ISSN: 0212-8799

214
Volume 40 (2)
March - April 2023

Archivos de medicina del deporte

Órgano de expresión de la Sociedad Española de Medicina del Deporte

ORIGINAL ARTICLES

ARCHIVOS DE MEDICINA DEL DEPORTE

UCAM
Universidad Católica San Antonio

SMD
Sociedad Española de Medicina del Deporte

CELAD
Comisión Española para la Lucha Antidopaje en el Deporte

CSD
Consejo Superior de Deportes

UCAM Universidad Católica San Antonio de Murcia

Campus de los Jerónimos,
Nº 135 Guadalupe 30107

(Murcia) - España

Tlf: (+34)968 27 88 01 · info@ucam.edu

UCAM
UNIVERSIDAD
CATÓLICA DE MURCIA

Sociedad Española de Medicina del Deporte

Archivos de medicina del deporte

Revista de la Sociedad Española de Medicina del Deporte

Afiliada a la Federación Internacional de Medicina del Deporte, Sociedad Europea de Medicina del Deporte y Grupo Latino y Mediterráneo de Medicina del Deporte

Sociedad Española de Medicina del Deporte

Junta de Gobierno
Presidente
Miguel Enrique del Valle Soto
Vicepresidente
Gonzalo María Correa González
Secretario General
Luis Franco Bonafonte
Tesorero
Javier Pérez Ansón
Vocales
Ostaiska Eguia Lecumberri
Francisco Javier Rubio Pérez
Mª Concepción Ruiz Gómez
Ex-Presidente
Pedro Manonelles Marqueta

Edita
Sociedad Española de Medicina del Deporte
C/ Cánovas nº 7, local
50004 Zaragoza (España)
Tel. +34 976 02 45 09
femede@femede.es
www.femede.es

Correspondencia:
C/ Cánovas nº 7, local
50004 Zaragoza (España)
archmeddeporte@semede.es
http://www.archivosdemedicinadeldeporte.com/

Publicidad
ESMON PUBLICIDAD
Tel. 93 2159034

Publicación bimestral
Un volumen por año

Depósito Legal
Zaragoza. Z 988-2020

ISSN
0212-8799

Soporte válido
Ref. SVR 389

Indexada en: EMBASE/Excerpta Medica, Índice Médico Español, Sport Information Resource Centre (SIRC), Índice Bibliográfico Español de Ciencias de la Salud (IBECS), Índice SJR (SCImago Journal Rank), y SCOPUS

La dirección de la revista no acepta responsabilidades derivadas de las opiniones o juicios de valor de los trabajos publicados, la cual recaerá exclusivamente sobre sus autores.
Esta publicación no puede ser reproducida total o parcialmente por ningún medio sin la autorización por escrito de los autores.
Cualquier forma de reproducción, distribución, comunicación pública o transformación de esta obra sólo puede ser realizada con la autorización de sus titulares, salvo excepción prevista por la ley.
Diríjase a CEDRO (Centro Español de Derechos Reprográficos, www.cedro.org) si necesita fotocopiar o escanear algún fragmento de esta obra.

Director
Pedro Manonelles Marqueta

Editor
Miguel E. Del Valle Soto

Administración
Melissa Artajona Pérez

Adjunto a dirección
Oriol Abellán Aynés

Comité Editorial

Norbert Bachl. Centre for Sports Science and University Sports of the University of Vienna. Austria. **Araceli Boraita.** Servicio de Cardiología. Centro de Medicina del Deporte. Consejo Superior de deportes. España. **Mats Borjesson.** University of Gothenburg. Suecia. **Josep Brugada Terradellas.** Hospital Clinic. Universidad de Barcelona. España. **Maria Cascais.** Presidenta de la Sociedade Portuguesa de Medicina Desportiva. Lisboa (Portugal). **Ana Cintrón-Rodríguez.** Puerto Rico. Departamento de Medicine Física y Rehabilitación VA Caribbean Healthcare System. San Juan. Puerto Rico. **Nicolas Christodoulou.** President of the UEMS MJC on Sports Medicine. Chipre. **Demitri Constantinou.** University of the Witwatersrand. Johannesburgo. Sudáfrica. **Jesús Dapena.** Indiana University. Estados Unidos. España. **Walter Frontera.** Universidad de Vanderbilt. Past President FIMS. Estados Unidos. **Teresa Gaztañaga Aurrekoetxea.** Médico responsable nutrición y fisiología del esfuerzo. Hospital Quirón. San Sebastián. **Dusan Hamar.** Research Institute of Sports. Eslovaquia. **José A. Hernández Hermoso.** Servicio COT. Hospital Universitario Germans Trias i Pujol. España. **Pilar Hernández Sánchez.** Universidad Católica San Antonio. Murcia. España. **Anca Ionescu.** University of Medicine "Carol Davila". Bucarest. Rumanía. **Markku Jarvinen.** Institute of Medical Technology and Medical School. University of Tampere. Finlandia. **Anna Jegier.** Medical University of Lodz. Polonia. **Peter Jenoure.** ARS Ortopedica, ARS Medica Clinic, Gravesano. Suiza. **José A. López Calbet.** Universidad de Las Palmas de Gran Canaria. España. **Javier López Román**. Universidad Católica San Antonio. Murcia. España. **Alejandro Lucía Mulas.** Universidad Europea de Madrid. España. **Emilio Luengo Fernández.** Servicio de Cardiología. Hospital General de la Defensa. España. **Nicola Maffully.** Universidad de Salerno. Salerno (Italia). **Alejandro Martínez Rodríguez**. Universidad de Alicante. España. **Estrella Núñez Delicado**. Universidad Católica San Antonio. Murcia. España. **Sakari Orava.** Hospital Universitario. Universidad de Turku. Finlandia. **Eduardo Ortega Rincón.** Universidad de Extremadura. España. **Nieves Palacios Gil-Antuñano.** Centro de Medicina del Deporte. Consejo Superior de Deportes. España. **Antonio Pelliccia.** Institute of Sport Medicine and Science. Italia. **Fabio Pigozzi.** University of Rome Foro Italico, President FIMS. Italia. **Yannis Pitsiladis.** Centre of Sports Medicine. University of Brighton. Inglaterra. **Per Renström.** Stockholm Center for Sports Trauma Research, Karolinska Institutet. Suecia. **Juan Ribas Serna.** Universidad de Sevilla. España. **Peter H. Schober.** Medical University Graz. Austria. **Jordi Segura Noguera.** Laboratorio Antidopaje IMIM. Presidente Asociación Mundial de Científicos Antidopajes (WAADS). España. **Giulio Sergio Roi.** Education & Research Department Isokinetic Medical Group. Italia. **Luis Serratosa Fernández.** Servicios Médicos Sanitas Real Madrid CF. Madrid. España. **Nicolás Terrados Cepeda.** Unidad Regional de Medicina Deportiva del Principado de Asturias. Universidad de Oviedo. España. **José Luis Terreros Blanco.** Director de la Agencia Estatal Comisión Española para la Lucha Antidopaje en el Deporte. CELAD. **Rosa Ventura Alemany.** Directora del Laboratorio Antidopaje de Cataluña (IMIM). **Mario Zorzoli.** International Cycling Union. Suiza. **Petra Zupet.** IMS Institute for Medicine and Sports. Liubliana. Eslovenia.

ANALIZADOR de LACTATO LAK-EN310

La App permite la exportación de datos en formato .CSV
No realiza gráficos

OFERTA PLAN RENOVE

Haznos llegar tu analizador de Lactato antiguo y te enviaremos un **Lak-EN310 y 50 tiras reactivas** por solo **122,21 €**

OFERTA

- ✔ Tiempo de análisis: solo 10 segundos
- ✔ Solo requiere 0,8 µl de sangre
- ✔ Rango de medición: 0,5 – 18,0 mmol/L
- ✔ Las tiras incluyen electrodos de oro que mejoran la fiabilidad y precisión de los resultados
- ✔ Memoria para 800 resultados
- ✔ Incluye una App en Android e iOS para la transmisión de datos vía Bluetooth

Laktate
www.laktate.com

619 284 022

Archivos
de medicina del deporte
Volume 40(2) - Num 214. March - April 2023 / *Marzo - Abril 2023*

Summary / Sumario

Editorial

Original articles / Originales

The prevention of accidents in extreme sports

Prevención de accidentes en deportes extremos

Miguel del Valle

Catedrático de la Facultad de Medicina. Universidad de Oviedo.

doi: 10.18176/archmeddeporte.00120

The practice of physical activity, as well as participation in competitive sports, right up to the highest level of competition, offers considerable health benefits. However, these athletes may also face a risk of sustaining injuries and illnesses of varying degrees of severity, including the sudden death of the athlete or a fatal accident.

Serious injuries that could affect the CNS are relatively frequent in some competitive sports, including American football, rugby, ice hockey, boxing and wrestling.

All these sports are governed by regulations that include rules of the game, sports materials, safety protections on the playing field and specific accessories directed at the prevention of injuries, such as helmets, mouthguards, eye protection, gloves, wrist guards, elbow guards, ankle guards and special footwear. Furthermore, all teams are required to be supervised by a doctor who will monitor the athletes' state of health, supervise injuries, the duration of sick leave due to injury, and the moment when the athletes restart training and competitions.

These sports have a known and controlled risk of injuries and accidents and the rules of the game are progressively modified in order to guarantee the safety of the athletes.

However, other types of sports are now becoming increasingly popular, grouped under the term extreme or adventure sports. These extreme sports, which present some important differences when compared to traditional ones, include land sports such as snowboarding, Alpine skiing, sport climbing, skateboarding, mountain biking and ultra-endurance races, air sports such as bungee jumping, parachuting, hang gliding, and base jumping, and water sports such as scuba diving, white-water rafting and surfing.

All are considered to be high-risk, extremely dangerous sports due to the inhospitable environments and conditions in which they are practised. Although some are already organised, most are performed in adverse environmental conditions with no regulations or medical supervision, despite the high risk of serious injury and even death.

For these athletes, the risk represents a physical and mental challenge that brings pleasure and satisfaction and involves a physical and emotional release. All these sports are having a major social impact and the number of participants has been steadily increasing over the last few years.

Most of these activities are practised at high speed, great heights or extreme temperatures, involving a real or perceived risk and requiring a high level of physical strength, leading to the overload of many organs and systems. These athletes are required to exert full concentration given that a single mistake in some activities, which can occur in a fraction of a second, could be fatal.

The type and severity of injuries and accidents in extreme sports can vary considerably, depending on the sport in question and on many other circumstances that have received little scientific analysis to date. Minor injuries frequently occur when practising these sports, although there is still a risk of more serious injuries. Fractures, sprains and muscle injuries caused by falls, direct impact, etc. are more frequent than when practising traditional sports.

Injuries to the head and neck, which frequently lead to cranioencephalic trauma (CET) or spinal injuries are of greatest concern due to their consequences in the short and long term. Although existing studies show that the risk of head and neck injuries, and also the percentage of fatal accidents is low, the number of serious injuries sustained during the practice of extreme sports has been increasing in the last few decades as these sports become more popular. The injury mechanisms for all these sports are less well-known than for traditional sports due to the fact that

Correspondence: Miguel del Valle
E-mail: miva@uniovi.es

there are no reliable records. Injuries are generally a result of human mistakes made either by novices or by experts taking extreme risks.

Many of these athletes depend on sponsors to earn their living with their sport and this has a great bearing on increased risk in order to obtain some impressive images. If it were possible to change this situation, then the risk of serious accidents would decrease.

What can be done to reduce the risk of accidents in extreme sports?

From a medical point of view, all these sports carry a greater risk of serious injury than traditional sports, given that the athletes may be affected by the heat, cold, deep waters or great heights and, although there are few serious scientific studies to support this, CET is known to be more frequent than in traditional sports.

Until now, medical services have paid little attention to all these sports and there are but few well-designed scientific investigations of related injuries. In general, sports medicine specialists have very little training in the risks involved in the practice of extreme and adventure sports, although there is some specific training in some countries. In order to provide good medical care, it is necessary to understand the health risks faced by the athletes participating in these sports.

The health of these athletes can be seriously at risk during the rescue operation, therefore the doctor assisting the injured athlete must be trained to deal with accidents of this nature.

The factors causing injuries in extreme sports depend on many variables and it is only possible to act on those variables that are controllable. Thus, the introduction of a series of safety measures in these sports would prevent many injuries and accidents.

While in other types of sport an accident or mistake may cause an injury, in extreme sports it could prove fatal.

In order to better prevent injuries caused by the practice of sports of this nature, the doctors responsible for these patients must have a sound understanding of the sports in question, the environment in which they are practised, environmental factors, materials used, training methodology and many other aspects such as psychological factors and potential trauma mechanisms. It is also extremely important to understand the motivations of these athletes and to have specific training in order to offer them individualised medical care.

There is a need to implement effective prevention schemes for all these sports. Among the accident prevention measures for extreme sports, consideration should be given to the following:

- Mandatory sports medical examination for anyone practising extreme sports, assessing the ability of each athlete for the specific sport in question.
- It is also important to improve the quality of the risk assessment of each sport and to make individual assessments.
- Control the nutrition and dietary supplements based on the energy needs of these athletes.
- Establish age limits for practising these sports.
- Monitor symptoms of fatigue and overtraining given that these increase the risk of accidents.
- Participants in extreme sports must have suitable physical preparation and training.
- Conduct psychological work on those obsessed with the need for risk.
- With regard to the strategy to prevent serious or fatal accidents, sportswear must be considered as well as the use of protective equipment such as helmets, gloves and joint protectors, given that the margins of error in all these sports are very small.
- For mountain and snow sports, it is very important to monitor the environmental variables (weather conditions) and to take them into account when planning the activity.
- Use of the social media to improve the dissemination of injury prevention mechanisms, to ensure that these athletes are more aware of the risk and how to prevent accidents.
- The establishment of specific locations and spaces to practice the different types of extreme sports would also considerably improve accident prevention, taking account of the possibilities of evacuation and the action of the medical services.

Recommended bibliography

- Brymer E, Feletti F. Beyond risk: the importance of adventure in the everyday life of young people. *Annals of Leisure Research*. 2020;23:429-46.
- Caine DJ. The epidemiology of injury in adventure and extreme sports. *Med Sport Sci*. 2012;58:1-16.
- Emery CA. Injury prevention in kids' adventure and extreme sports: future directions. *Res Sports Med*. 2018;26(sup1):199-211.
- Feletti F. *Extreme Sports Medicine*. Springer; Cham, Switzerland: 2017.
- Gomez AT, Rao A. Adventure and Extreme Sports. *Med Clin North Am*. 2016;100:371-91.
- Laver L, Pengas IP, Mei-Dan O. Injuries in extreme sports. *J Orthop Surg Res*. 2017;12:59. doi: 10.1186/s13018-017-0560-9.
- Monasterio E, Mei-Dan O, Hackney AC, Lane AR, Zwir I, Rozsa S, Cloninger CR. Stress reactivity and personality in extreme sport athletes: The psychobiology of BASE jumpers. *Physiol Behav*. 2016;167:289-97.
- Peterson AR, Gregory AJ. Extreme Sports and the Adolescent Athlete. *Adolesc Med State Art Rev*. 2015;26:208-20.
- Sharma VK, Rango J, Connaughton AJ, Lombardo DJ, Sabesan VJ. The Current State of Head and Neck Injuries in Extreme Sports. *Orthop J Sports Med*. 2015;3(1): 2325967114564358. doi: 10.1177/2325967114564358.
- Trease L, Albert E, Singleman G, Brymer E. What Is an Extreme Sports Healthcare Provider: An Auto-Ethnographic Study of the Development of an Extreme Sports Medicine Training Program. *Int J Environ Res Public Health*. 2022;19(14):8286. doi: 10.3390/ijerph19148286.

Analizador Instantáneo de Lactato

Lactate Pro 2

arkray

LT-1730

- Sólo 0,3 µl de sangre
- Determinación en 15 segundos
- Más pequeño que su antecesor
- Calibración automática
- Memoria para 330 determinaciones
- Conexión a PC
- Rango de lectura: 0,5-25,0 mmol/litro
- Conservación de tiras reactivas a temperatura ambiente y
- Caducidad superior a un año

TÜV PRODUCT SERVICE Quality system certified to DIN EN ISO 9001
ISO 9001 CERTIFIED

Importador para España:

francisco j. bermell ELECTROMEDICINA
www.bermellelectromedicina.com
EQUIPOS PARA EL DEPORTE Y LA MEDICINA DEL DEPORTE

c/ Lto. Gabriel Miro, 54, ptas. 7 y 9
46008 Valencia Tel: 963857395
Móvil: 608848455 Fax: 963840104
info@bermellelectromedicina.com
www.bermellelectromedicina.com

Bermell Electromedicina | @BermellElectromedicina | Bermell Electromedicina

Monografías Femede nº 12
Depósito Legal: B. 27334-2013
ISBN: 978-84-941761-1-1
Barcelona, 2013
560 páginas.

