses hardly change, the diametrical deformation in the trabecular bone increases by almost 50% in the

contact areas affected transversely by the pressure of some of the screw teeth. The high values of strain reached at certain points could imply a localized deterioration of the trabecular bone and the consequent loss of pressure on the reconstruction.

Based on these results, it is conceivable that the ideal tunnel will be the one that manages to fix the plasty without extremely high values of strain in the trabecular bone, regardless of the pressure reached. Thus, it is necessary to analyze the displacements suffered by the plasty after the rehabilitation process, which are summarized in Figure 5.

Analyzing the results showed in Figure 5, it could be inferred that the use of a 10 mm diameter tibial tunnel is unable to fix a 4 mm plasty with a 7 mm diameter interference screw, so the choice of this combination of parameters would be completely wrong. It should be noted that the verification of screw slippage is usually carried out one or two months after the reconstruction, subjecting the joint to cyclic loads¹⁹. The fact that there could be tendon slippage in such an early and non-aggressive rehabilitation is a reason to dismiss the tibial tunnel configuration studied with the selected tendon and screw.

However, the use of a 9 mm diameter tunnel already ensures that the tendon is totally fixed in zones 4 and 5 (displacement 0 mm) and that in the rest of the zones the displacement is very small, so it could be considered that the choice of this tunnel diameter would already be sufficiently valid. Nevertheless, if the diameter tunnel used is 8 mm, the displacements suffered by the plasty during rehabilitation are even lower, without the implication of a sudden change in the values of stress and strain in the different elements involved, something that happens when the diameter of the tunnel decrease (Figure 4.b). Then, it seems that the optimal choice for a successful reconstruction of a 4 mm tendon (assuming a double arrangement), using a screw with the analyzed geometry (7 mm in diameter and 25 mm in length) would be a tibial tunnel diameter of 8 mm or 9 mm, which also coincides with that obtained by other authors²⁰⁻²³ for a similar arrangement. Going below that diameter would mean an excessive increase of the strain in the trabecular bone, without providing any improvement in terms of tendon support.

Having presented the results and discussed them, it is worth noting that the model which has been developed is capable of simulating ACL reconstruction in a reliable and relatively simple manner. Thus, it is emerging as a very useful tool in making decisions about the most appropriate tibial tunnel diameter to use depending on the interference screw and the plasty chosen for the patient.

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Conflict of interest

The authors do not declare a conflict of interest.

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Body Composition and Somatotype of Athletes in the Chilean Sport Talent Development Program

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Summary

Introduction: Determining the body composition and somatotype in sport talents provides a useful reference to improve the trajectory toward high-level competition.

Objective: The aim of this study is to determine the body composition and somatotype by discipline of children and adolescents of both genders in the sport talent development program at the Regional Training Center.

Material and method: Seventy-two subjects participated (29 females, 15.9 ± 2.0 years; 43 males, 15.9 ± 2.3 years) from the disciplines of athletics, cycling, judo, karate, and table tennis. a) Baseline measurements: weight, height, and body mass index (BMI); b) Body masses by fractioning into five components (in %): muscle, fat, bone, residual and skin, using Kerr's method and c) Somatotype, according to the model proposed by Heath and Carter were performed.

Results: Females have a higher percentage of fat mass than males. Exactly the opposite occurs with muscle mass, where males present a higher percentage than females, with the exception of table tennis. Regarding residual mass, males present higher values in all the disciplines. The males were classified as endo-mesomorphs, except for those in athletics, who were classified as ecto-mesomorphs, while the females from athletics and table tennis were classified as central, those from cycling and judo as endomorph-mesomorphs, and those from karate as meso-endomorphs.

Conclusion: Through a two-dimensional contrast of the somatotype of CER athletes and that of adult athletes at the High Performance Center in Chile, it was determined that both groups are different, indicating that CER athletes do not yet meet the structural requirements necessary for a trajectory to high-level competition, suggesting that training modifications be considered to get closer to the ideal somatotype.

Key words:

Anthropometry. Somatotypes. Body composition. Athletes. Sports.

Composición corporal y somatotipo de los atletas del programa de desarrollo de talentos deportivos chilenos

Resumen

Introducción: Determinar la composición corporal y el somatotipo en los talentos deportivos es una referencia útil para mejorar la trayectoria hacia la competición de alto nivel.

Objetivo: El objetivo de este estudio es determinar la composición corporal y el somatotipo por disciplina de los niños y adolescentes de ambos géneros en el programa de desarrollo de talentos deportivos del Centro de Entrenamiento Regional.

Material y método: Participaron setenta y dos sujetos (29 mujeres, 15,9 ± 2,0 años; 43 hombres, 15,9 ± 2,3 años) de las disciplinas de atletismo, ciclismo, judo, karate y tenis de mesa. Se realizaron las siguientes evaluaciones a) peso, altura e índice de masa corporal (IMC); b) Masas corporales fraccionadas en cinco componentes (en %): músculo, grasa, hueso, residual y piel, utilizando el método de Kerr y c) somatotipo, según el modelo propuesto por Heath y Carter.

Resultados: Las mujeres tienen un mayor porcentaje de masa grasa que los hombres. Exactamente lo contrario ocurre con la masa muscular, donde los hombres presentan un porcentaje mayor que las mujeres, con la excepción del tenis de mesa. En cuanto a la masa residual, los hombres presentan valores más altos en todas las disciplinas. Los hombres se clasificaron como endo-mesomorfos, excepto los de atletismo, que se clasificaron como ecto-mesomorfos, mientras que las mujeres de atletismo y tenis de mesa se clasificaron como centrales, las de ciclismo y judo como endomorf-mesomorfos, y las de karate como meso-endomorfos.

Conclusión: Mediante un contraste bidimensional del somatotipo de los atletas del CER y el de los atletas adultos del Centro de Alto Rendimiento de Chile, se determinó que ambos grupos son diferentes, lo que indica que los atletas del CER no cumplen aún con los requisitos estructurales necesarios para una trayectoria hacia la competencia de alto nivel, sugiriendo que se consideren modificaciones del entrenamiento para acercarse al somatotipo ideal.

Palabras clave:
Antropometría. Somatotipo.
Composición corporal.
Atletas. Deportes.

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Introduction

Using several anthropometric studies conducted on elite athletes, precise data have been obtained on the structural requirements needed in the different disciplines, as there are morphological characteristics that will be selective in the development of top-level sports^{1,2}. Anthropometry not only enables the design of physical activity and training programs, but it is also useful as a predictive measure in identifying sport talents³. Thus, although all individuals have similar training conditions, both qualitatively and quantitatively, those athletes with more favorable morphological conditions for sports would perform better^{4,5}. Even the anthropometric characteristics and state of maturation have been considered as predictors of success in young athletes⁶. Consequently, the information that can be obtained from these evaluations acquires great importance for the trajectory of sport talents toward high-level competition. Accordingly, the Chilean government program responsible for detecting, selecting, and developing sport talents, called the "National Sport Projection – Regional Training Centers (*Centro de Entrenamiento Regional -CER-* in Spanish) Program)" and dependent on the National Sports Institute of Chile, establishes as part of its technical guidelines certain training processes with technical instruments for detecting and developing talent, including periodic anthropometric assessments⁷. However, although there are multiple anthropometric studies on children and adolescents in schools⁸, there is little information about the morphological characteristics of boys and girls who train regularly⁹ and who are considered potential sport talents to enable the definition of a characteristic anthropometric profile by gender and sport. Therefore, the aim of this study is to determine the body composition and somatotype by discipline of children and adolescents of both genders in the sport talent development program at the Regional Training Center in (CER).

Materials and method

Sample

Seventy-two subjects participated in the study (29 females, 15.9 ± 2.0 years; 43 males, 15.9 ± 2.3 years) belonging to athletics, cycling, karate, table tennis, and judo who are part of the sport talent development program at the CER. They train a minimum of 10 hours per week and regularly participate in official competitions of the respective national federations. The study followed the guidelines of the Declaration of Helsinki with respect to the ethical principles of human research: each athlete participated voluntarily; signed an informed assent and consent form; had the permission of their parents, coaching staff, and respective physician.

Instrument and Procedures

The assessments were carried out by a level I anthropometrist certified by the International Society for the Advancement of Kinanthropometry (ISAK) and supervised by a level III instructor. Every six months during the measurement process, standardization of the measurements was checked with 20 subjects of similar physical characteristics, obtaining a technical error of measurement (% TEM) for the evaluating anthropometrist of 0.68% in the diameters, 0.43% in the perimeters, and 3.57%

in the skin folds. The procedures were routinely performed during the annual sports season, establishing by protocol that these were outside the training schedule, with no sport practice for at least 24 hours, with a food intake of more than four hours prior, and with gastric and bladder emptying prior to the assessment. The ISAK assessment protocol was followed¹⁰, measuring 25 variables, using a Seca® 769 electronic column scale with an accuracy to 100 grs., a Seca® 217 stadiometer with an accuracy to 1mm, a Harpenden skinfold caliper with an accuracy to 0.2 mm, two Campbell sliding calipers with long and short branches, and a Rosscraft anthropometric tape measure, all from Rosscraft, and a Gaucho Pro model with an accuracy to 1mm. With this, the following variables of interest were determined individually: a) Baseline measurements: weight, height, and body mass index (BMI); b) Body masses by fractioning into five components (in %): muscle, fat, bone, residual and skin, using Kerr's method¹¹; and c) Somatotype, according to the model proposed by Heath and Carter¹². Using the concepts of classification that correspond to the literal translation of the original work.