Índice

Foreward
Presentación
1. Introducción
2. Valoración muscular
3. Valoración del metabolismo anaeróbico
4. Valoración del metabolismo aeróbico
5. Valoración cardiovascular
6. Valoración respiratoria
7. Supuestos prácticos
Índice de autores

Dep. Legal: B.24072-2013
ISBN: 978-84-941074-7-4
Barcelona, 2013
75 páginas. Color

Índice

Introducción
1. Actividad mioeléctrica
2. Componentes del electrocardiograma
3. Crecimientos y sobrecargas
4. Modificaciones de la secuencia de activación
5. La isquemia y otros indicadores de la repolarización
6. Las arritmias
7. Los registros ECG de los deportistas
8. Términos y abreviaturas
9. Notas personales

Información: www.femede.es

Original article

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

Ningyi Zhang[1], Sebastián Gómez-Lozano[1], Ross Armstrong[2], Hui Liu[3], Alfonso Vargas-Macías[4]

[1]UCAM Universidad Catolica de Murcia. Murcia. Spain. [2]University of Cumbria. Carlisle. England. [3]Beijing Sport University. Beijing. China. [4]Telethusa Centre for Flamenco Research. Cádiz. Spain.

doi: 10.18176/archmeddeporte.00121

Received: 30/09/2022
Accepted: 03/11/2022

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 accelerometery. 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 bailaoras 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 bailarines 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.

Correspondence: Sebastián Gómez-Lozano
E-mail: sglozano@ucam.edu

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 risk[1-3]. Injuries have been reported in various styles of dance[4-8], including flamenco dance and a high incidence of injuries is prevalent in the lower limbs, lumbar and cervical vertebrae[9-11]. 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 dancers[7]. 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 risks[19-21].

Previous studies indicated that range of motion (ROM) is an important contributor to dance performance[22]. Efficient ankle function is fundamental to success in dance and is an important factor in establishing low extremity stability between the leg and the foot[23] and can improve dance performance[24]. Ankle ROM is related to the injury development[25-27], and research has suggested that reduced right ankle plantarflexion is a risk factor for injury between injured and non-injured pre-professional dancers[28] 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 syndrome[30].

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 injury[31]. 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 performance[33], 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 joints[10]. The footwork technique requires dancers to use different foot locations to strike the floor and produce a rhythmic and loud sound[34], and the huge vibration produced during this time[11], 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 injuries[9]. 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 base[35]. Furthermore, the frequency of this step can reach 11.8 steps for each second[34]. 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 overusing 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 hypothesis 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/m^2; 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/m^2; 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 bone[33].

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 with[39-41]. 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); snd 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 respectively. 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).

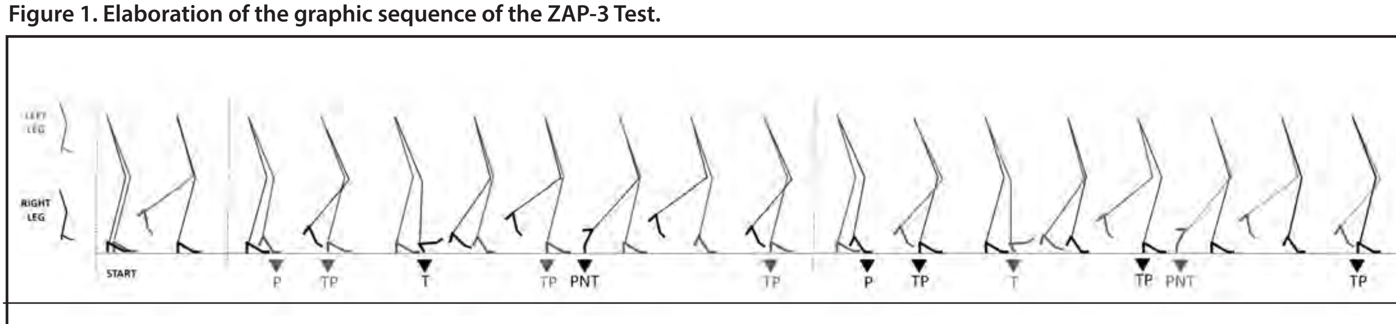
External load measurement during footwork: Playerload

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 ± 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 to1.00 (-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 correlation[44]. 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, Plantarflexion 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% at160 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	160	0.357	0.809	0.099	-0.378
au	180	0.347	0.71	-0.003	-0.383
	F	0.417	0.684	-0.01	-0.006
DA-PLml	160	0.177	0.77	0.355	-0.419
au	180	0.233	0.74	0.27	-0.413
	F	0.146	0.682	0.171	0.041
DA-PLv	160	0.478	0.783	-0.227	-0.372
au	180	0.36	0.626	-0.238	-0.381
	F	0.505	0.579	-0.17	-0.021
DA-PLap	160	0.634	0.916*	-0.115	-0.294
au	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). $P<.001$
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 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).

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
	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).

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 floor[34]. 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 style[45]. Therefore, active dorsiflexion and plantarflexion may potentially affect the performance of this technical step[45]. 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 injured[46].

In flamenco dance, professionals showed greater negative perception about pain and injuries than flamenco dance student[14]. 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 ROM[47] 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 athletes[48] and a lack of strength in the muscles around the joints often limit the active ROM, which may decrease joint stability[49]. Ligament laxity may contribute to the high prevalence of lower limb injuries in dancers[50]. Furthermore, increasing arch height is associated with decreased mediolateral control of single-limb stance[51]. 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 balance[52].

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 incidence[27] 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 syndrome[30]. Pedersen[45] 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°). Bejjani[54] 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-Méndez[55] 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 walking[35] 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 technique 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.

Accelerometery 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.

Acknowledgments

The authors would like to thank the subjects for participating in this study.

Conflict of interest

The authors do not declare a conflict of interest.

Bibliography

1. Angioi M, Metsios G, Koutedakis Y, Wyon MA. Fitness in contemporary dance: a systematic review. *Int J Sports Med.* 2009;30:475-84.
2. Bronner S, Ojofeitimi S, Spriggs J. Occupational musculoskeletal disorders in dancers. *Phys Ther.* 2003;8:57-68.
3. Motta-Valencia K. Dance-related injury. *Phys Med Rehabil Clin N Am.* 2006;17:697-723.
4. Allen N, Nevill AM, Brooks JH, Koutedakis Y, Wyon MA. The effect of a comprehensive injury audit program on injury incidence in ballet: a 3-year prospective study. *Clin J Sport Med.* 2013;23:373-8.

5. Cardoso AA, Reis NM, Vieira MDCS, Borgatto AF, Folle A, Guimarães ACDA. Associated factors and profile of injuries in professional ballroom dancers in Brazil: a cross-sectional study. *Mot Rev de Educ Fis*. 2020;26.
6. Dang Y, Koutedakis Y, Wyon M. Fit to Dance Survey: elements of lifestyle and injury incidence in Chinese dancers. *Med Probl Perform Art*. 2020;35:10-8.
7. Domene PA, Stanley M, Skamagki G. Injury surveillance of nonprofessional salsa dance. *J Phys Act Health*. 2018;15:774-80.
8. Uršej, Eva, Zaletel P. Injury occurrence in modern and hip-hop dancers: A systematic literature review. *Zdr Varst*. 2020;59:195-201.
9. Baena-Chicón I, Gómez-Lozano S, Abenza-Cano L, de Vicuña OAG, Fernández-Falero MR, Vargas-Macías A. Las algias como factor predisponente de lesión en estudiantes de baile flamenco. (Algias as a predisposing factor of injury in flamenco dance students). *Cult. Cienc. y Deporte*. 2020;15:245-53.
10. Forczek W, Baena-Chicón I. Vargas-Macías A. Variación de la posición del centro de gravedad en una bailaora profesional durante el zapateado flamenco. *Rev Cent Investig Telethusa*. 2016;9:30-6.
11. Pedersen M, Elizabeth, Wilmerding V. Injury profiles of student and professional flamenco dancers. *J Dance Med Sci*. 1998;2:108-14.
12. Vassallo AJ, Pappas E, Stamatakis E, Hiller CE. Differences in the occurrence and characteristics of injuries between full-time and part-time dancers. *BMJ Open Sport Exerc. Med*. 2018;4:e000324.
13. Wainwright SP, Williams C, Turner BS. Fractured identities: injury and the balletic body. *Health (London)*. 2005;9:49-66.
14. Baena-Chicón I, Gómez-Lozano S, Cano LA. Vargas-Macías A. Pain catastrophizing in Flamenco dance students at professional dance conservatories. *Arch de Medicina del Deporte*. 2021;86-90.
15. Steinberg N, Hershkovitz I, Zeev A, Rothschild B, Siev-Ner I. Joint hypermobility and joint range of motion in young dancers. *J Clin Rheumatol*. 2016;22:171-8.
16. Campoy FAS, de Oliveira Coelho LR, Bastos FN, Júnior JN, Vanderlei LCM, Monteiro HL, Padovani CR, Pastre CM. Investigation of risk factors and characteristics of dance injuries. *Clin J Sport Med*. 2011;21:493-8.
17. Vetter RE, Symonds ML. Correlations between injury, training intensity, and physical and mental exhaustion among college athletes. *J Strength Cond. Res*. 2010;24:587-96.
18. Young A, Paul L. Incidence of Achilles tendon injuries in competitive Highland dancers. *J Dance Med Sci*. 2002;6:46-9.
19. Cummins C, Welch M, Inkster B, Cupples B, Weaving D, Jones B, King D, Murphy A. Modelling the relationships between volume, intensity and injury-risk in professional rugby league players. *J Sports Sci Med*. 2019;22:653-60.
20. Drew MK, Finch CF. The relationship between training load and injury, illness and soreness: a systematic and literature review. *Sports Med*. 2016;46:861-83.
21. Jaspers A, Kuyvenhoven JP, Staes F, Frencken WG, Helsen WF, Brink MS. Examination of the external and internal load indicators' association with overuse injuries in professional soccer players. *J Sci Med Sport*. 2018;21:579-85.
22. Deighan MA. Flexibility in dance. *J Dance Med Sci*. 2005;9:13-7.
23. Russell JA, McEwan IM, Koutedakis Y, Wyon MA. Clinical anatomy and biomechanics of the ankle in dance. *J Dance Med Sci*. 2008;12:75-82.
24. Kadel NJ, Donaldson-Fletcher EA, Gerberg LF, Micheli LJ. Anthropometric measurements of young ballet dancers examining body composition, puberty, flexibility, and joint range of motion in comparison with non-dancer controls. *J Dance Med Sci*. 2005;9:84-90.
25. Armstrong R, Relph N. Screening tools as a predictor of injury in dance: systematic literature review and meta-analysis. *Sports Med Int Open*. 2018;4:1-28.
26. Steinberg N, Hershkovitz I, Peleg S, Dar G, Masharawi Y, Siev-Ner I. Paratenonitis of the foot and ankle in young female dancers. *Foot Ankle Int*. 2011;32:1115-21.
27. Storm JM, Wolman R, Bakker EW, Wyon MA. The relationship between range of motion and injuries in adolescent dancers and sportspersons: A systematic review. *Front Psychol*. 2018;9:287.
28. Gamboa JM, Roberts LA, Maring J, Fergus A. Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics. *J Orthop Sports Phys Ther*. 2008;38:126-36.
29. Briggs J, McCormack M, Hakim AJ, Grahame R. Injury and joint hypermobility syndrome in ballet dancers—a 5-year follow-up. *Rheumatology*. 2009;48:1613-4.
30. Steinberg N, Siev-Ner I, Peleg S, Dar G, Masharawi Y, Zeev A, Hershkovitz I. Joint range of motion and patellofemoral pain in dancers. *Int J Sports Med*. 2012;33:561-6.
31. van Seters C, van Rijn RM, van Middelkoop M, Stubbe JH. Risk factors for lower-extremity injuries among contemporary dance students. *Clin J Sport Med*. 2020;30:60-6.
32. Bennell KL, Khan KM, Matthews BL, Singleton C. Changes in hip and ankle range of motion and hip muscle strength in 8–11 year old novice female ballet dancers and controls: a 12 month follow up study. *Br J Sports Med*. 2001;35:54-9.
33. Kim SG. Kim WS. Effect of ankle range of motion (ROM) and lower-extremity muscle strength on static balance control ability in young adults: a regression analysis. *Med. Sci. Monit*. 2018;24:3168-75.
34. Vargas-Macías A, Baena-Chicón I, Gorwa J, Michnik RA, Nowakowska-Lipiec K, Gómez-Lozano S, Forczek-Karkosz W. Biomechanical Effects of Flamenco Footwork. *J Hum Kinet*. 2021;80:19-27.
35. Forczek-Karkosz W, Michnik R, Nowakowska-Lipiec K, Vargas-Macias A, Baena-Chicón I, Gómez-Lozano S, Gorwa J. Biomechanical description of zapateado technique in flamenco. *Int. J Environ Res Public Health*. 2021;18:2905.
36. Russell JA, Kruse DW, Nevill AM, Koutedakis Y, Wyon MA. Measurement of the extreme ankle range of motion required by female ballet dancers. *Foot Ankle Spec*. 2010;3:324-30.
37. Steinberg N, Hershkovitz I, Peleg S, Dar G, Masharawi Y, Heim M, Siev-Ner I. Range of joint movement in female dancers and nondancers aged 8 to 16 years: anatomical and clinical implications. *Am J Sports Med*. 2006;34:814-23.
38. Vargas-Macias A. *El baile flamenco: estudio descriptivo, biomecánico y condición física*. Universidad de Cádiz, 2006.
39. Coren S. The lateral preference inventory for measurement of handedness, footedness, eyedness, and earedness: Norms for young adults. *Psychon Bull Rev*. 1993;31:1-3.
40. Lin CW, Su FC, Wu HW, Lin CF. Effects of leg dominance on performance of ballet turns (pirouettes) by experienced and novice dancers. *J Sports Sci*. 2013;31:1781-8.
41. Wilson BR, Robertson KE, Burnham JM, Yonz MC, Ireland ML, Noehren B. The relationship between hip strength and the Y balance test. *J Sport Rehabil*. 2018;27:445-50.
42. Barrett S, Midgley A, Lovell R. PlayerLoad™: reliability, convergent validity, and influence of unit position during treadmill running. *Int J Sports Physiol Perform*. 2014;9:945-52.
43. Boyd LJ, Ball K, Aughey RJ. The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. *Int J Sports Physiol Perform*. 2011;6:311-21.
44. Mukaka MM. A guide to appropriate use of correlation coefficient in medical research. *Malawi Med J*. 2012;24:69-71.
45. Pedersen ME, Wilmerding MV, Milani J, Mancha J. Measures of plantar flexion and dorsiflexion strength in flamenco dancers. *Med Probl Perform Art*. 1999;14:107-12.
46. Wanke EM, Schreiter J, Groneberg DA, Weisser B. Muscular imbalances and balance capability in dance. *J Occup Med Toxicol*. 2018;13:1-8.
47. Armstrong R, Brogden CM, Milner D, Norris D, Greig M. Functional movement screening as a predictor of mechanical loading and performance in dancers. *J Dance Med Sci*. 2018;22:203-8.
48. Trajković N, Kozinc Ž, Smajla D, Šarabon N. Relationship between ankle strength and range of motion and postural stability during single-leg quiet stance in trained athletes. *Sci. Rep*. 2021;11:1-8.
49. Gannon LM, Bird HA. The quantification of joint laxity in dancers and gymnasts. *J. Sports Sci*. 1999;17:743-50.
50. Armstrong R, Brogden CM, Greig M. Joint Hypermobility as a Predictor of Mechanical Loading in Dancers. *J Sport Rehabil*. 2020;29:12-22.
51. Cobb SC, Bazett-Jones DM, Joshi MN, Earl-Boehm JE, James CR. The relationship among foot posture, core and lower extremity muscle function, and postural stability. *J Athl Train*. 2014;49:173-80.
52. Armstrong R. Joint hypermobility, dynamic balance and postural control in dancers: Implications for clinical practice. *J Physiother*. 2022;114:e145.
53. Cho H-J, Kim S, Jung J-Y, Kwak D-S. Foot and ankle joint movements of dancers and non-dancers: A comparative study. *Sports Biomech*. 2018;18:587-94.
54. Bejjani F, Halpern N, Pio A, Dominguez R, Voloshin A, Frankel VH. Musculoskeletal demands on flamenco dancers: a clinical and biomechanical study. *J. Foot Ankle.*. 1988;8:254-63.
55. Castro-Méndez A, Mateos-Martínez D, Castillo-López JM, Vargas-Macías A. Evaluation of the Correlation Between Flamenco Dance and Ankle and Foot Posture. *J Am Podiatr Med Assoc*. 2022;112.
56. Klemp P, Stevens JE, Isaacs S. A hypermobility study in ballet dancers. *J Rheumatol*. 1984;11:692-6.
57. Echegoyen S, Aoyama T, Rodríguez C. Zapateado technique as an injury risk in Mexican folkloric and Spanish dance: an analysis of execution, ground reaction force, and muscle strength. *Med Probl Perform Art*. 2013;28:80-3.
58. Domene PA, Easton C. Combined triaxial accelerometry and heart rate telemetry for the physiological characterization of Latin dance in non-professional adults. *J Dance Med Sci*. 2014;18:29-36.
59. O'Neill JR, Pate RR, Beets MW. Physical activity levels of adolescent girls during dance classes. *J Phys Act Health*. 2012;9:382-8.
60. Voloshin AS, Bejjani FJ, Halpern M. Frankel VH. Dynamic loading on flamenco dancers: a biomechanical study. *Hum Mov Sci*. 1989;8:503-13.
61. Armstrong R, Brogden CM, Greig M. The Star Excursion Balance Test as a predictor of mechanical loading and performance in dancers. Gazzetta Medica Ital. *Arch per le Sci Mediche*. 2019;178:98-105.

Original article

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

Alicia S. Canda, Luis F. Agorreta, Manuel Marina-Breysse, Lucia Sainz, Manuel Rabadán

Centro de Medicina del Deporte. Agencia Española de Protección de la Salud en el Deporte. Consejo Superior de Deportes. Madrid.

doi: 10.18176/archmeddeporte.00122

Received: 03/12/2021
Accepted: 11/11/2022

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}, $l.min^{-1}$) 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 $l.min^{-1}$, BR vs FR, 4.67 ± 0.48 $l.min^{-1}$ vs 5.06 ± 0.06 $l.min^{-1}$; 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 ± 3,4 años; masa corporal (MC): 89,8 ± 11,7 kg, talla: 182,4 ± 6,5 cm; 52 defensas (DF) y 55 delanteros (DL). El VO_{2max} ($l.min^{-1}$) 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 ± 0,56 $l.min^{-1}$, DF vs DL, 4,67 ± 0,48 $l.min^{-1}$ vs 5,06 ± 0,06 $l.min^{-1}$; MLG: 77,5 ± 7,7 kg, 73,5 ± 7 kg vs 81,3 ± 6,3 kg; y MM: 52,9 ± 6,5 kg, 49,6 ± 5,6 kg vs 56,1 ± 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.

Correspondence: Alicia S. Canda
E-mail: alicia.canda@csd.gob.es

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 ($l*min^{-1}$) or in comparison to body mass ($ml*kg^{-1}*min^{-1}$). The dependency between a biological variable such as VO_{2max} (y) and body mass (x) can be expressed through allometric scaling in the form $y = a * x^b$, where b is the exponent or power of the scaling. When we express oxygen uptake as $ml*kg^{-1}*min^{-1}$, 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 mass[1-4], 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*., 2001[5] 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, 2021[6] 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 studies[7]. 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 field[10-16]. 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 fat[17-19]. 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 mass[21], 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 players[16]. Their body composition may undergo changes in the course of the season and the player's sporting life[22-25]. 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} ($l*min^{-1}$) 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 society[28], except for the measurement of the perimeter of the medial thigh[29].

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, 1996[30]; 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 VO_{2max} ($l*min^{-1}$) and the VO_{2max} ($ml*kg^{-1}*min^{-1}$) relative to body mass (BM), fat-free mass (FFM) and muscle mass (MM). The aerobic-anaerobic transition was determined from ventilation and gas exchange[31]. The ventilatory threshold [1] (VT1) was defined as the first non-linear increase in ventilation with an equivalent increase in oxygen (VE/VO2) without any concomitant increase in the equivalent CO2 (VE/VCO2). Ventilatory threshold 2 (VT2) was considered to be the second non-linear increase in ventilation with a non-linear increase in the VE/VO2 ratio and a simultaneous increase in the VE/VCO2 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]. VO_{2max} values were assessed according to the percentiles established.

The potential curvilinear regression model was developed according to the allometric model, $y = a * x^b$, where absolute VO_{2max} 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 VO_{2max} 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 VO_{2max} 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 VO_{2max} 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 VO_{2max} values are assessed in absolute terms, as well as by BM and MM, but not by FFM. FR players have higher VO_{2max} values in absolute terms, whereas in relative terms, the BR have better VO_{2max} 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 VO_{2max} relative to masses using allometric scaling is virtually zero, while the effect size is medium with respect to body mass. The percentiles of VO_{2max} 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 VO_{2max} ($l*min^{-1}$) and body mass (kg), fat-free mass (kg) and muscle mass (kg) for 107 male rugby players; *P* <0.0001.

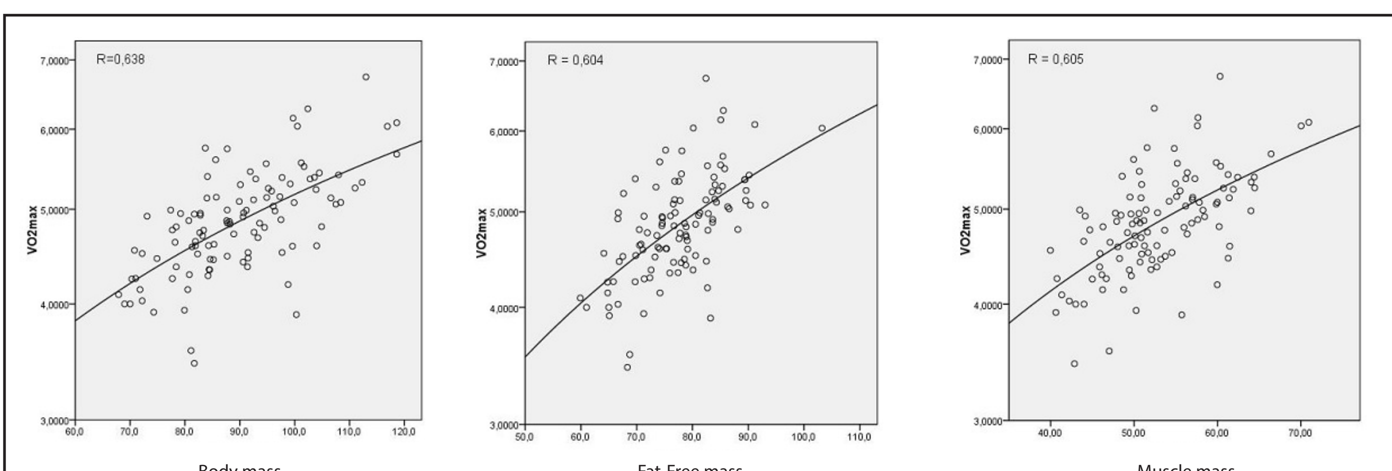


Table 1. Anthropometric and physiological characteristics of rugby union players (mean±SD).

	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
VO_2 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
VO_2 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, 1996[30]; FFM: fat-free mass; MM: muscle mass, estimated by Martin *et al*. 1990[29]. p, significantly different between BR (backs) and FR (forwards). r effect size: small, <30; medium, 0.30–0.49; and large, 0.50 and greater[21].

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

	VO_{2max}	VO_{2max} relative					
Percentile	**$l*min^{-1}$**	**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} ($l*min^{-1}$) (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} ($l*min^{-1}$), of whom five also showed variation with respect to body mass ($ml*kg^{-1}*min^{-1}$). Two players (11.8%) had variations in their VO_{2max} ($ml*kg^{-1}*min^{-1}$) but not in VO_{2max} ($l*min^{-1}$). Lastly, seven players (41.2%) showed no change in their VO_{2max} values in either absolute terms nor in relation to their body mass.

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

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

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/√n); effect size: small, <30; medium, 0.30–0.49; and large, 0.50 and greater[21]. % body fat estimated by Withers *et al*. 1987, in Norton 1996[30] and MM by Martin *et al.* 1990[29].

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 nº 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 nº 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 nº 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 nº 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 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	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
kg	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	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
kg	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	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
kg	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}	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
$l*min^{-1}$	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
$VO_{2max}BM$	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
$ml*min^{-1}*kg^{-1}$	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
$VO_{2max}FFM$	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
$ml*min^{-1}*kg^{-1}$	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
$VO_{2max}MM$	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
$ml*min^{-1}*kg^{-1}$	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
$VO_{2max}BMas$	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
$ml*min^{-1}*kg^{-0.58}$	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
$VO_{2max}FFMas$	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
$ml*min^{-1}*kg^{-0.71}$	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
$VO_{2max}MMas$	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
$ml*min^{-1}*kg^{-0.58}$	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	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
min	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	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
min	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 1996[30]. FFM: fat-free mass; MM: muscle mass by Martin *et al.* 1990[29]; 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 0.75[33-36]. 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, 1995[37] 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.*, 2001[5], 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.,* 2009[38] 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, 1984[39] 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 Döbeln[40] 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, Batterrham *et al.*[2] found that FFM models resulted in a larger coefficient of determination and a lower SE of the estimate in predicting $VO2peak_{2peak}$. 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 age[41].

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 $ml*kg^{-1}*min^{-1}$. By playing position, FR are between 58 - 48 $ml*kg^{-1}*min^{-1}$ and BR are between 60 - 55 $ml*kg^{-1}*min^{-1}$ [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.,* 2006[54], 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.,* 1994[55] in BR (10%) and FR (13%) for the US team; and, also in the USA, Maud y Shultz, 1984[56] in BR (7.8%) and FR (10.5%). Similar values were obtained by Brewer *et al.,* 1994[57] and by Scott *et al.,* 2003[58] 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, 2011[59] obtained by Yuhasz's E. a fat percentage of 12% in BR and 16.4% in FR. In Australia, Zemski *et al.,* 2015[12] 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.,* 2020[16] 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 out[60- 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 VO_{2max} 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 betewen players.

Funding

No external funding has been received.

Conflict of interest

The authors do not declare a conflict of interest.

Bibliography

1. Åstrand PO, Rodahl K, Dal HA, Strommee SB. Body dimensions and muscular exercise. In: Textbook of work physiology: Physiological bases of exercise .4th ed., Champaign, IL: *Human Kinetics;* 2003. p. 299-312.
2. Batterham AM, Vanderburgh PM, Mahar MT, Jackson AS. Modeling the influence of body size on VO2peak: effects of model choice and body composition. *J Appl Physiol.* 1999;87:1317-25.
3. Bergh U, Sjödin B, Forsberg A, Svedenhag J. The relationship between body mass and oxygen uptake during running in humans. *Med Sci Sports Exerc.* 1991;23:205-11.
4. Chamari K, Moussa-Chamari I, Boussaidi L, Hachana Y, Kaouech F, Wisloff U. Appropriate interpretation of aerobic capacity: allometric scaling in adult and young soccer players. *Br J Sports Med*. 2005;39:97-101.
5. Jensen K, Johansen L, Secher NH. Influence of body mass on maximal oxygen uptake: effect of sample size. *Eur J Appl Physiol*. 2001;84:201-5.
6. Lee J, Zhang X. Is there really a proportional relationship between VO2max and body weight? A review article. *PLoS One.* 2021;16:e0261519.
7. Lolli L, Batterham AM, Weston KL, *et al.* Size Exponents for Scaling Maximal Oxygen Uptake in Over 6500 Humans: A Systematic Review and Meta-Analysis. *Sports Med.* 2017;47:1405-19.
8. Beekley M, Abe T, Kondo M, Midorikawa T, Yamauchi T. Comparison of normalized maximum aerobic capacity and body composition of sumo wrestlers to athletes in combat and other sports. *J. Sports Sci. Med*. 2006;5:13-20.
9. Trinschek J, Zieliński J, Kusy K. Maximal Oxygen Uptake Adjusted for Skeletal Muscle Mass in Competitive Speed-Power and Endurance Male Athletes: Changes in a One-Year Training Cycle. *Int J Environ Res Public Health*. 2020;17:6226.
10. Gabbett T, King T, Jenkins DG. Applied physiology of rugby league. *Sports Medicine.* 2008;38:119-38.
11. Vaz L, Morais T, Rocha H, James N. Fitness profiles of elite portuguese rugby union players. *J Hum Kinet.* 2014;41:235-44.
12. Zemski AJ, Slater GJ, Broad EM. Body composition characteristics of elite australian rugby union athletes according to playing position and ethnicity. *J Sports Sci.* 2015;33:970-8.
13. Darrall-Jones JD, Jones B, Till K. Anthropometric, sprint, and high-intensity running profiles of English academy rugby union players by position. *J Strength Cond Res.* 2016;30:1348-58.
14. Till K, Scantlebury S, Jones B. Anthropometric and Physical Qualities of Elite Male Youth Rugby League Players. *Sports Med*. 2017;47:2171-86.
15. Stoop R, Hohenauer E, ML Rucker A, Clijsen R. Anthropometric Properties versus Physical Performance in Rugby Union Forwards and Backs - A Systematic Review. *Ann Appl Sport Sci.* 2018;6:1-13.
16. Posthumus L, Macgregor C, Winwood P, Darry K, Driller M, Gill N. Physical and Fitness Characteristics of Elite Professional Rugby Union Players. *Sports*. 2020;8:85.
17. Johnston RD, Gabbett TJ, Jenkins DG. Applied sport science of rugby league. *Sports Med*. 2014;44:1087-100.
18. Gabbett TJ. Influence of Fatigue on Tackling Ability in Rugby League Players: Role of Muscular Strength, Endurance, and Aerobic Qualities. *PLoS One.* 2016; 31;11:e0163161.
19. Fontana FY, Colosio AL, Da Lozzo G, Pogliaghi S. Player's success prediction in rugby union: From youth performance to senior level placing. *J Sci Med Sport.* 2017;20:409-14.
20. Cunniffe B, Proctor W, Baker JS, Davies B. An evaluation of the physiological demands of elite rugby union using Global Positioning System tracking software. *J Strength Cond Res.* 2009;23:1195-203.
21. Appleby B, Newton RU, Cormie P. Changes in strength over a 2-year period in professional rugby union players. *J Strength Cond Res.* 2012;26:2538-46.
22. Duthie GM, Pyne DB, Hopkins WG, Livingstone S, Hooper SL. Anthropometry profiles of elite rugby players: quantifying changes in lean mass. *Br J Sports Med*. 2006;40:202-7.
23. Gabbett T, Kelly J, Ralph S, Driscoll D. Physiological and anthropometric characteristics of junior elite and sub-elite rugby league players, with special reference to starters and non-starters. *J Sci Med Sport*. 2009;12:215-22.
24. Ungureanu AN, Beratto L, Daga FA, Boccia G, Lupo C, Brustio PR. Changes in anthropometric and fitness profile of Italian regional academy rugby union players. Biol Sport. 2022;39:621-8.
25. Jones B, Till K, Roe G, O'Hara J, Lees M, Barlow MJ, Hind K. Six-year body composition change in male elite senior rugby league players. *J Sports Sci.* 2017;36:266-71.
26. Chiwaridzo M, Oorschot S, Dambi JM, Ferguson GD, Bonney E, Mudawarima T, Tadyanemhandu C, Smits-Engelsman BCM. A systematic review investigating measurement properties of physiological tests in rugby. *BMC Sports Sci Med Rehabil.* 2017;28;9:24.
27. Owen C, Till K, Weakley J, Jones B.Testing methods and physical qualities of male age grade rugby union players: A systematic review. *PLoSONE.* 2020;5:e0233796.
28. Norton K, Whittingham N, Carter L, Kerr D, Gore C, Marfell-Jones M. Measurement Techniques in Anthropometry. In Norton KI, Olds TS. *Anthropometrica*. Sydney, NSW: University of New South Wales Press; 1996. p. 25-75.
29. Martin AD, Spenst LF, Drinkwater DT, Clarys JP. Anthropometric estimation of muscle mass in men. *Med Sci Sports Exerc*. 1990;22:729-33.
30. Norton K. Anthropometric estimation of body fat. In Norton KI, Olds TS. Anthropometrica. Sydney, NSW: University of New South Wales Press; 1996. p. 171-98.
31. Davis JA. Anaerobic threshold: review of the concept and directions for future research. *Med Sci Sports Exerc.* 1985;17:6-18.
32. Cohen J. A Power primer. *Psychol Bull.* 1992;112:155-9.
33. McMahon T. Size and shape in biology. *Science.* 1973;179:1201-4.
34. Nevill AM, Ramsbottom R, Williams C. Scaling physiological measurements for individuals of different body size. *Eur J Appl Physiol Occup Physiol.* 1992;65:110-7.
35. West GB, Brown JH, Enquist BJ. A general model for the origin of allometric scaling laws in biology. *Science.* 1997;276:122-6.
36. Darveau CA, Suarez RK, Andrews RD, Hochachka PW. Allometric cascade as a unifying principle of body mass effects on metabolism. *Nature.* 2002;417:166-70.
37. Svedenhag J. Maximal and submaximal oxygen uptake during running: how should body mass be accounted for? *Scand J Med Sci Sports.* 1995;5:175-80.
38. Markovic G, Vucetic V, Nevill AM. Scaling behaviour of in athletes and untrained individuals. *Ann Hum Biol.* 2009;34:315-28.
39. Secher NH. The physiology of rowing. *J Sports Sci*. 1984;1:23-53.
40. Von Döbeln W. Maximal oxygen intake, body size, and total hemoglobin in normal man. *Acta Physiol.* 1957;38:193-9.
41. Nevill AM, Bate A, Holder RL. Modeling physiological and anthropometric variables known to vary with body size and other confounding variables. *Am J Phys Anthropol.* 2005;128:141-53.
42. Olds T. The evolution of physique in male rugby union players in the twentieth century. *J Sports Sci.* 2001;19:253-62.
43. Sedeaud A, Marc A, Schipman J, Tafflet M, Hager JP, Toussaint JF. How they won rugby world cup through height, mass and collective experience. *Br J Sports Med.* 2012;46:580-4.
44. Goran M, Fields DA, Hunter GR, Herd SL, Weinsier RL. Total body fat does not influence maximal aerobic capacity. Int J Obes. 2000;24:841-8.
45. Loftin M, Sothern M, Trosclair L, O'Hanlon A, Miller J, Udall J. Scaling VO2 peak in obese and non-obese girls. *Obes Res.* 2001;9:290-6.
46. Brewer J, Davis J. Applied physiology of rugby league. *Sports Med*. 1995;20:129-35.
47. Duthie G, Pyne D, Hooper S. Applied physiology and game analysis of rugby union. *Sports Med.* 2003;33:973-91.