Statistical Analyses

All the variables were grouped by sport in addition to being divided by gender. For their descriptive analysis, the means and standard deviations were recorded by discipline and gender. The Kolmogorov-Smirnov test was applied to assess the level of normality of the data. The statistical program SPSS 17.0 was used to develop these tests.

Results

Table 1 presents the anthropometric characteristics of the baseline measurements in the athletes belonging to the sport talent development program at the CER, distributed by sport, according to gender. Regarding the variable BMI, only in judo do females present values slightly higher than males.

Table 2 show the results corresponding to the body composition fractionated into five components. With the exception of table tennis, females have a higher percentage of fat mass than males. Exactly the opposite occurs with muscle mass, where males present a higher percentage than females, with the exception of table tennis. Regarding residual mass, males present higher values in all the disciplines. In terms of bone mass, males present a percentage higher than females, whereas in skin mass none of the disciplines have significant differences between the two genders.

With reference to the calculation of the somatotype of the athletes in the CER, Table 3 shows the values distributed according to discipline for both genders. A review of the somatotype classification reveals that all males are in the endo-mesomorph category, with the exception of males in athletics, who are in the ecto-mesomorph category. The female athletes in athletics and table tennis are in the central category, those in cycling and judo in the endomorph–mesomorph category, and those in karate are classified as meso-endomorph.

Figures 1 and 2 contain somatocharts with the somatopoints of the athletes from each of the disciplines at the CER, distributed for females and males, respectively.

Table 1. Baseline anthropometric measurements of the athletes in the CER Program, according to their discipline.

Disciplines	Gender	n	Age		Weight		Height		BMI	
			M	±	M	±	M	±	M	±
Athletics	F	10	15.42	1.56	52.63	7.26	161.39	4.03	20.21	2.83
	M	5	15.8	1.54	63.42	7.29	172.68	10.87	21.36	2.54
Cycling	F	7	15.93	1.98	55.13	8.58	157.31	7.1	22.17	2.11
	M	8	16.41	1.49	66.28	5.27	170.35	6.15	22.93	2.52
Judo	F	8	17.56	1.63	64.71	7.33	158.19	5.39	25.8	1.87
	M	12	17.1	2.53	69.32	8.96	170.1	6.21	24.03	3.46
Karate	F	2	14.3	1.56	54.6	7.35	156.5	2.12	22.35	3.61
	M	6	13.93	1.57	54.28	11.47	154.78	11.08	22.52	3.18
Table Tennis	F	2	13	0.42	45.75	5.3	152.65	1.2	19.6	1.98
	M	12	15.23	2.29	58.38	12.76	163.72	10.56	21.52	2.79

BMI: Body Mass Index; M: Mean; ±: Standard deviation.

Table 2. Body masses expressed as percentages of the athletes in the CER Program, according to their discipline.

Disciplines	Gender	n	% fat mass		% muscle mass		% mass residual		% bone mass		% skin mass	
			M	±	M	±	M	±	M	±	M	±
Athletics	F	10	31.67	2.99	41.01	2.27	9.38	0.8	11.56	1.00	6.38	0.69
	M	5	24.29	3.57	45.43	3.49	11.41	0.84	12.69	0.85	6.19	0.55
Cycling	F	7	32.39	3.45	41.18	3.26	10.07	1.2	10.47	0.9	5.88	0.41
	M	8	26.57	4.43	44.62	3.08	10.79	1.14	12.31	1.8	5.72	0.44
Judo	F	8	33.1	2.29	41.24	1.8	10.22	1.00	10.11	0.71	5.32	0.32
	M	12	22.55	4.09	48.42	4.17	11.71	1.06	11.91	1.08	5.42	0.58
Karate	F	2	33.61	0.57	42.01	0.78	9.48	0.95	8.93	0.45	5.98	0.71
	M	6	25.52	5.18	44.75	3.48	11.31	2.07	12.58	1.21	5.85	0.62
Table Tennis	F	2	29.5	3.46	42.52	0.63	9.86	1.08	11.62	0.92	6.51	0.83
	M	12	29.15	4.21	42.81	3.57	10.28	1.19	11.97	1.36	5.79	0.69

M: Mean; ±: Standard deviation.