48. Gabbett T, King T, Jenkins D. Applied Physiology of Rugby League. *Sports Med.* 2008;38:119-38.
49. Higham DG. Applied physiology of rugby sevens: performance analysis and elite player development. [Doctoral Thesis]. 2013.
50. La Monica MB, Fukuda DH, Miramonti AA, Beyer KS, Hoffman MW, Boone CH, et al. Physical Differences Between Forwards and Backs in American Collegiate Rugby Players. *J Strength Cond Res.* 2016;30:2382-91
51. Comfort P, Graham-Smith P, Matthews MJ, Bamber C. Strength and power characteristics in English elite rugby league players. *J Strength Cond Res.* 2011;25:1374-84.
52. Darrall-Jones JD, Jones B, Till K. Anthropometric, Sprint, and High-Intensity Running Profiles of English Academy Rugby Union Players by Position. *J Strength Cond Res.* 2016;30:1348-58.
53. Brazier J, Antrobus M, Stebbings GK, Day SH, Callus P, Erskine RM, *et al.* Anthropometric and Physiological Characteristics of Elite Male Rugby Athletes. *J Strength Cond Res.* 2020;34:1790-801.
54. Lundy B, O'Connor H, Pelly F, Caterson I. Anthropometric characteristics and competition dietary intakes of professional rugby league players. I*nt J Sport Nutr Exerc Metab.* 2006;16:199-213.
55. Carlson BR, Carter JEL, Patterson P, Petti K, Orfanos SM, Noffal GJ. Physique and motor performance characteristics of US national rugby players. *J Sports Sci.* 1994;12:403-12.
56. Maud PJ, Shultz BS. The US national rugby team: A physiological and anthropometric assessment. *Phys Sportsmed.* 1984;12:86-99.
57. Brewer J, Davis J, Kear J. A comparison of the physiological characteristics of rugby league forwards and backs. *J Sports Sci*. 1994;12:158.
58. Scott AC, Roe N, Coats AJ, Piepoli MF. Aerobic exercise physiology in a professional rugby union team. *Int J Cardiol.* 2003;87:173-7.
59. Suárez-Moreno LJ, Nuñez FJ. Physicological and antropometric characteristics of elite rugby players in Spain and relative power out as predictor of performance in sprint and RSA. *J Sport Health Res*. 2011;3:191-202.
60. Crewther BT, Gill ND, Weatherby RP, Lowe T. A comparison of ratio and allometric scaling methods for normalizing power and strength in elite rugby union players. *J Sports Sci.* 2009;27:1575-80.
61. Crewther BT, McGuigan MR, Gill ND. The ratio and allometric scaling of speed, power, and strength in elite male rugby union players. *J Strength Cond Res.* 2011;25:1968-75.
62. Jaric S, Mirkov D, Markovic G. Normalizing physical performance tests for body size: a proposal for standardization. *J Strength Cond Res.* 2005;19:467-74.

Original article

Combined active and passive warm-ups as a technique to increase the number of deep squat repetitions

Martín Pérez Zazueta[1], Brandon Lira Samano[1], Alfredo Castro Flores[1], Francisco Gaspar Celis[1], Cristobal Hernández Noriega[1], Luis M. Gómez Miranda[2], Roberto Espinoza-Gutiérrez[2], Jorge A. Aburto-Corona[2]

[1]Facultad de Deportes Tijuana. Universidad Autónoma de Baja California. México. [2]Grupo de Investigación UABC-CA-341 Rendimiento Físico y Salud. Laboratorio de Biociencias de la Motricidad Humana. Facultad de Deportes Tijuana. Universidad Autónoma de Baja California. México.

doi: 10.18176/archmeddeporte.00123

Received: 26/07/2022
Accepted: 15/11/2022

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.

Key words:
Heating pad. Lower body. Physical performance.

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

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 ± 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 ± 1,8 rep) y CA_{ct+P} (8,7 ± 1,6 rep) en la cantidad de sentadillas realizadas. Sin embargo, la condición CC_{om} (11,1 ± 2,0 rep; p = 0,001; d = -2,107) mostró ser más efectiva en comparación a CA_{ct} (8,6 ± 1,8 rep) y CA_{ct+P} (8,7 ± 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.

Correspondence: Jorge A. Aburto-Corona
E-mail: jorge.aburto@uabc.edu.mx

Introduction

Regardless of the type of physical exercise or sport, warming up is a fundamental part of the training session or competition and can even be considered to be an essential activity during exercise or competition. However, its effect on physical performance is still at issue[1-4].

Warming up is considered to be any activity that results in an increase in body temperature. It may be performed actively and/or passively in order to improve neuromuscular response and reduce the probability of injury[5]. Active warm-up is achieved through physical exercise (aerobic and/or anaerobic) while passive warm-up refers to the use of some external means to raise the body temperature (hot water immersion, increase of environmental temperature, compression sleeves, heating pads, among others)[6].

Today, it is highly recommended to perform an active warm-up routine prior to a sports activity due to the improvement in physical performance caused by the muscular metabolism and the muscle fibre conduction velocity, as well as generating greater emotional stability, confidence and mental preparation[4,6,7]. Likewise, passive warming-up has been shown to be beneficial in improving the joint range of motion and reducing the probability of injury[8,9].

It has been demonstrated that the increase in body temperature, through a passive warm-up, improves physical performance in activities of short and long duration due to the increase in the muscular metabolism and the degradation of glycogen, production of adenosine triphosphate and phosphocreatine. Furthermore, it increases the muscle fibre conduction velocity, in other words it generates an increase in muscle power caused by the rapid release of calcium from the sarcoplasmic reticulum and the hyperpolarization of the membrane as a result of the increased activity of the sodium-potassium pump. Another factor that increases physical performance is muscle relaxation, which improves at high temperatures (25-37 °C) due to the efficiency of the mechanisms for the removal of calcium from the sarcoplasm, calcium-troponin dissociation and the separation of the actin-myosin bridges[10,11].

In the case of an active warm-up, apart from the mechanisms mentioned above, it also drives the oxygen uptake kinetics due to a greater gas exchange, to a change in the oxyhemoglobin curve and to the activation of the oxidative enzymes. It also improves post-activation potentiation, in other words, intense muscle activity generates greater force in the subsequent exercise. The above is the result of an increase in the electrical activity in the spinal cord, increased actin filament calcium sensitivity and an increase in the calcium concentrations in these muscle fibres[4].

Considering the benefits of warming up on physical performance, the purpose of this study was to determine whether the combination of an active and passive warm-up (heating pad) leads to an increase in the number of deep squat repetitions (85%RM) compared to solely active warm-up.

Material and method

Participants

10 subjects were recruited (5 men and 5 women), who were physically active and apparently healthy (age 26.2 ± 5.9 years, weight 70.0 ± 11.8 kg, height 166.6 ± 10.9 cm), with 2.8 ± 1.4 years of experience performing deep squat exercises. Subjects were selected non-probabilistically for convenience. All participants were informed in detail with regard to the objectives and procedures of the study, emphasising the risks involved. This was set out in a letter of informed consent and voluntary participation signed by each participant. The investigation protocol was developed in compliance with the guidelines for investigations on human beings established in the declaration of Helsinki[12].

Procedure

The subjects attended a fitness centre on four separate occasions. At the first session, an estimation was made of the maximum deep squat weight (75.4 ± 26.9 kg) using the formula proposed by Brzycki[13], weight lifted in kg / (1.0278-0.0278)* number of repetitions). For this test the subjects performed a conventional warm-up focussed on two key aspects: low-intensity aerobic activity (15 seconds of sideways head movements, shoulder rotation, hip rotation, knee flexion-extension, ankle circling in the air and jogging for 3 minutes) and dynamic muscle stretching (pectoralis major, latissimus dorsi, hamstrings, quadriceps and iliopsoas, 15 sec. each)[14].

Once the maximum squat weight had been estimated, the order of the following three conditions was randomly assigned, consisting in performing the greatest number of deep squat repetitions at 85% of their estimated maximum capacity in session one (64.1 ± 22.9 kg) (Figure 1). It should be mentioned that all the subjects attended together at the same time (8:30 to 10:30 h) with a 3-day interval between sessions.

Combined warm-up (CC_{om})

For this condition, the subjects performed the active warm-up indicated in session one. They subsequently sat down and a pad heated to 42°C was placed on their legs (GAON Innovación, State of Mexico, Mexico) (Figure 2) for a period of five minutes. At the end of the five minutes, the skin temperature was 37.4 ± 1.0°C.

Active warm-up (CA_{ct})

The subjects performed the conventional active warm-up of session one, they then sat down for a five-minute period without the heating pad. At the end of this seated period, the skin temperature at the quadriceps was 32.0 ± 1.0°C. The skin temperature was taken with an infrared thermometer, Fluke 68 (Washington, USA), which had a resolution of 0.1°C and an accuracy of ± 1°C.

Active warm-up plus placebo (CA_{ct+P})

PFor this condition, the subjects performed the same active warm-up as for session one. Subsequent to this, they sat down for a five-minute period and a disconnected heating pad was placed on their legs with the temperature control display facing downwards (so that they were unable to see that it was off). This condition was proposed in order

Figure 1. Example of a deep squat.

Figure 2. Example of the application of the heating pad for condition CC_{om} and CA_{ct+P}.

to determine whether the use of the heating pad created a placebo effect on physical performance. At the end of the five minutes, the skin temperature was 32.1± 0.3°C.

The active warm-up intensity was measure subjectively by the Borg Rating of Perceived Exertion (0-10). The subjects rated the warm-up as hard (5.3±1.3). At the end of the seated period, irrespective of the condition, the subjects were instructed to perform the greatest possible number of squats at 85% of maximum weight. For all sessions, the subjects were informed that they should not do any physical exercise in the 24 hours prior to the session, and that they should refrain from consuming medication, drinks and food considered to be diuretic.

Statistical analysis

The SPSS version 23 statistical analysis package was used for the data analysis. Descriptive statistics were used for the variables of age, height, weight and years of experience performing deep squats. The Shapiro-Wilk test of normality gave a normal data distribution ($p > 0.05$). A one-way ANOVA was performed (conditions) on related samples in order to compare the ambient temperature, relative humidity, skin temperature, number of repetitions made and for the sum of the lifted weight (weight multiplied by repetitions) following a warm-up with a heating pad turned on, off and without a heating pad.

Results

No significant differences were found in ambient temperature (CC_{om} 20.0 ± 2.3ºC, CA_{ct} 19.2 ± 5.3 ºC, CA_{ct+P} 20.4 ± 5.5 ºC; $p = 0.91$) or in relative humidity (CC_{om} 59.6 ± 5.9%, CA_{ct} 54.0 ± 5.6%, CA_{ct+P} 49.2 ± 2.8%; $p = 0.41$) between the different conditions. This result indicates that the subjects performed the assessments in the same ambient conditions.

The one-way ANOVA showed no skin temperature differences between condition CA_{ct} and CA_{ct+P} ($p > 0.05$). However, differences were found for condition CCom compared to the other two conditions ($p = 0.001$). These results indicate that the application of the passive warm-up generated an increase in the skin temperature of 5.3°C in comparison to those conditions without this type of warm-up (Table 1).

The variance analysis showed no significant differences ($p > 0.05$; CI95% -1.294, 1.094; $d = -0.079$) between conditions CA_{ct} and CA_{ct+P} in the number of deep squat repetitions made. However, differences were found ($p = 0.001$; CI95% -3.182, -1.618; $d = -2.107$) between CC_{om} and CA_{ct} and between CC_{om} and CA_{ct+P} ($p = 0.001$; CI95% 1.407, 3.593; $d = -2.683$) (Figure 3). The data suggest that the combined warm-up (CC_{om}) leads to a greater number of deep squat repetition (Table 1).

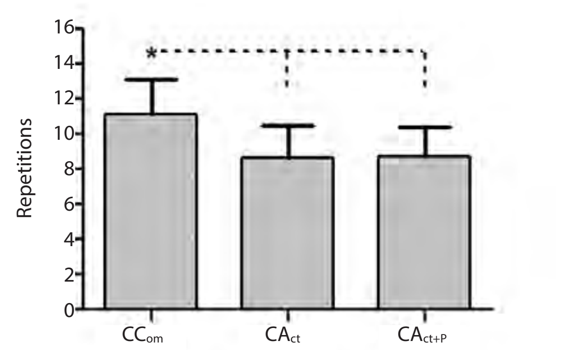
With regard to the total sum of the lifted weight (weight multiplied by repetitions), no differences were found ($p > 0.079$; CI95% -178.329, 8.993; $d = -0.618$) between conditions CA_{ct} and CA_{ct+P}. On the other hand, differences were found ($p = 0.001$; CI95% 137.497, 336.115; $d = 1.469$) between CC_{om} and CA_{ct} and between CC_{om} and CA_{ct+P} ($p = 0.001$; CI95% 91.215, 213.061; $d = 1.055$). This result suggest that the combined warm-

Table 1 Description of the data obtained.

	Skin Temperature (ºC)	Number of repetitions	Sum of lifted weight (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

*Significant differences compared to the other two conditions (p = 0.001).

Figure 3. Number of deep squat repetitions made, comparing the combined warm-up (CC_{om}), active warm-up (CA_{ct}) and active warm-up plus placebo (CA_{ct+P}). * p = 0.001



up (CC_{om}) is the most effective technique for achieving a greater number of squat repetitions (Table 1).

Discussion

The purpose of this study was to determine whether or not the combination of an active and passive warm-up technique (heating pad) leads to an increase in the number of deep squat repetitions (85%RM) compared to solely active warm-up. The key finding was that, with the combined warm-up there was a greater number of squat repetitions compared to the active warm-up and active warm-up with placebo. In other words, combined warm-up enhances physical performance with regard to the number of deep squat repetitions made.

Given that passive warm-up by itself has been demonstrated to be insufficient to put the body through strenuous physical effort, it is therefore necessary to perform active warm-up in order to ensure that the joints and muscle tissue are in optimal condition for greater effort.

For decades it has been reported that one of the principal results of a warm-up session is the increase in body and muscle temperature. According to different authors, a 1ºC increase in muscle temperature is sufficient to observe improvement in the subsequent exercise of between 2-5%[15,16], which was also observed in this study in condition CC_{om}, whereby, although the muscle temperature was not directly measured, a temperature increase was propitiated through the muscle contractions of he active warm-up plus the passive warm-up, increasing the skin temperature by 5.3 °C.

The increase in body temperature through an active or passive warm-up can lead to an increase in the muscular metabolism, muscle fibre conduction velocity and muscle contractile performance[5]. For their part McGowan *et al.*[4], reported that active and passive warm-ups exert a considerable influence on subsequent performance due to an increase in adenosine triphosphate (a nucleotide that is essential in obtaining cellular energy), the actin–myosin cross bridge cycling rate and oxygen uptake kinetics.

Recent investigations report that the combination of active and passive warm-ups improves physical performance compared to when used separately, despite the use of different passive warm-up techniques and application protocols. For example, in their study, Baskaran, Seemathan and Sadhasivam[17] used an infrared lamp to passively increase the body temperature of their subjects, with similar characteristics to those of this study; on the other hand, McGawley, Spencer, Olofsson and Andersson[18], conducted a study with exercise protocols at -7.2 ± 0.2°C implemented with Alpine skiers who wore a lower-body heated garment as a passive warm-up method. However, when discussing which is the best type of warm-up (active - passive) prior to practising a sport, evidence points to an active warm-up as the most suitable for improving strength, anaerobic power and the range of motion[19,20]. Even so, there is a considerable amount of literature that reports that a warm-up exercise, whether active, passive or combined, is not a factor that improves or negatively affects physical performance, something that is not consistent with the findings of this study. Ahsan and Mohammad[21] reported that there was no difference in muscular strength in any warm-up technique used in their study (active, passive and combined). This could be due to the fact that muscle strength was measured using an isokinetic dynamometer, which measures the strength in the upper extremities, yet the passive warm-up protocol was implemented in the lower body (Gluteus, Hamstrings, Quadriceps, Gastrocnemius, and soleus). Furthermore, the study was on independent samples, analysing volleyball, basketball and handball players, sports in which grip strength may not hold the same importance as explosive strength[22-24]. For their part, Gogte, Srivastav and Balthillaya[25] also reported that they had found no differences in the three different types of warm-up. This could be due to the fact that the active warm-up comprised more intense activities (cycling, leg press, jump squats, squat jumps) than those that are normally part of active warm-up (low-intensity running, for example). Likewise, passive warm-up was implemented through the application of moist towels on the lower limbs for 20 minutes, which is a long period of time in which they do not explain whether the heat was lost or topped up in some way.

Just like the above investigators, Gray and Nimmo[2] found no differences between the active and passive warm-up techniques. This result may have been obtained due to the fact that, in the passive warm-up session, the investigators left the subjects in a climate-controlled room (45°C-70%) until they reached the same body temperature as that obtained in the active warm-up (36.9±0.2°C). However, the subjects remained seated during the passive warm-up, with no physical exertion, unlike the active warm-up. A further limitation of the studies is that they did not report the muscle, body or skin temperature on completion of the passive warm-up[21-25], which is an important variable for the effectiveness of the warm-up. Unlike the active warm-up, the passive one can increase both the body and muscle temperature without depleting energy substrates. It has been documented that a 1ºC increase in muscle temperature improves physical performance by 2 to 5%[4]. In this study, the subjects increased their leg skin temperature by 5.3ºC with the heating pad, improving their physical performance by 27% with the combined warm-up.

Conclusion

The results of this study demonstrate that the combination of an active and passive (heating pad) warm-up technique increases the number of deep squat repetitions made. However, in order to achieve this improvement, the skin temperature needs to be around 37.5ºC.

Conflict of interest

The authors have no conflict of interest at all.