Table 3. Somatotype of the athletes in the CER Program, according to their discipline.

Disciplines	Gender	n	Endo		Meso		Ecto		X	Y	Categoría
			M	±	M	±	M	±			
Athletics	F	10	3.25	1.49	3.16	0.75	3.12	1.27	-0.16	-0.08	Central
	M	5	2.02	0.67	4.04	1.28	3.18	1.68	1.14	2.92	Ecto-Mesomorph
Cycling	F	7	4.34	0.91	4.04	0.84	1.81	0.84	-2.54	1.93	Endo-Mesomorph
	M	8	3.09	1.61	4.75	0.64	2.31	1.34	-0.75	4.09	Endo-Mesomorph
Judo	F	8	5.5	0.75	5.25	0.64	0.65	0.46	-4.86	4.35	Endo-Mesomorph
	M	12	2.58	1.2	5.5	1.27	1.96	1.77	-0.61	6.46	Endo-Mesomorph
Karate	F	2	4.5	1.27	3.7	1.27	1.8	1.56	-2.65	1.2	Meso-Endomorph
	M	6	3.28	1.76	5.52	0.76	1.72	1.06	-1.55	6.02	Endo-Mesomorph
Table Tennis	F	2	3	1.27	3.6	0.42	2.7	0.99	-0.3	1.45	Central
	M	12	3.28	1.21	4.92	0.7	2.54	0.96	-0.74	3.98	Endo-Mesomorph

Ecto: Ectomorphy; Meso: Mesomorph; Endo: Endomorphy.

Table 4. Somatotype values of athletes in the CER Program contrasted with the somatotype values of athletes in the CAR.

Disciplines	Gender	Study	n	Endo	Meso	Ecto	X	Y	Category	SDD of SM
Ciclyng	F	CER	7	4.34 ± 0.9	4.04 ± 0.8	1.81 ± 0.8	-2.54	1.93	Endo-Mesomorph	2.95
		CAR	7	3.8 ± 1.8	1.7 ± 4.7	1.9 ± 1.5	-1.3	-0.09	Endomorph Balanced	
	M	CER	8	3.09 ± 1.6	4.75 ± 0.6	2.31 ± 1.3	-0.75	4.09	Endo-Mesomorph	2.11
		CAR	6	3.0 ± 1.3	5.7 ± 1.3	2.0 ± 1.2	-0.7	6.2	Endo-Mesomorph	
Judo	F	CER	8	5.50 ± 0.8	5.25 ± 0.6	0.65 ± 0.5	-4.86	4.35	Endo-Mesomorph	5.55
		CAR	3	3.6 ± 1.3	6.5 ± 0.5	0.7 ± 0.3	-2.8	8.6	Endo-Mesomorph	
	M	CER	12	2.58 ± 1.2	5.50 ± 1.3	1.96 ± 1.8	-0.61	6.46	Endo-Mesomorph	5.23
		CAR	4	2.6 ± 0.3	3.2 ± 7.3	1.5 ± 0.9	-2.2	10.9	Endo-Mesomorph	
Karate	F	CER	2	4.50 ± 1.3	3.70 ± 1.3	1.80 ± 1.6	-2.65	1.2	Meso-Endomorph	4.95
		CAR	2	3.1 ± 0.2	5.2 ± 0.07	1.4 ± 0.3	-1.6	5.8	Endo-Mesomorph	
	M	CER	6	3.28 ± 1.8	5.52 ± 0.8	1.72 ± 1.1	-1.55	6.02	Endo-Mesomorph	3.75
		CAR	3	3.0 ± 1.0	5.8 ± 0.6	1.5 ± 0.4	-3	8.8	Endo-Mesomorph	
Table Tennis	F	CER	2	3.00 ± 1.3	3.60 ± 0.4	2.70 ± 1.0	-0.3	1.45	Central	4.04
		CAR	5	4.6 ± 0.7	4.4 ± 0.7	1.9 ± 0.8	-2.6	2.1	Endo- Mesomorph	
	M	CER	12	3.28 ± 1.2	4.92 ± 0.7	2.54 ± 1.0	-0.74	3.98	Endo-Mesomorph	4.48
		CAR	6	4.4 ± 1.6	4.0 ± 6.6	1.2 ± 1.7	0.5	7.9	Endo-Mesomorph	

CAR: High Performance Center; CER: Regional Training Center; Ecto: Ectomorphy; Meso: Mesomorph; Endo: Endomorphy.

Figure 1. Somatotype of the female athletes in the CER Program, according to their discipline.

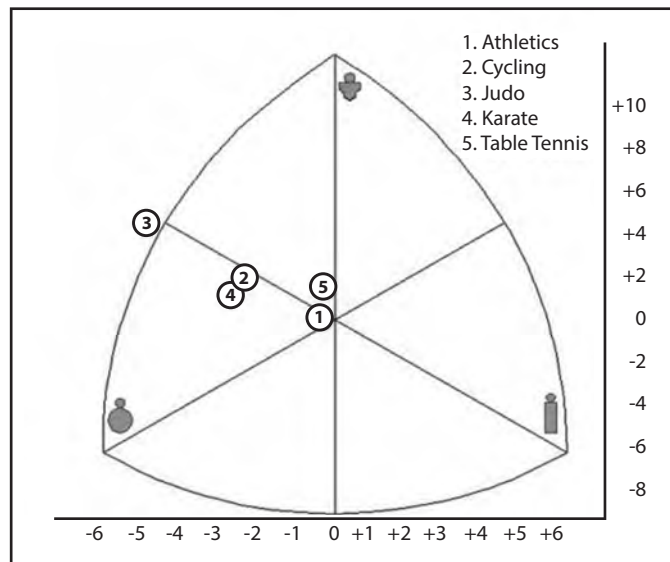
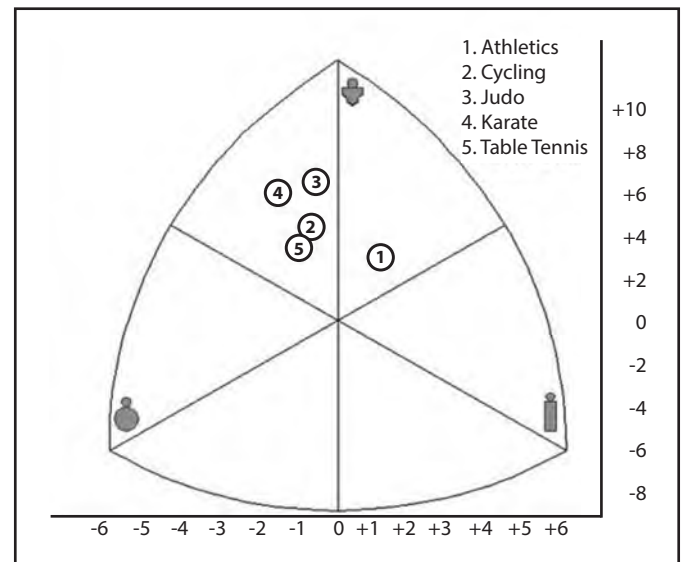


Figure 2. Somatotype of the male athletes in the CER Program, according to their discipline.



Discussion

The present study provides the values of body composition and somatotype by sport discipline and gender in children and adolescents in the sport talent development program at the CER. When analyzing the baseline anthropometric measurements according to gender, with the exception of the athletes in karate, males have higher values in weight and height than females, which is consistent with similar studies involving Chilean children and adolescents^{13,14}. In addition, with the

exception of female Judo and male Karate who are between +1 and +2 standard deviations, all groups are in the range considered normal (median to +1 standard deviation)¹⁵, which is to be expected considering that athletes are a very active population. However, this situation is not of great relevance given that the BMI does not discriminate several variables that influence the nutritional state¹⁶, as occurs in this case, since it concerns athletes. Moreover, considering that it is a sport that is divided into weight categories, it is common that in the combat disciplines the athletes have a slightly higher weight than that of their

category^{17,18}. The contrast of the body composition results obtained in this study with other investigations studying child and adolescent athletes of similar ages is complex, as different methodologies are used to measure this variable, fractioning into four or five components. Nevertheless and in the face of little existing evidence, they serve as a reference to create an image of the similarities or differences between equivalent populations. In that context, in the case of judo, the male athletes in the CER (assessed with the five-component methodology) present higher percentages of muscle mass (48.4%) and fat mass (22.6%) than Spanish adolescent judokas (assessed with the four-component methodology), with 45.6% muscle mass and 14.8% fat mass¹⁹. The female judokas in the CER present a very high percentage of fat (33.1%) compared to data found in the Spanish sample of selected female judokas²⁰, who present a percentage of fat mass of 19.9%, whereas in the percentage of muscle mass there is no evidence of a substantial difference between the two groups (judokas in the CER 41.2%, Spanish judokas 42.5%). In the case of the results obtained for body composition of table tennis athletes, there is a difference with the other sports in the CER, since only in this discipline do females present a higher percentage of muscle mass than males, and males present a higher percentage of fat mass than females. These results could be explained by the reduced size of the female sample, a situation similar to that found in the study by Pradas de la Fuente *et al.*⁴ with selected Spanish table tennis players, where it was also found that the muscle component of females in the junior category was significantly greater than the percentage in males, noting that this could be due to the small sample size. Referring to the body composition in junior athletes in karate, males in the CER present a percentage of fat mass of 25.5%, a much higher value than junior Spanish karatekas (assessed with the four-component methodology), who present 12.2% of fat mass²¹. On the other hand, the percentage of muscle mass in the male karatekas in the CER is slightly less (44.8%) than junior Spanish karatekas, who present a muscle mass of 45.2%.