Bibliography

1. Faghy MA, Brown PI. Whole-body active warm-up and inspiratory muscle warm-up do not improve running performance when carrying thoracic loads. *Appl Physiol Nutr Metab.* 2017;42:810-5.
2. Gray S, Nimmo M. Effects of active, passive or no warm-up on metabolism and performance during high-intensity exercise. *J Sports Sci.* 2001;19:693-700.
3. McCrary JM, Ackermann BJ, Halaki M. A systematic review of the effects of upper body warm-up on performance and injury. *Br J Sports Med*. 2015;49:935-42.
4. McGowan CJ, Pyne DB, Thompson KG, Rattray B. Warm-up strategies for sport and exercise: mechanisms and applications. *Sports Med*. 2015;45:1523-46.
5. Takeuchi K, Takemura M, Nakamura M, Tsukuda F, Miyakawa. Effects of active and passive warm-ups on range of motion, strength, and muscle passive properties in ankle plantarflexor muscles. *J Strength Cond Res.* 2018;35:141-6.
6. Silva LM, Neiva HP, Marques MC, Izquierdo M, Marinho DA. Effects of warm-Up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: A systematic review. *Sports Med.* 2018;48:2285-99.
7. Park H, Jung M, Park E, Lee C, Jee Y, Eun D, Cha J, Yoo J. The effect of warm-ups with stretching on the isokinetic moments of collegiate men. *J Exerc Rehabil*. 2018;14:78-82.
8. Carlson B, Petushek E, Moore M, Dermyer, H. *Effect of sauna warm-up on overhead squat depth in elite weightlifters.* 33rd International Conference on Biomechanics in Sports; 2015; Poitiers, France.
9. Singh S, Mehta A. Effect of concomitant use of PNF stretching with thermotherapy and massage on plantar flexors flexibility in young females. *Int J Health Rehabil Sci.* 2015;4:84-94.
10. Christensen P, Bangsbo J. Warm-up strategy and high-intensity endurance performance in trained cyclists. *Int J Sports Physiol Perform*. 2015;10:353-60.
11. Gil MH, Neiva HP, Sousa AC, Marques MC, Marinho DA. Current approaches on warming up for sports performance: A critical review. *Strength Cond J.* 2019;41:70-9.
12. Harris DJ, Macsween A, Atkinson G. Standards for ethics im sport and exercise science research: 2018 update. *Int J Sports Med*. 2018;38:1126-31.
13. Brzycki M. Strength testing: predicting a one-rep max from repetitions to fatigue. *J Phys Educ Recreat Dance.* 1993;64:88-90.
14. Jeffreys I. *The warm-up. Maximize performance and improve long-term athletic development.* Champaign, Human Kinetics; 2019.
15. Racinais S, Oksa J. Temperature and neuromuscular function. *Scand J Med Sci Sports.* 2010;20:1-18.
16. Sargeant AJ. Effect of muscle temperature on leg extension force and short-term power output in humans. *Eur J Appl Physiol Occup Physiol.* 1987;56:693-8.
17. Baskaran S, Seemathan P, Sadhasivam S. Effect of passive, active and combined warm up on the lower limb of healthy individuals. *Inter J Res Pharm Sci.* 2019;10:1785-8.
18. McGawley K, Spencer M, Olofsson A, Andersson E. Active, passive, and combined warm-ups among junior alpine skiers in -7°C. *Int J Sports Physiol Perform*. 2021;16:1140-7.
19. Kosuke T, Masahiro T, Masatoshi N, Fumiko T, Shumpei M. Effects of active and passive warm-ups on range of motion, strength, and muscle passive properties in ankle plantarflexor muscles. *J Strength Cond Res.* 2021;35:141-6.
20. Özcan M, Bicer M, Özdal M, Şan G. The effect of active and passive warm-up on individual and team sports athletes anaerobic power. *Biol Exerc.* 2018;14:51-9.
21. Ahsan M, Mohammad A. Effects of different warm-up techniques on dynamic balance and muscular strength on players: a study. *Eur J Phys Educ Sport Sci*. 2018;4:29-39.
22. da Costa JV, da Costa JV, Oliveira M, Pires GP. Efectos del entrenamiento pliométrico e isométrico en la fuerza explosiva de miembros superiores de atletas de balonmano. *Rev Cienc Act Fís UCM.* 2020;16:49-54.
23. González Y, Gálvez AY, Mendoza D. Comparación antropométrica, fuerza explosiva y agilidad en jugadoras jóvenes de baloncesto de Bogotá-Colombia. *Retos.* 2020;38:406-10.
24. Moreno CJ, Herrera IG. La fuerza explosiva y rápida como capacidades físicas determinantes en el entrenamiento de voleibol contemporáneo. *Rev Cub Med Dep Cul.* 2013;8:1-15.
25. Gogte K, Srivastav P, Balthillaya MG. Effect of passive, active and combined warm up on lower limb muscle performance and dynamic stability in recreational sports players. *J Clin Diagnostic Res.* 2017;11:5-8.

Original article

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

Jorge Salvador Marín[1], Juan D. Ayala Mejías[2]

[1]Licenciado en medicina, especialista en cirugía ortopédica y traumatología, doctorado en deporte y salud sobresaliente cum laude por la Universidad Miguel Hernández de Elche. Hospital General Universitario de Alicante Doctor Balmis. [2]Licenciado en medicina, especialista en cirugía ortopédica y traumatología, doctorado en medicina sobresaliente cum laude por la Universidad de Alcalá de Henares. Hospital San Rafael de Madrid.

doi: 10.18176/archmeddeporte.00124

Received: 30/06/2022
Accepted: 26/11/2022

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.

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

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.

SECOND PLACE at 2022 SEMED research awards

Correspondence: Jorge Salvador Marín
E-mail: salvadormarinj@gmail.com

Introduction

The anterior cruciate ligament (ACL) injury of the knee is currently one of the most limiting pathologies for athletes[1]. The instability that it causes in the knee means that sport is out of the question in most cases and so it requires reconstruction surgery with a tissue graft to replace it.

The type of reconstruction has varied over the last century. Firstly, attempts were made to repair the ACL, although this was not particularly successful, so this is now not recommended for athletes[2]. Nevertheless, some work groups are currently performing repair techniques with comparable results to reconstruction techniques[3]. Even so, reconstruction is the most recommended treatment among elite athletes nowadays.

Different types of grafts are available to replace ACL. Within these types, there are different classes of grafts and multiple factors to consider when choosing one or the other: the type of sport, the patient's sporting level and job, their availability, the presence of multiple injuries, the presence of previous surgeries, the surgeon's philosophy and experience, patient preference, aesthetics and economic means[4,5]. The main issues of these grafts initially revolve around the donor zone, the area where they are extracted, where residual pain is the most frequent[6].

The success of this ACL surgery is based on the capacity to get patients back playing sport and to work by recovering the sporting or working level prior to their injury.

The general objective of the study is to reveal specific indications for each graft in our medium when choosing the plasty for primary reconstruction of ACL in older professional athletes depending on the sport the patients play, the reasons for this choice and observe whether our results match the recommendations obtained in the bibliography which was consulted.

Material and method

An online, anonymous, unpublished survey was carried out, comprising 5 questions: 3 open questions and 2 multiple choice questions (Annex 1). The survey was sent out via the *Sociedad Española de Traumatología del Deporte* (SETRADE) (Spanish Sports Traumatology Society) and the European Society for Sports Traumatology, Knee Surgery and Arthroscopy (ESSKA) to all Spanish and European orthopaedic surgeons who perform ACL reconstruction as part of their usual clinical practice.

All the questions refer to the context of a mature professional athlete who has completely torn their ACL with no previous history, injuries or surgeries.

Firstly, information was compiled on the quantity of ACL reconstruction surgeries that they carried out every year, the number and type of plasties that they had mastered for this reconstruction, choosing from among the most frequently used (BTB autograft, hamstring, QT, allograft, ACL reconstruction + extra-articular plasty or other), where it was possible to pick more than one option.

Subsequently, they were asked for the surgeon's main reason when choosing the plasty to be used (complications in the donor zone, greater plasty stability/rigidity, faster osteointegration, biomechanical properties, re-tear rate, etc.) and if they consider the patent's sport when picking one plasty over another.

Finally, various scenarios were raised to see how the chosen graft preferences changed according to the sport and the level of activity and functional needs of the patient: the participants were asked to pick one type of graft for each scenario and the results were analysed.

All the data obtained were recorded in a database designed for this study.

A descriptive analysis was made for the sample. The "reason for choice of plasty" variable was analysed by stratifying the sample into different groups, analysing them separately: surgeons that carried out more than or less than 40 plasties a year, surgeons who belong to SETRADE and ESSKA and any influenced by the sport when choosing one plasty over another.

Statistical analysis

The statistical analysis used the SPSS computer program, version 18.0 (SPSS Inc., Chicago, USA). The Kolmogorov-Smirnov test was used to determine whether the data fitted the normal distribution. The quantitative variables are presented as means and standard deviation and the qualitative variables as percentages. To compare the characteristics between the groups, 2x2 tables were constructed for the categoric variables. For the qualitative variables, the chi square test was used with Yates's correction depending on the Mantel-Haenszel parametric.

Results

The survey was answered by 83 surgeons (n=83) who are members of SETRADE (n=71) and ESSKA (n=12).

The mean number of plasties performed per year for each survey respondent was 55.93 (1-220 range typical deviation 47.82) and the median was 40. In this range, the 25th percentile was 20, the 50th percentile was 40 and the 75th percentile was 100. 26.5% of survey respondents performed more than 100 ACL reconstruction surgeries a year.

89.1% (n=74) mastered at least 2 plasties when performing this surgery. From the total, 60 of them (72.2%) were familiar with the BTB graft technique and 75 (90%) mastered the STG technique. Only 21 surgeons were aware of the QT tendon technique (25.3%) while 55 (66.2%) were able to use the allograft technique. The extra-articular plasty was used by 50.6% of the responding surgeons (n=42) (Figure 1).

For 86.7% of the survey respondents, the sport influences the decision on the type of graft to be used, where the main reason is the biomechanical properties of the plasty (49.4%), followed by complications in the donor zone (19.3%) and thirdly, the type of sport that the patient plays (12%) (Figure 2).

When different scenarios were suggested, their graft choices varied as follows: More detailed information is available in Table 1:

Figure 1. Knowledge of the plasties by the survey respondents.

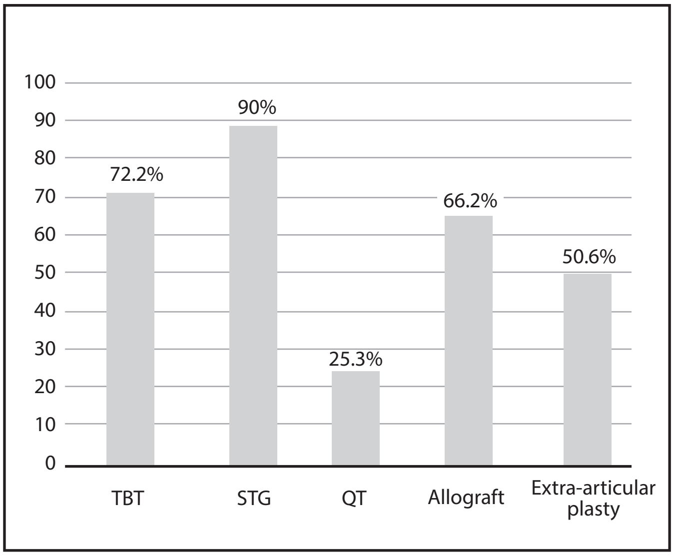


Figure 2. Reasons for choosing the plasty.

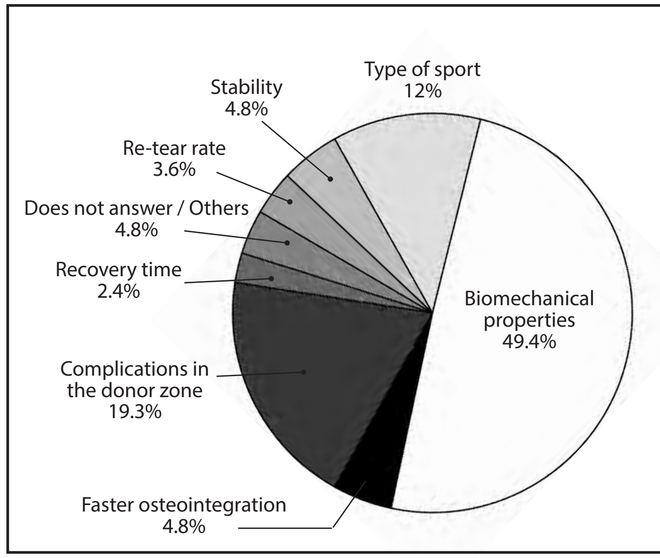
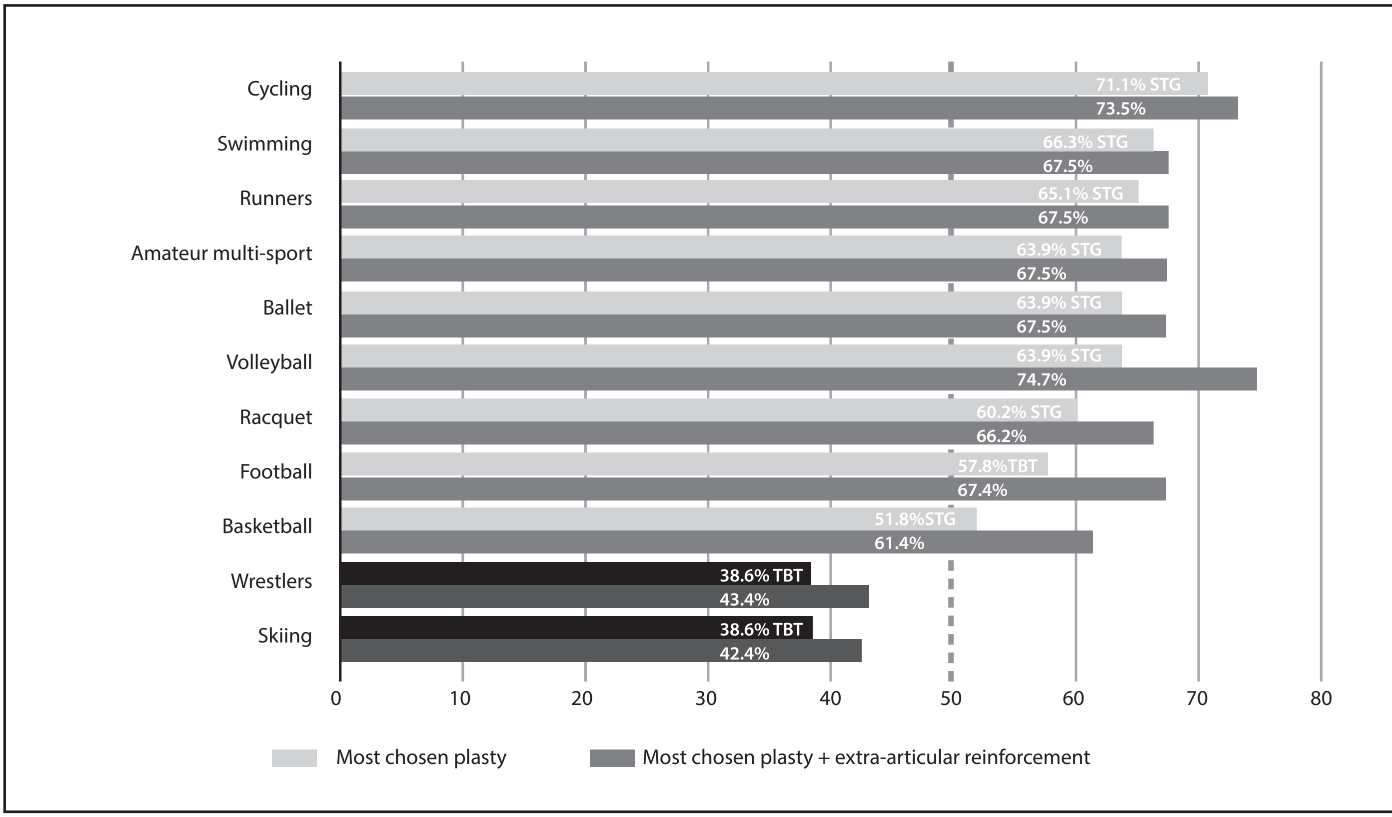


Table 1. Distribution of choice of plasty by sport.

Sport	BTB (%)	STG (%)	QT (%)	BTB + Plasty extra-articular (%)	STG + Plasty extra-articular (%)	Allograft (%)	No answer (%)
Football	57.8	21.7	4.8	9.6	2.4	3.6	-
Basketball - jumping events	27.7	51.8	2.4	-	9.6	7.2	1.2
Racquet	22.9	60.2	2.4	-	6	6	2.4
Wrestlers	38.6	38.6	4.8	4.8	2.4	7.2	3.6
Volleyball	18.1	63.9	1.2	-	10.8	3.6	2.4
Cycling	14.5	71.1	1.2	-	2.4	8.4	2.4
Skiing	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
Runners	14.5	65.1	2.4	-	2.4	12	3.6
Swimming	18.1	66.3	-	-	1.2	10.8	3.6
Multi-sport	24.1	63.9	-	-	3.6	7.2	1.2

- For football, 57.8% of survey respondents preferred the BTB autograft, followed by STG (21.7%) and BTB + extra-articular plasty (9.6%). 4.8% of the survey respondents use QT as the first option, 3.6% autograft while 2.4% use the plasty with STG + extra-articular plasty.
- For basketball and jumping events, 51.8% of the survey respondents preferred the STG autograft, followed by BTB (27.7%) and STGI + extra-articular plasty (9.6%). 7.2% of survey respondents use allograft in this type of athletes.
- For racquet sports, the most used plasty is STG (60.2%), followed by the BTB autograft (22.9%) and the STG + extra-articular plasty and allograft, both used as the primary option for 6% of surgeons who answered the survey.
- Among wrestlers, 38.6% of survey respondents chose both BTB and STG as their first option. In third place, 7.2% of surgeons use the allograft as the main option among these patients.
- For volleyball, 63.9% of survey respondents preferred the STG autograft, followed by BTB (18.1%) and STG + extra-articular plasty (10.8%).
- For cycling, 71.1% of survey respondents preferred the STG autograft, followed by BTB (14.5%) and allograft (8.4%).
- For skiing, 38.6% of survey respondents chose both BTB and 37.3 % chose STG as their first option. In third place, 8.4% of surgeons use the allograft as the main option among these patients.
- For ballet, 63.9% of survey respondents preferred the STG autograft, followed by BTB (15.7%) and allograft (10.8%).
- For running, 65.1% of survey respondents preferred the STG autograft, followed by BTB (14.5%) and allograft (12%).
- For swimming, 66.3% of survey respondents preferred the STG autograft, followed by BTB (18.1%) and allograft (10.8%).
- For amateur multi-sport patients, 63.9% of the survey respondents preferred the STG autograft, followed by BTB (24.1%) and allograft (7.2%).