With respect to the variable somatotype, the results found that the athletes in the CER are different when contrasted with other studies on somatotype in athletes of the same disciplines and categories, there being similarities and differences. On the one hand, in the study of Godoy-Cumillaf *et al.*¹⁴, the athletes belonging to the schools of karate present a somatotypical classification of endo-mesomorph in the men of both groups, whereas in the women it is categorized as mesomorph-endomorph, unlike the CER that was meso-endomorph. Likewise, in the discipline of athletics, in both studies, male athletes present a somatotype categorized as ecto-mesomorphic and central in women. On the other hand, in judo and table tennis results differed as to the somatotype found in other studies. In the former, the athletes in the CER are categorized as endo-mesomorph, which differs from the somatotype of the Spanish judokas in a similar category, since the most common categorization is balanced ectomorph¹⁹. In the case of females, the judokas in the CER were classified as endomorph-mesomorph, which differs from the results of female judokas from Spain of the same age, categorized as endo-mesomorph²⁰. Regarding table tennis, the somatotype of males in the CER, classified as endomorph-mesomorph, also does not coincide with the table tennis players from Spain, who are classified as balanced mesomorph²². In the case of female table tennis players, the athletes in the CER are categorized as having a central

somatotype, whereas the Spanish table tennis players are classified as meso-endomorph²².

In addition to comparing the somatotypes of the athletes in the CER with other studies that analyze similar variables, specifically discipline and age, and despite these athletes still being in a stage of structural development, it seems important to establish a contrast with elite adult athletes, whose reference appears as the somatotype value “to look for” by the current talents who are expected to be the future elite athletes in Chile, since an athlete performs better when their physical configuration is similar to the model for their sport¹². Table 4 shows the somatotype values of the disciplines in the CER and the somatotype values of the nationally selected athletes at the High Performance Center (Centro de Alto Rendimiento (CAR) in Spanish), although without considering the athletics athletes because the data in the study by Rodriguez *et al.*²³ differentiate the athletes according to groups of track and field disciplines. A contrast of the values of the athletes at the CER and the CAR shows that the male cyclists, judokas, and karatekas in the CER are consistent in biotypical classification with the somatotype of the adult athletes at the CAR in their respective disciplines. However, a bidimensional comparison of the group of athletes in the CER with the athletes at the CAR as a reference, using the somatotype dispersion distance (SDD) of the somatotype mean (SM)²⁴ between the two groups, shows significant distances ($SDD \geq 2.0$), with these being considered as different groups.

Conclusions

Considering that in each region of Chile there is a Regional Training Center dedicated to the development of children and adolescents with sport talent, this study is relevant as it provides data on a subject for which there is little information, making it a useful tool for teachers and trainers in this program. Thus, the recommendations made by De Rose and Guimaraes²⁵ can be followed, modifying the training in the direction suitable for adopting the somatotype according to age, the components (meso and endomorphic) and the discipline, to decide correctly whether to train strength to increase mesomorphy or to control caloric intake and increase the volume of training to reduce endomorphy.

Considering that the children and adolescents in the sport talent development program are still at an important stage of development, the physical structure of these athletes will be modified according to their evolution during their pubertal development and maintaining or increasing the volume and intensity of training according to the sport advances and the biological support they possess²⁶. Additionally, the characteristics studied demonstrate several differences between genders for the same practice of a sport. Consequently, this study gives referential values to be taken into account by other populations of up-and-coming athletes and without a doubt, more research on this topic may contribute to recognizing better anthropometric aptitudes linked to sport development and thus provide a more detailed background for the planning and optimization of training potential elite athletes.

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Conflict of interest

The authors do not declare a conflict of interest.