Figure 3. Choice of the plasty depending on the patient's chosen sport.



The most chosen plasty matched or was the same by 58.29% on average (range 71.1 - 38.6%) in each sport among the different sports studied (Figure 3).

When analysing the results, it was seen that 43 survey respondents (51.8%) performed 40 or more plasties a year, while 40 (48.2%) performed less than 40 plasties. When comparing these groups, there were no statistically significant differences in the reasons for choosing the plasty (Fisher Test p=1) (Table 2).

When comparing these groups of surgeons from the SETRADE and ESSKA societies, there were no statistically significant differences in the reasons for choosing the plasty (Fisher's Exact Test p=0.22) (Table 3).

When comparing surgeons influenced by the sport when choosing the plasty, there were no statistically significant differences in the reasons for choosing the plasty (Fisher's Test p=0.734) (Table 4).

Discussion

Our survey was completed by 83 surgeons or heads of surgical teams. In the light of the results, we observe that most of them are surgeons with wide-ranging experience, with an average number of plasties carried out per year for each surgeon or team of 55.93. Furthermore, the majority of these surgeons had mastered at least 2 plasties. These findings show the suitability of the survey respondent for this work. The range of plasties performed every year was 1 to 220, where 220 was the number of plasties performed by one of the Spanish surgical teams. These figures are similar to other surveys published[7]. The best known plasty among surgeons filling in the survey were hamstring, handled by 90% of the survey respondents. These findings match those from Arnold and his team[8] whose article presents the evolution of plasties for this surgery: In 1992, the most frequent choice of graft was BTB, accounting for almost 90%. Hamstring autografts have become more popular, and currently exceed 50%, followed by the BTB autograft with a little under 40%. The QT autograft has become more popular since 2014.

Other findings worth mentioning include the influence of the sport when choosing the plasty for 86.7% of the survey respondents, and this was the 3rd most important reason for choosing the plasty in the survey. The biomechanical properties were the main reason for picking the graft. There were no statistically significant differences concerning the reason for choosing the plasty among surgeons from different societies, more or less experienced surgeons and surgeons who considered the sport in this choice, indicating a homogeneous sample.

Analysing each sport separately, we find that the most chosen plasty matched or was the same in an average of 58.29% (71.1 - 38.6% range) in each sport studied. From this data, it can be interpreted that

Table 2. Statistical analysis. Groups that perform more or less than 40 plasties a year.

			Reason for choosing the plasty		
			Properties	Others	Total
Number of plasties	≥40	Count	22	21	43
		% within the number of plasties	51.2%	48.8%	100%
	<40	Count	19	18	37
		% within the number of plasties	51.4%	48.6%	100%
Total		Count	41	39	80
		% within the number of plasties	51.3%	48.8%	100%

Chi-square tests

	Value	Gl	Asymptotic sig. (bilateral)	Exact sig. (bilateral)	Exact sig. (unila-teral)
Pearson's chi-square	0.000*	1	0.000*		
Continuity correction**	0.000	1	0.000		
Authenticity reason	0.000	1	0.000		
Fisher's Exact statistic				1.000	0.582
Line by line association	0.000	1	0.987		
No. of valid cases	80				

*0 boxes (0.0%) have an expected frequency under 5. The minimal expected frequency is 18.04.
**Calculated only for a 2x2 table.

Table 3. Statistical analysis. Setrade and ESSKA groups.

			Reason for choosing the plasty		
			Properties	Others	Total
Origin	Setrade	Count	37	31	68
		% within the origin	54.4%	45.6%	100%
	ESSKA	Count	4	8	12
		% within the origin	33.3%	66.7%	100%
Total		Count	41	39	80
		% within the origin	51.3%	48.8%	100%

Chi-square tests

	Value	Gl	Asymptotic sig. (bilateral)	Exact sig. (bilateral)	Exact sig. (unilateral)
Pearson's chi-square	1.814*	1	0.178		
Continuity correction**	1.068	1	0.301		
Authenticity reason	1.839	1	0.175		
Fisher's Exact statistic				0.220	0.151
Line by line association	1.791	1	0.181		
No. of valid cases	80				

*0 boxes (0.0%) have an expected frequency under 5. The minimal expected frequency is 5.85.
**Calculated only for a 2x2 table.

the majority agree on the choice of the same plasty in most of the sports studied. Furthermore, in sports such as football or basketball, if we consider the sum of the main or most chosen plasty, plus the extra-articular reinforcement (the main plasty is the same, but an extra technique is added), the plasty choice percentages would rise to 67.4% (adding isolated BTB and BTB with extra-articular plasty) in the case of football, and 61.4% in the case of basketball (adding hamstring and hamstring plus extra-articular reinforcement). In the case of volleyball, as the sport

Table 4. Statistical analysis. Groups where the sport may or may not influence the decision on the ACL reconstruction plasty.

			Reason for choosing the plasty		
			Properties	Others	Total
Does the sport influence your choice?	Yes	Count	37	34	71
		% within the sport, does the sport influence?	52.1%	47.9%	100%
	No	Count	4	5	9
		% within the sport, does the sport influence?	44.4%	55.6%	100%
Total		Count	41	39	80
		% within the sport, does the sport influence?	51.3%	48.8%	100%

Chi-square tests

	Value	Gl	Asymptotic sig. (bilateral)	Exact sig. (bilateral)	Exact sig. (unilateral)
Pearson's chi-square	0.188*	1	0.665		
Continuity correction**	0.006	1	0.937		
Authenticity reason	0.188	1	0.664		
Fisher's Exact statistic				0.734	0.468
Line by line association	0.186	1	0.667		
No. of valid cases	80				

*2 boxes (50%) have an expected frequency under 5. The minimal expected frequency is 4.39.
**Calculated only for a 2x2 table.

where surgeons chose the option of extra-articular reinforcement most often, this percentage would rise to 74.7% when adding hamstring and hamstring plus extra-articular reinforcement, providing the greatest percentage of coherence in the response chosen in our survey.

Our study found the most heterogeneity in sports such as wrestling and skiing, where no choice prevailed over 50%.

When reviewing the literature, we find that within the framework of a primary isolated reconstruction of ACL, most of the authors and reviews make recommendations concerning the type of plasty by dividing the patients into 3 groups[9]. Firstly, there are the elite, active athletes where the graft of choice is the BTB autograft, although the quadriceps tendon autograft can be an increasingly viable option in this population given that the hamstring autograft and the allograft have demonstrated greater failure rates and greater laxity, although they can be used if the patient must frequently kneel in their profession. Secondly, there are moderately active patients where the graft of choice is the hamstring autograft. It has a low failure and revision rate compared to allografts, and it also avoids the morbidity of donor zone associated with the BTB extraction. Although some residual laxity can remain, compared to a BTB graft, it is not clear whether this difference is clinically relevant. Finally, there are older patients who are less active for whom non-surgical treatment fails, where the graft of choice remains the hamstring autograft. However, the allograft can be considered for patients who are prepared to accept a greater risk of graft failure.

Other BTB indications could be athletes with a patellar tendinopathy, to the extent that it can be treated concomitantly with taking the graft of the patellar tendon, and patients with medial laxity of the knee for chronic injuries, then the hamstring acts as a medial stabiliser and its resection would not be recommended for taking the graft[5].

We thereby seen that BTB is the main option in the elite athletes' group and this is where we would like to step in. For us, one graft is no better than another, but a precise indication of its use. Not all sports are the same or have the same requirements.

Other revisions, such as Calvo and their group,10 go one step further regarding recommendations to select a graft according to the patient's characteristics and their sport: it is recommended to use a patellar tendon autograft in professional and top competition patients (football and rugby), patients who require an early return to their sport, patients who are susceptible to hamstring injury (sprinters, American football) and hyperlax patients; meanwhile, a hamstring graft is recommended for patients with open physes, women (aesthetic advantage), patients who have to kneel and sports which are susceptible to patellar tendon damage (basketball, volleyball, tennis). Finally, allograft is recommended in cases of multi-ligament injuries, patients over 40 years old with low demand, revisions.

This guide already made recommendations according to which sport is played and this is what we are trying to analyse.

Recent prospective studies of cohorts have identified risk factors for the failure of the ACL reconstruction graft failure, such as younger patients, greater levels of activity, fitting a non-anatomical tunnel and the use of allografts. Among these, the most easily modifiable risk factor is the choice of graft where the most suitable must be chosen for the patient, so Buerba and their team[11] also recommend considering these risk factors and the sport played, recommending BTB in sports or professions that do not involve kneeling; hamstring grafts in sports that do not depend to a great extent on the hamstring musculature; and QT in athletes that depend on their hamstring, and in athletes and workers who spend time on their knees (wrestlers, judo and carpenters).

Likewise, Arnold and Houck[8,12] also concluded that the graft selection must be individualised for each patient and understanding the global trends in the choice of graft can help orthopaedic surgeons to discuss the graft options with their patients and determine the appropriate graft for each case. Therefore, the surgeon must be familiar with all ACL reconstruction options available to optimise the treatment and the results of each patient.

Some considerations on the possible limitations of this work could be due to only using data from 2 European societies as the selection bias. Many answers were received from the Spanish society (SETRADE) but not so many from the European society (ESSKA) and so these data may not be representative of the society. Furthermore, the range of plasties carried out every year by the surgeons is very high, and there are broad differences between groups with a lot of experience and surgeons with little experience.

As aspects to be highlighted, surgeons and teams with broad experience completed the survey, both in terms of volume of surgeries per year and in plasties mastered by the survey respondents, which strengthens our results.

After evaluating the situation and making all the considerations, the following terms and consensus could be determined:

The performance of athletes in football, rugby, American football, weightlifting, sprinting, ballet dancers, taekwondo or karate, that compromise the hamstring, can be affected if we use them as a graft as this might considerably reduce the strength of the final flexion. There is also a greater incidence of muscle contractures and tears in the donor area and in female athletes if we use hamstring plasties; consequently, BTB would be the plasty of choice in these sports.

On the other hand, for sports where the extensor plays an important role, and kneeing is usual practice, as in martial arts, skiing, volleyball and basketball, we would choose hamstring plasties, so as not to injure the extensor.

In racquet sports, cycling, runners, swimming and amateur multisport patients, where hamstring power and the requirements are not as important, a hamstring plasty can be recommended given the advantages and disadvantages analysed above.

For athletes with open growth cartilage, only a hamstring graft is used, regardless of the sport, as the tunnel must always be filled with soft tissue to avoid damage to the epiphyseal growth.

We only recommend allografts in multi-ligament injuries, amateur athletes over 35 years old, as the inclusion and the strength of the graft requires double the time of the autografts, and the re-tear rate is higher. Patient preference should also be considered in the choice.

Currently we see that for almost 90% of the survey respondents, the sport influences the decision on the type of graft to use. If we analyse each sport separately, in general lines and the most popular sports, there is a coincidence in the plasty used, although for others there is not as much concordance as might be expected. With all this, the authors recommend mastering at least 2 plasties for primary reconstructions of ACL and individualising each case considering the type of sport when selecting the graft, considering what has been analysed in this work and in the literature.

Conclusions

Our survey was completed by a significant number of surgeons with experience in LCA plasties, where the biomechanical properties were the main reason when choosing the graft to be used. Most of them were influenced by the type of sport involved when making this choice.

The most chosen plasty was the same in 58.29% on average in each sport being studied, where most of them coincided with this same choice, although there are sports where no option prevails.

The authors recommend mastering at least 2 plasties for primary reconstructions of ACL and individualising each case by considering the type of sport when selecting the graft.

Appendix 1. Survey

All the questions refer to the context of complete rupture of the anterior cruciate ligament in a mature professional athlete with no previous history, injuries or surgeries.

1. How many ACL tear reconstruction surgeries do you perform per year?
2. Do you consider the type of sport that the patient plays when choosing the plasty in the ACL surgery?
3. What is the main reason that you consider when choosing the plasty to be used? (Complications in the donor zone, greater stability/rigidity of the plasty, faster osteointegration, biomechanical properties, re-break rate, etc.).
4. How many plasties for ACL reconstruction and which type have you mastered? Choose the options that consider patellar tendon autograft (BTB)?
   a) BTB-Patellar tendon.
   b) Hamstring autograft (STG).
   c) Quadricipital tendon autograft (QT).
   d) Allograft.
   e) ACL reconstruction + extra-articular plasty.
   f) Other.

5. Depending on the following type of activity, which ACL reconstruction plasty among the above do you think is the most appropriate? More than one answer is possible:
   a) Football player and impact sports – rugby, American football, handball.
   b) Basketball player /athletics – jumping events.
   c) Racquet sport or similar: tennis, paddle tennis, ping pong, badminton, squash, baseball, cricket.
   d) Wrestlers and martial arts.
   e) Volleyball.
   f) Cycling.
   g) Skiing / snowboard, ice or roller hockey.
   h) Ballet and other types of dancing.
   i) Long distance runners.
   j) Swimming.
   k) Amateur multi-sport patients.
   l) Low activity patients.

Conflicts of interest

The authors declare that there is no conflict of interest.

Bibliography

1. Sanders TL, Maradit Kremers H, Bryan AJ, Larson DR, Dahm DL, Levy BA, *et al.* Incidence of Anterior Cruciate Ligament Tears and Reconstruction: A 21-Year Population-Based Study. *Am J Sports Med.* 2016;44(6):1502-7.
2. Hey Groves EW. Operation for repair of the crucial ligaments. *Clin Orthop Relat Res* 1980;147:4-6.
3. Murray MM, Fleming BC, Badger GJ; BEAR Trial Team, Freiberger C, Henderson R, *et al.* Bridge-Enhanced Anterior Cruciate Ligament Repair Is Not Inferior to Autograft Anterior Cruciate Ligament Reconstruction at 2 Years: Results of a Prospective Randomized Clinical Trial. *Am J Sports Med.* 2020;48(6):1305-15.
4. Duchman KR, Lynch TS, Spindler KP. Graft Selection in Anterior Cruciate Ligament Surgery: Who gets What and Why? *Clin Sports Med*. 2017;36(1):25-33.
5. Yañez RD, Ocaranza DD, Dölz RL. Elección del injerto en cirugía de reconstrucción de ligamento cruzado anterior. *Artroscopia*. 2010;17(3):199-204.
6. Lee GH, McCulloch P, Cole BJ, Bush-Joseph CA, Bach BR Jr. The incidence of acute patellar tendon harvest complications for anterior cruciate ligament reconstruction. *Arthroscopy*. 2008;24(2):162-6.
7. Tuca MJ, Richard J, Espinoza G. Tendencias en Reconstrucción en Ligamento Cruzado Anterior: Encuesta a 103 Cirujanos. *Revista Chilena de Ortopedia y Traumatología*. 2020:61(01):11-7.
8. Arnold MP, Calcei JG, Vogel N, Magnussen RA, Clatworthy M, Spalding T, Campbell JD, Bergfeld JA, Sherman SL; ACL Study Group. ACL Study Group survey reveals the evolution of anterior cruciate ligament reconstruction graft choice over the past three decades. *Knee Surg Sports Traumatol Arthrosc.* 2021;29(11):3871-6.
9. Lin KM, Boyle C, Marom N, Marx RG. Graft Selection in Anterior Cruciate Ligament Reconstruction. *Sports Med Arthrosc Rev.* 2020;28(2):41-8.
10. Calvo R, Anastasiadis Z, Calvo Mena R, Figueroa D. Elección del injerto en la reconstrucción de ligamento cruzado anterior. ¿Existe un injerto ideal? *Rev Esp Artrosc Cir Articul.* 2017;24(1):59-66.
11. Buerba RA, Boden SA, Lesniak B. Graft Selection in Contemporary Anterior Cruciate Ligament Reconstruction. *J Am Acad Orthop Surg Glob Res Rev*. 2021;5(10):e21.00230.
12. Houck DA, Kraeutler MJ, Vidal AF, McCarty EC, Bravman JT, Wolcott ML; MOON Knee Group. Variance in Anterior Cruciate Ligament Reconstruction Graft Selection based on Patient Demographics and Location within the Multicenter Orthopaedic Outcomes Network Cohort. *J Knee Surg*. 2018;31(5):472-8.

Effect of tibial tunnel diameter on the outcome of ACL reconstruction

Covadonga Quintana-Barcia[1], Cristina Rodríguez[2], Covadonga Betegón[2], Antonio Maestro[3]

[1]Doctora en Ingeniería. SIMUMECAMAT Research Group, Universidad de Oviedo. Escuela Politécnica de Ingeniería de Gijón. EDO-7. [2]Catedrática y Doctora en Ingeniería. SIMUMECAMAT Research Group, Universidad de Oviedo. Escuela Politécnica de Ingeniería de Gijón. EDO-7. [3]Doctor en Medicina. SIMUMECAMAT Research Group, Universidad de Oviedo. Escuela Politécnica de Ingeniería de Gijón. EDO-7. MD in Hospital Begoña. Head of medical services of Real Sporting de Gijón. Gijón.

doi: 10.18176/archmeddeporte.00125

Received: 18/07/2022
Accepted: 26/11/2022

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.

Premio SEMED a la investigación 2022

Correspondence: Covadonga Quintana-Barcia
E-mail: covaquimbar89@gmail.com/quintanacovadonga@uniovi.es

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 population[1]. 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 tools[2].

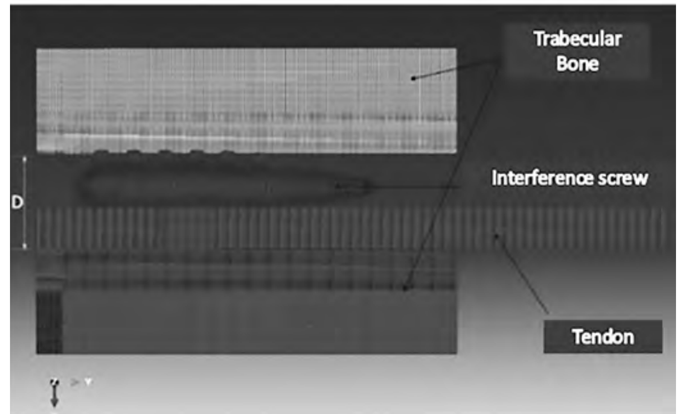
The objective of this work is, therefore, the analysis of the mechanical response of the tibia-plasty-screw assembly after the anterior cruciate ligament reconstruction, evaluating the influence of the different variables that come into play[3]. This would not be possible without the correct mechanical characterization, through laboratory tests, of the different materials involved. This need arises, in large part, due to the enormous variability in the existing bibliographic data[4-10], 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.

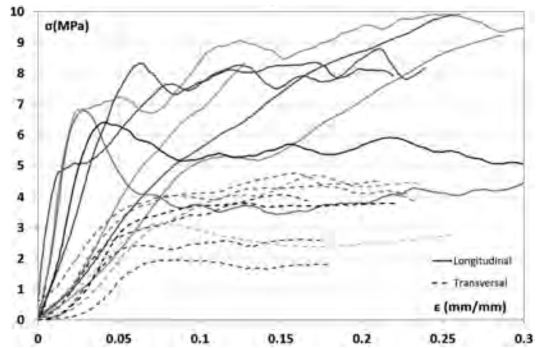
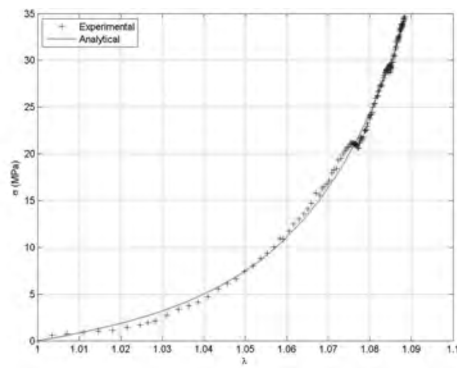
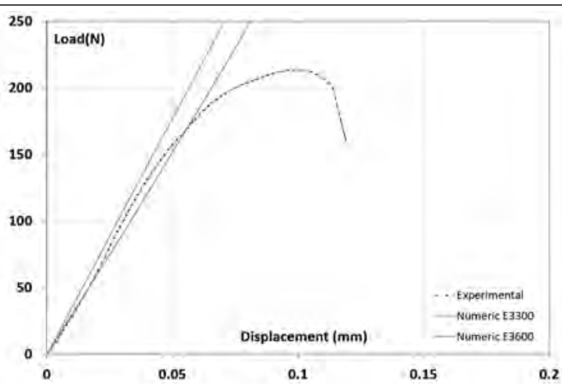
The material models used are a reflection of the results obtained after an extensive experimental work, which are collected in detail in previous publications[11,12].

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, v) 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 calculus[11].

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 equipment[12]. 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 Peña[13], 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 v), 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		Elastic-perfectly plastic	E=73 MPa v = 0.27 σ_Y 2.7 MPa
Tendon		uanisohyper_inv[13]	C_{10} = 7.98 C_3 = 0.374 C_4 = 19.24
Interference screw		Elastic	E = 3600 MPa v = 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 conditions[12] 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 process[12], 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 authors[16] 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 30º, position of maximum load during rehabilitation[17]. 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.

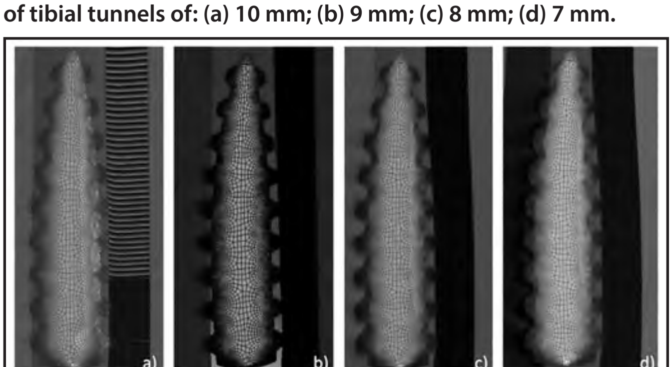
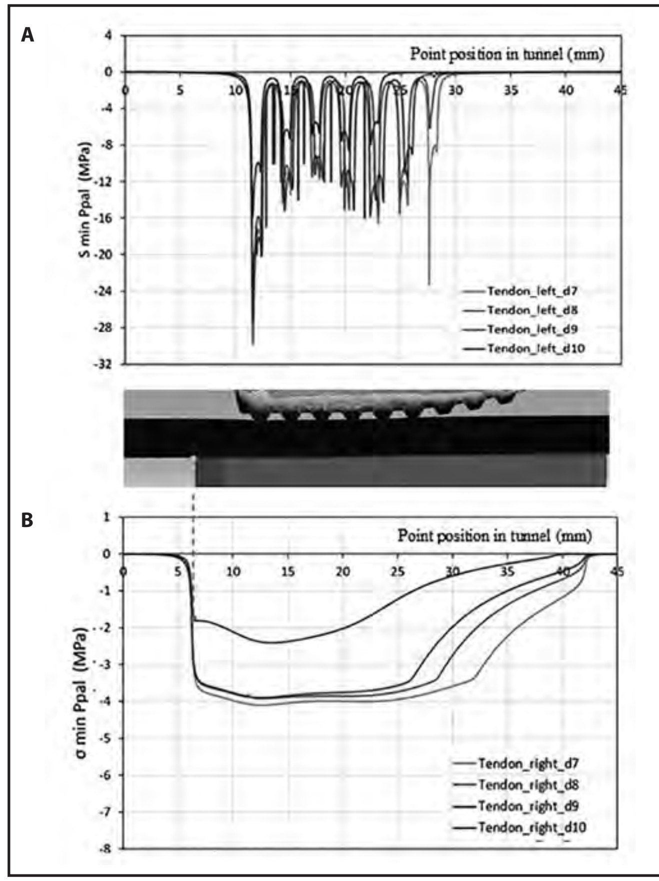


Figure 3. Influence of the tibial tunnel diameter on the Minimum Principal Stress in the tendon: (A) in contact with the screw; (B) in contact with trabecular bone.



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.

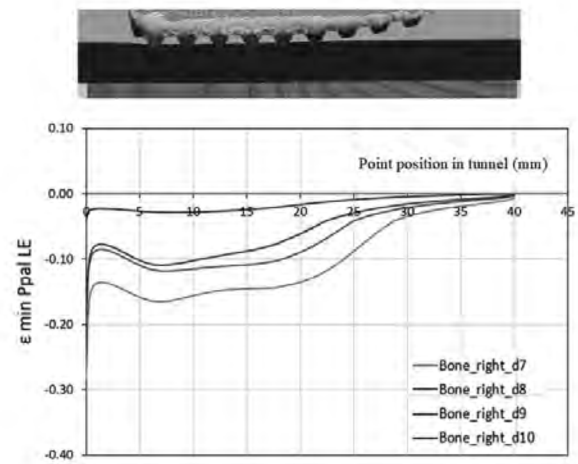
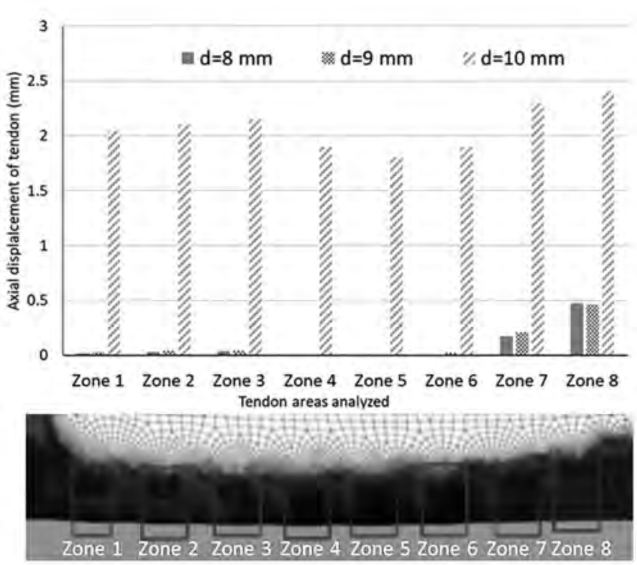


Figure 5. Displacement of the different points of the tendon along the tibial tunnel for different diameters of tunnel (d=10, 9 y 8 mm).



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 authors[18], 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 loads[19]. 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 authors[20-23] 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.

Acknowledgments

The SIMUMECAMAT research group appreciates the help of the Principality of Asturias through the Science, Technology and Innovation Plan (IDI/2018/0000134). Finally, Covadonga Quintana-Barcia thanks the regional government of the Principality of Asturias for the help granted through the Severo Ochoa post-doctoral training program (contract BP17-27 QBC).

Conflict of interest

The authors do not declare a conflict of interest.

Bibliography

1. Takazawa Y, Ikeda H, Saita Y, Ishijima M, Nagayama M, Kaneko H, *et al.* Case series: Revision anterior cruciate ligament reconstructions using patellar tendon autografts. *Knee.* 2015;22:569-73. https://doi.org/10.1016/j.knee.2015.06.005
2. Peña E, Calvo B, Doblaré M. Biomecánica de la articulación de la rodilla tras lesiones ligamentosas. *Rev Int Mét Num Cálc Dis Ing.* 2006;22:63-78.
3. Peña E, Calvo B, Martínez MA, Palanca D, Doblaré M. Influence of the tunnel angle in ACL reconstructions on the biomechanics of the knee joint. *Clin Biomech.* 2006;21:508-16. https://doi.org/10.1016/j.clinbiomech.2005.12.013
4. Kopperdahl DL, Keaveny TM. Yield strain behavior of trabecular bone. *J Biomech.* 1998;31:601-8. https://doi.org/10.1016/S0021-9290(98)00057-8
5. Morgan EF, Bayraktar HH, Keaveny TM. Trabecular bone modulus-density relationships depend on anatomic site. *J Biomech.* 2003;36:897-904. https://doi.org/10.1016/S0021-9290(03)00071-X
6. Morgan EF, Keaveny TM. Dependence of yield strain of human trabecular bone on anatomic site. *J Biomech.* 2001;34:569-577. https://doi.org/10.1016/S0021-9290(01)00011-2
7. Wang X, Shen X, Li X, Mauli Agrawal C. Age-related changes in the collagen network and toughness of bone. *Bone.* 2002;31:1-7. https://doi.org/10.1016/S8756-3282(01)00697-4
8. Angulo Carrere MT. Biomecánica de los tejidos del aparato locomotor 1. *Biomecánica de los tendones. Enfermería, Fisioter. y Podol.* 2010;2:1-13.
9. Goldstein SA. The mechanical properties of trabecular bone: Dependence on anatomic location and function. *J Biomech.* 1987;20:1055-61. https://doi.org/10.1016/0021-9290(87)90023-6
10. Ding M, Dalstra M, Danielsen CC, Kabel J, Hvid I, Linde F. Age variations in the properties of human tibial trabecular bone and cartilage. *Acta Orthop Scand. Suppl.* 2000;292:1-45. https://doi.org/10.1080/17453674.2000.11744841
11. Quintana-Barcia C, Rodríguez C, Álvarez G, Maestro A. Biomechanical Behavior Characterization and Constitutive Models of Porcine Trabecular Tibiae. *Biology.* 2021;10(6):532. https://doi.org/10.3390/biology10060532
12. Quintana-Barcia C. *Análisis del comportamiento mecánico del conjunto tibia-plastia-tornillo tras la reconstrucción de ligamento cruzado anterior. Influencia de distintas variables*. Tesis doctoral, 2021. Universidad de Oviedo.
13. Peña E, Calvo B, Martínez MA, Doblaré M. An anisotropic visco-hyperelastic model for ligaments at finite strains. Formulation and computational aspects. *Int J Solids Struct.*2007;44:760-78. https://doi.org/10.1016/j.ijsolstr.2006.05.018
14. Salehghaffari S, Dhaher YY. A model of articular cruciate ligament reconstructive surgery: A validation construct and computational insights. *J Biomech.* 2014;47:1609-17. https://doi.org/10.1016/j.jbiomech.2014.03.003
15. Seral Garcia B, Cegoñino Banzo J, Garcia Aznar JM, Doblaré Castellano M, Seral Iñigo F. Simulación en 3D con elementos finitos de un modelo de prótesis de rodilla. *Rev. Ortop. y Traumatol.* 2003;47:64-72. https://doi.org/10.1016/s1888-4415(03)76072-x
16. Wang L, Lin L, Feng Y, Fernandes TL, Asnis P, Hosseini A, *et al.* Anterior cruciate ligament reconstruction and cartilage contact forces - A 3D computational simulation. *Clin Biomech.* 2015;30:1175-80. https://doi.org/10.1016/j.clinbiomech.2015.08.007
17. Escamilla RF, MacLeod TD, Wilk KE, Paulos L, Andrews JR. Anterior cruciate ligament strain and tensile forces for weight-bearing and non-weight-bearing exercises: A guide to exercise selectiona. *J. Orthop. Sports Phys. Ther.* 2012;42: 208-20. https://doi.org/10.2519/jospt.2012.3768
18. Abdullah AH, Rashid H, Mahmud J, Othman MF, Ibrahim MWAJ. Effects of screw materials in Anterior Cruciate Ligament reconstruction using finite element analysis. *Procedia Eng.* 2012;41:1614-9. https://doi.org/10.1016/j.proeng.2012.07.358
19. Moré ADO, Pizzolatti ALA, Fancello EA, Salmoria GV, De Mello Roesler CR. Graft tendon slippage with metallic and bioabsorbable interference screws under cyclic load: A biomechanical study in a porcine model. *Rev Bras Eng Biomed.* 2015;31:56-61. https://doi.org/10.1590/2446-4740.0652
20. Gokce A, Beyzadeoglu T, Ozyer F, Bekler H, Erdogan F. Does bone impaction technique reduce tunnel enlargement in ACL reconstruction? *Int Orthop.* 2009;33:407-12. https://doi.org/10.1007/s00264-007-0496-5
21. Raj MAV, Ram SM, Venkateswaran S, Manoj J. Bone tunnel widening following arthroscopic reconstruction of anterior cruciate ligament (ACL) using hamstring tendon autograft and its functional consequences. *Int J Orthop Sci.* 2018;4:160-3. https://doi.org/10.22271/ortho.2018.v4.i1c.24
22. Harvey A, Thomas NP, Amis AA. Fixation of the graft in reconstruction of the anterior cruciate ligament. *J Bone Jt Surg.* 2005;Ser. B;87:593-603. https://doi.org/10.1302/0301-620X.87B5.15803
23. Webb J. Hamstrings and the anterior cruciate ligament deficient knee. *Knee.* 2001;8:65-7. https://doi.org/10.1016/S0968-0160(01)00063-1

Original article

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

Carlos Bahamondes-Avila[1], Jaime Cárcamo-Oyarzún[2], Esteban Aedo-Muñoz[3], Claudio Hernandez-Mosqueira[2], Cristian Martínez-Salazar[2], Marcelo Rosas-Mancilla[4], Pedro Delgado-Floody[2], Felipe Caamaño-Navarrete[5], Daniel Jerez-Mayorga[6]

[1]Escuela de Kinesiología, Facultad de Medicina y Ciencias de la Salud, Universidad Mayor, Temuco, Chile. [2]Department of Physical Education, Sport and Recreation, Universidad de La Frontera, Temuco, Chile. [3]Universidad de Santiago de Chile. [4]Instituto Nacional de Deportes. Centro de Entrenamiento Regional. Centro de Evaluación Funcional. Región de Aysén. Chile. [5]Pedagogía en Educación Física, Universidad Autónoma de Chile, Temuco, Chile. [6]Escuela de Kinesiología. Facultad de Ciencias de la Rehabilitación. Universidad Andrés Bello. Santiago. Chile.

doi: 10.18176/archmeddeporte.00126

Received: 15/04/2020
Accepted: 23/11/2020

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 endomorfas-mesomorfas, y las de karate como meso-endomorfas.
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.

Correspondence: Daniel Jerez-Mayorga
E-mail: daniel.jerez@unab.cl

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 talents[3]. 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 athletes[6]. 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 assessments[7]. However, although there are multiple anthropometric studies on children and adolescents in schools[8], there is little information about the morphological characteristics of boys and girls who train regularly[9] 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 followed[10], 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 method[11] ; and c) Somatotype, according to the model proposed by Heath and Carter[12], 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.