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Normas de publicación de Archivos de Medicina del Deporte

La Revista ARCHIVOS DE MEDICINA DEL DEPORTE (Arch Med Deporte) con ISSN 0212-8799 es la publicación oficial de la Sociedad Española de Medicina del Deporte (SEMED). Edita trabajos originales sobre todos los aspectos relacionados con la Medicina y las Ciencias del Deporte desde 1984 de forma ininterrumpida con una periodicidad trimestral hasta 1995 y bimestral a partir de esa fecha. Se trata de una revista que utiliza fundamentalmente el sistema de revisión externa por dos expertos (*peer-review*). Incluye de forma regular artículos sobre investigación clínica o básica relacionada con la medicina y ciencias del deporte, revisiones, artículos o comentarios editoriales, y cartas al editor. Los trabajos podrán ser publicados EN ESPAÑOL O EN INGLÉS. La remisión de trabajos en inglés será especialmente valorada.

En ocasiones se publicarán las comunicaciones aceptadas para presentación en los Congresos de la Sociedad.

Los artículos Editoriales se publicarán sólo previa solicitud por parte del Editor.

Los trabajos admitidos para publicación quedarán en propiedad de SEMED y su reproducción total o parcial deberá ser convenientemente autorizada. Todos los autores de los trabajos deberán enviar por escrito una carta de cesión de estos derechos una vez que el artículo haya sido aceptado.

Envío de manuscritos

1. Los trabajos destinados a publicación en la revista Archivos de Medicina del Deporte se enviarán a través del sistema de gestión editorial de la revista (<http://archivosdemedicinadeldeporte.com/revista/index.php/amd>).
2. Los trabajos deberán ser remitidos, a la atención del Editor Jefe.
3. Los envíos constarán de los siguientes documentos:
 - a. **Carta al Editor** de la revista en la que se solicita el examen del trabajo para su publicación en la Revista y se especifica el tipo de artículo que envía.
 - b. **Página de título** que incluirá exclusivamente y por este orden los siguiente datos: Título del trabajo (español e inglés), nombre y apellidos de los autores en este orden: primer nombre, inicial del segundo nombre si lo hubiere, seguido del primer apellido oficial y académica, centro de trabajo, dirección completa y dirección del correo electrónico del responsable del trabajo o del primer autor para la correspondencia. También se incluirán los apoyos recibidos para la realización del estudio en forma de becas, equipos, fármacos...
 - c. **Manuscrito**. Debe escribirse a doble espacio en hoja DIN A4 y numerados en el ángulo superior derecho. Se recomienda usar formato Word, tipo de letra Times New Roman tamaño 12.

Este texto se iniciará con el título del trabajo (español e inglés), resumen del trabajo en español e inglés, que tendrá una extensión de 250-300 palabras. Incluirá la intencionalidad del trabajo (motivo y objetivos de la investigación), la metodología empleada, los resultados más destacados y las principales conclusiones. Ha de estar redactado de tal modo que permita comprender la esencia del artículo sin leerlo total o parcialmente. Al pie de cada resumen se especificarán de tres a diez palabras clave en castellano e inglés (keyword), derivadas del Medical Subject Headings (MeSH) de la National Library of Medicine (disponible en: <http://www.nlm.nih.gov/mesh/MBrowser.html>).

Después se escribirá el texto del trabajo y la bibliografía.

En el documento de texto, al final, se incluirán las leyendas de las tablas y figuras en hojas aparte.

- d. **Tablas**. Se enviarán en archivos independientes en formato JPEG y en formato word. Serán numeradas según el orden de aparición en el texto, con el título en la parte superior y las abreviaturas descritas en la parte inferior. Todas las abreviaturas no estándar que se usen en las tablas serán explicadas en notas a pie de página.

Las tablas se numerarán con números arábigos según su orden de aparición en el texto.

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- e. **Figuras**. Se enviarán en archivos independientes en formato JPEG de alta resolución. Cualquier tipo de gráficos, dibujos y fotografías serán denominados figuras. Deberán estar numeradas correlativamente según el orden de aparición en el texto y se enviarán en blanco y negro (excepto en aquellos trabajos en que el color esté justificado).

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- f. **Propuesta de revisores**. El responsable del envío propondrá un máximo de cuatro revisores que el editor podrá utilizar si lo considera necesario. De los propuestos, uno al menos será de nacionalidad diferente del responsable del trabajo. No se admitirán revisores de instituciones de los firmantes del trabajo.
- g. **Carta de originalidad y cesión de derechos**. Se certificará, por parte de todos los autores, que se trata de un original que no ha sido previamente publicado total o parcialmente.
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Normas de publicación

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En el sistema de gestión editorial de la revista se encuentran modelos de los documentos anteriores.
4. La extensión del texto variará según la sección a la que vaya destinado:
 - a. **Originales:** Máximo de 5.000 palabras, 6 figuras y 6 tablas.
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 - a. **ORIGINALES:** Constará de una **introducción**, que será breve y contendrá la intencionalidad del trabajo, redactada de tal forma que el lector pueda comprender el texto que le sigue. **Material y método:** Se expondrá el material utilizado en el trabajo, humano o de experimentación, sus características, criterios de selección y técnicas empleadas, facilitando los datos necesarios, bibliográficos o directos, para que la experiencia relatada pueda ser repetida por el lector. Se describirán los métodos estadísticos con detalle. **Resultados:** Relatan, no interpretan, las observaciones efectuadas con el material y método empleados. Estos datos pueden publicarse en detalle en el texto o bien en forma de tablas y figuras. No se debe repetir en el texto la información de las tablas o figuras. **Discusión:** Los autores expondrán sus opiniones sobre los resultados, posible interpretación de los mismos, relacionando las propias observaciones con los resultados obtenidos por otros autores en publicaciones similares, sugerencias para futuros trabajos sobre el tema, etc. Se enlazarán las conclusiones con los objetivos del estudio, evitando afirmaciones gratuitas y conclusiones no apoyadas por los datos del trabajo. Los **agradecimientos** figurarán al final del texto.
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La abreviatura de la revista Archivos de Medicina del Deporte es *Arch Med Deporte*.

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 - **Capítulo en libro:** Número de orden; autores, título del capítulo, editores, título del libro, ciudad, editorial, año y páginas. Ejemplo: Iselin E. Maladie de Kienbock et Syndrome du canal carpien. En: Simon L, Alieu Y. *Poignet et Medecine de Reeducation*. Londres: Collection de Pathologie Locomotrice Masson; 1981. p. 162-6.
 - **Libro.** número de orden; autores, título, ciudad, editorial, año de la edición, página de la cita. Ejemplo: Badius R. *Ecografía muscular de la extremidad inferior. Sistemática de exploración y lesiones en el deporte*. Barcelona. Editorial Masson; 2005. p. 34.
 - **Material electrónico,** artículo de revista electrónica: Ejemplo: Morse SS. Factors in the emergence of infectious diseases. *Emerg Infect Dis*. (revista electrónica) 1995 JanMar (consultado 0501/2004).
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Ética

Los autores firmantes de los artículos aceptan la responsabilidad definida por el Comité Internacional de Editores de Revistas Médicas <http://www.wame.org/> (World Association of Medical Editors).

Los trabajos que se envían a la Revista ARCHIVOS DE MEDICINA DEL DEPORTE para evaluación deben haberse elaborado respetando las recomendaciones internacionales sobre investigación clínica y con animales de laboratorio, ratificados en Helsinki y actualizadas en 2008 por la Sociedad Americana de Fisiología (<http://www.wma.net/es/10home/index.html>).

Para la elaboración de ensayos clínicos controlados deberá seguirse la normativa CONSORT, disponible en: <http://www.consort-statement.org/>.

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Miguel Ángel López

Campeón del Mundo en 20 km. marcha (Pekín, 2015)
Estudiante y deportista de la UCAM



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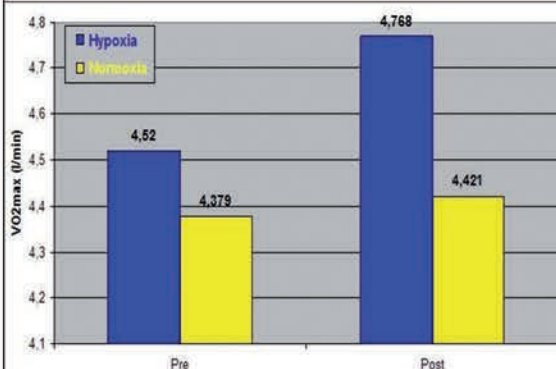
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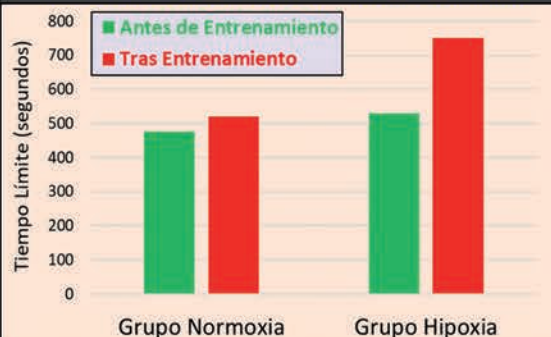


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