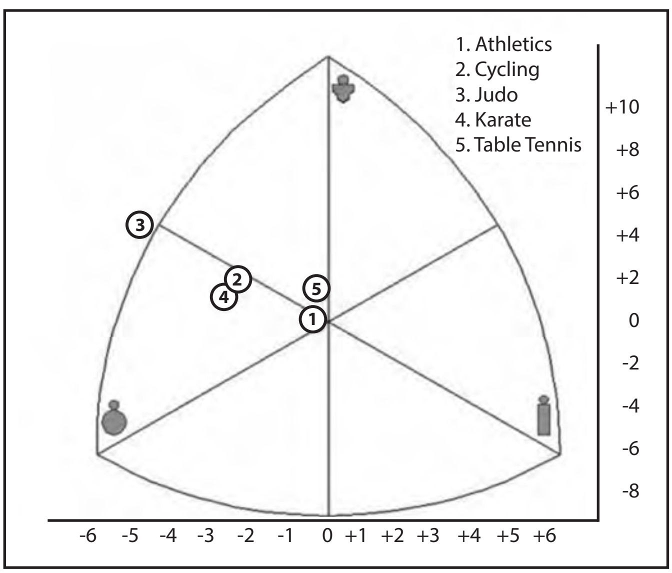
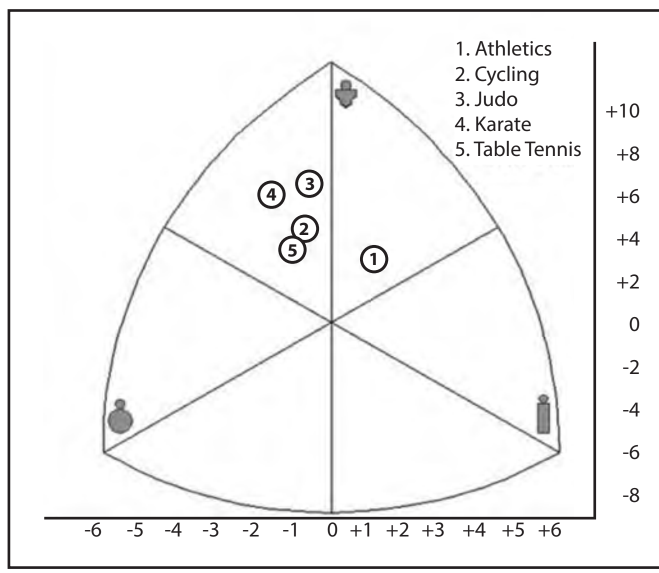


Figure 2. Somatotype of the male athletes in the CER Program, according to their discipline.



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 conside-ring 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 state[16], 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 mass[19]. 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 judocas[20], 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 mass[21]. On the other hand, the percentage of muscle mass in the male karatekas in the CER is slightly less (44.8%) than junior Spanish karatecks, 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 ectomorph[19]. 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-mesomorph[20]. 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 mesomorph[22]. 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-endomorph[22].

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 sport[12]. 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 biotypological 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 ≥ 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 Guimaraes[25] 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 possess[26]. 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.

Acknowledgments

Thanks to the Chilean National Sports Institute (IND) and to the trainers and professionals of the CER Program in the Region of Aysén,

Chile, who collaborated in this study, as well as all the athletes who participated in the assessments.

Conflict of interest

The authors do not declare a conflict of interest.

Bibliography

1. Lentini NA, Gris GM, Cardey ML, Aquilino G, Dolce, PA. Estudio somatotípico en deportistas de alto rendimiento de Argentina. *Arch Med Deporte.* 2004;21:497-509.
2. Silva R, Morouço P. Avaliação das características antropométricas e capacidades físicas ao longo de uma época desportiva em futebol: comparação entre sub-15, sub-17 esub-19. *Motricidade.* 2017;13:38–49.
3. Vitale M. Bio-anthropometric evaluation in sport and talent ID. Ital J Anat Embryol. 2010;115:195.
4. De la Fuente FP, Páez LC, Pardo EM, Pagán RH. Perfil antropométrico, somatotipo y composición corporal de jóvenes jugadores de tenis de mesa. *RICYDE*. 2007;3:11–23.
5. Cabral BG, Cabral SA, Medeiros RM, Alcatara T, Dantas PMS. Relationship of maturation with anthropometric and physical valences in sports initiation boys and girls. *Motricidade*. 2013;9:12–22.
6. Le Gall F, Carling C, Williams M, Reilly T. Anthropometric and fitness characteristics of international, professional and amateur male graduate soccer players from an elite youth academy. *J Sci Med Sport.* 2010;13:90–5..
7. Instituto Nacional de Deportes. Orientaciones Técnico-Administrativas Centros de Entrenamiento Regional. Santiago de Chile: Departamento de Alto Rendimiento del Instituto Nacional de Deportes de Chile; 2017.
8. Fernandez S, Alvero JR. La producción científica en cineantropometría: datos de referencia de composición corporal y somatotipo. *Arch Med Deporte*. 2006;23:17–28.
9. Haas AN, Plaza MR. Estudio comparativo del somatotipo de niñas-bailarinas cordobesas y porto-alegregrenses. *Arch Med Deporte*. 2016;33:18–23
10. Marfell-Jones MJ, Stewart AD, De Ridder JH. *International standards for anthropometric assessment*. Wellington. Editorial ISAK ;2011. p . 100.
11. Ross WD, Kerr DA. Fraccionamiento de la masa corporal: un nuevo método para utilizar en nutrición clínica y medicina deportiva. *Apunt Sport Med.* 28:175–88.
12. Heath BH, Carter JEL. A modified somatotype method. *Am J Phys Anthropol.* 1967;27:57–74
13. Garrido CR, Vásquez RM, Vitoria RV, Salazar CM, Alarcón VC. Descripción del estado nutricional en una muestra de estudiantes de colegios municipalizados de la ciudad de vilcún, ix región-chile. *Rev Ciencias la Act Física*. 2012;13:7–14.
14. Godoy-Cumillaf AER, Valdés-Badilla PA, Salvador Soler N, Carmona-López MI, Fernández JJ. Características antropométricas de adolescentes pertenecientes a distintas escuelas deportivas formativas. *Int J Morphol.* 2015;33:1065–70.
15. MINSAL. Patrones de crecimiento para la evaluación nutricional de niños y adolescentes, desde el nacimiento hasta los 19 años de edad. Santiago: Ministerio de Salud de Chile; 2018.
16. Curilem C, Almagià FA, Rodríguez F, Yuing T, Berral F, Martínez C, *et al.* Evaluación de la composición corporal en niños y adolescentes: directrices y recomendaciones. *Nutr Hosp.* 2016;33:734–8.
17. Franchini E, Takito MY, Kiss M, Strerkowicz S. Physical fitness and anthropometrical differences between elite and non-elite judo players. *Biol Sport.* 2005;22:315.
18. Úbeda N, Palacios G, Montalvo Z, García B, García Á, Iglesias E. Hábitos alimenticios y composición corporal de deportistas españoles de élite pertenecientes a disciplinas de combate. *Nutr Hosp.* 2010;25:414–21.
19. Torres FJ, Lara-Padilla E, Sosa-Tallei G, Berral FJ. Análisis de composición corporal y somatotipo de judokas infantiles y cadetes en el campeonato de España 2012. *Int J Morphol.* 2014;32:194–201.
20. Carratalá E, Benavent J, Carqués L. Valoración de los componentes cineantropométricos de los judokas infantiles y cadetes del equipo nacional español. III Congreso de la Asociación Española de Ciencias del Deporte, Universitat de Valencia. (material electronico) 2004 (consultado 07/07/2018). Disponible en: http://www.eweb.unex.es/eweb/cienciadeporte/congreso/04%20val/pdf/c51.pdf.
21. Grijota J, Muñoz D, Crespo C, Robles MC, Maynar M. Análisis comparativo de la composición corporal y de la condición física en deportistas en edad escolar practicantes de balonmano, natación y kárate. *Rev Kronos.* 2012;11:14-21.
22. Carrasco L, Pradas F, Martínez A. Somatotype and body composition of young top-level table tennis players. *Int J Table Tennis Sci.* 2010;6:175–7.
23. Rodríguez X, Castillo O, Tejo J, Rozowski J. Somatotipo de los deportistas de alto rendimiento de Santiago, Chile. *Rev Chil Nutr.* 2014;41:29–39.
24. Hebbelinck M, Borms J. Biometrische Studie vam een Reeks Lichaamskenmerken en Lichamelijke van Belgische Dinderen uit het Lager Onderwijs, Cent voor Bevolkings en Gezinsstudien (CBGS).Brussels.1975.
25. De Rose EH, Guimaraes AC. A model for optimization o somatotype in young athetes. In: Ostyn, M. & Bremen, G. & Simons, J. *Kinanthropometry II*. Baltimore, University Park, 1980.
26. Gonçalves LG, Aquino RL, Puggina EF. Caracterização do perfil de jovens jogadores de futebol: uma análise das habilidades técnicas e variáveis antropométricas. *Motricidade.* 2016;12:27–37.

Guidelines of publication Archives of Sports Medicine

The ARCHIVES OF SPORTS MEDICINE Journal (Arch Med Deporte) with ISSN 0212-8799 is the official publication of the Spanish Federation of Sports Medicine. This journal publishes original works about all the features related to Medicine and Sports Sciences from 1984. This title has been working uninterruptedly with a frequency of three months until 1995 and two months after this date. Arch Med Deporte works fundamentally with the system of external review carried out by two experts (peer review). It includes regularly articles about clinical or basic research, reviews, articles or publishing commentaries, brief communications and letters to the publisher. The articles may be published in both SPANISH and ENGLISH. The submission of papers in English writing will be particularly valued.

Occasionally oral communications accepted for presentation in the Federation's Congresses will be published.

The Editorial papers will only be published after an Editor requirement.

The manuscripts accepted for publication will become FEMEDE property and their reproduction, total or partial, must be properly authorized. All the authors will have to send a written letter conceding these rights as soon as the article is accepted for publication.

Submit of manuscripts

1. The papers must be submitted at the Editor in Chief's attention, written in double space in a DIN A4 sheet and numbered in the top right corner. It is recommended to use Word format, Times New Roman and font size 12. They must be sent by e-mail to FEMEDE's e-mail address: femede@femede.es.
2. On the first page exclusively it should include: title (Spanish and English), authors' first name, initial of the second name (if applicable), surname and optionally the second one; Main official and academic qualifications, workplace, full address and corresponding author e-mail. Supports received in order to accomplish the study – such as grants, equipments, medicaments, etc- have to be included.
   A letter in which the first author on behalf of all signatories of the study, the assignment of the rights for total or partial reproduction of the article, once accepted for publication shall be attached.
   Furthermore, the main author will propose up to four reviewers to the editor. According to the reviewers, at least one must be from a different nationality than the main author. Reviewers from the same institutions as the authors, will not be accepted.
3. On the second page the abstract of the work will appear both in Spanish and English, and will have an extension of 250-300 words. It will include the intention of the work (aims of the research), methodology, the most out-standing results and the main conclusions. It must be written in such a way to allow the understanding of the essence of the article without reading it completely or partially. After the abstract, from three to ten key words will be specified in Spanish and English, derived from the Medical Subject Headings (MeSH) of the National Library of Medicine (available in: http://www.nlm.nih. gov/mesh/MBrowser.html).
4. The extension of the text will change according to the section applicable:
   a. Original research: maximum 5.000 words, 6 figures and 6 tables.
   b. Review articles: maximum 5.000 words, 5 figures and 4 tables. In case of needing a wider extension it is recommended to contact the journal Editor.
   c. Editorials: they will be written by Editorial Board request.
   d. Letters to the Editor: maximum 1.000 words.
5. Structure of the text: it will change according to the section applicable:
   a. **ORIGINALS RESEARCH**: It will contain an introduction, which must be brief and will contain the aim of the work, written in such a way that the reader can understand the following text.
   Material and method: the material used in the work will be exposed, as well as its characte¬ristics, selection criteria and used techniques, facilitating the necessary data in order to allow the reader to repeat the experience shown. The statistical methods will be detailed described.
   Results: Results must report and not describe the observations made with the material and method used. This information can be published in detail in the text or using tables and figures. Information given in the tables or figures must not be repeated in the text.
   Discussion: The authors will expose their opinions about the results, their possible interpretation, relating the observations to the results obtained by other authors in similar publications, suggestions for future works on the topic, etc. Connect the conclusions with the aims of the study, avoiding free affirmations and conclusions not supported by the information of the work.
   The acknowledgments will appear at the end of the text.

b. **REVIEWS ARTICLES:** The text will be divided in as much paragraphs as the author considers necessary for a perfect compre-hension of the topic treated.

c. **LETTERS TO THE EDITOR:** Discussion about published papers in the last two issues, with the contribution of opinions and experiences briefed in 3 pages, will have preference in this Section.

d. **OTHERS:** Specific sections commissioned by the Journal's Editorial Board.

6. **Bibliography:** it will be presented on pages apart and will be ordered following their appearance in the text, with a correlative numeration. In the text the quote's number will be presented between parentheses, followed or not by the authors' name; if they are mentioned, in case the work was made by two authors both of them will figure, and if there are more than two authors only the first will figure, followed by "et al".

   There will not be personal communication, manuscripts or any unpublished information included in the bibliographical ap-pointments.

   The official citation for the journal Archives of Sports Medicine is Arch Med Sport.

   References will be exposed in the following way:

   - **Journal: order number;** surnames and name's initial of the article authors with no punctuation and separated with a comma (if the number of authors is higher than six, only the six first will figure, followed by "et al"); work's title in its original language; abbreviated journal name, according to the World Medical Periodical; year of publication; volume number; first and last page of the quoted extract. Example: Calbet JA, Radegran G, Boushel R and Saltin B. On the mechanisms that limit oxygen uptake during exercise in acute and chronic hypoxia: role of muscle mass. *J Physiol.* 2009;587:477-90.
   - **Book chapter**: Authors, chapter title, editors, book title, city, publishing house, year and number of pages. Example: 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. p162-6.
   - **Book**. Authors, title, city, publishing house, year of publication, page of the quote. Example: Balius R. Ecografía muscular de la extremidad inferior. Sistemática de exploración y lesiones en el deporte. Barcelona. Editorial Masson; 2005. p 34.
   - **World Wide Web**, online journal. Example: Morse SS. Factors in the emergence of infectious diseases. Emerg Infect Dis (revista electrónica) 1995 JanMar (consultado 0501/2004). Available in: http://www.cdc.gov/ncidod/EID/ eid.htm

7. **Tables and figures.** Tables and figures will be sent on separate files in JPEG format. Tables must be sent in word format.

   Tables shall be numbered according to the order of appearance in the text, with the title on the top and the abbreviations described on the bottom. All nonstandard abbreviations which may be used in the tables shall be explained in footnotes.

   Any kind of graphics, pictures and photographies will be denomi-nated figures. They must be numbered correlatively by order of appearance in the text and will be sent in black and white (except in those works in which colour is justified). Color printing is an economic cost that has to be consulted with the editor.

   All tables as well as figures will be numbered with Arabic numbers following the order of appearance in the text.

   At the end of the text document the tables and figures captions will be included on individual pages.

8. The Journal's Editorial Staff will communicate the reception of sub-mitted articles and will inform about its acceptance and possible date of publication.
9. After hearing the reviewers' suggestions (journal uses peer correc-tion system), may reject the works which are not suitable, or indicate the author the modifications which are thought to be necessary for its acceptance.
10. The Editorial Board is not responsible for the concepts, opinions or affirmations supported by the authors.
11. Submissions of the papers: Archives of Sports Medicine. By e-mail to FEMEDE'S e-mail address: femede@femede.es. The submission will come with a cover letter on which the work's examination for its publication in the Journal will be requested, article type will be specified, and it will be certified by all authors that the work is original and has not been partially or totally published before.

Conflicts of interests

If there should be any relation between the work's authors and any public or private entity, from which a conflict of interests could appear, it must be communicated to the Editor. Authors must fulfil a specific document.

Ethics

All authors that sign the articles accept the responsibility defined by the World Association of Medical Editors.

The papers sent to the journal for evaluation must have been elaborated respecting the international recommendations about clinical and laboratory animals' researches, ratified in Helsinki and updated in 2008 by the American Physiology.

For the performance of controlled clinic essays the CONSORT normative shall be followed, available at http://www.consort-statement.org/

POSTGRADOS OFICIALES:
SALUD Y DEPORTE

UCAM
UNIVERSIDAD
CATÓLICA DE MURCIA

- **Actividad Física Terapéutica** (2)
- **Alto Rendimiento Deportivo: Fuerza y Acondicionamiento Físico** (2)
- **Performance Sport: Strength and Conditioning** (1)
- **Audiología** (2)
- **Balneoterapia e Hidroterapia** (1)
- **Desarrollos Avanzados de Oncología Personalizada Multidisciplinar** (1)
- **Enfermería de Salud Laboral** (2)
- **Enfermería de Urgencias, Emergencias y Cuidados Especiales** (1)
- **Fisioterapia en el Deporte** (1)
- **Geriatría y Gerontología: Atención a la dependencia** (2)
- **Gestión y Planificación de Servicios Sanitarios** (2)
- **Gestión Integral del Riesgo Cardiovascular** (2)
- **Ingeniería Biomédica** (1)
- **Investigación en Ciencias Sociosanitarias** (2)
- **Investigación en Educación Física y Salud** (2)
- **Neuro-Rehabilitación** (1)
- **Nutrición Clínica** (1)
- **Nutrición y Seguridad Alimentaria** (2)
- **Nutrición en la Actividad Física y Deporte** (1)
- **Osteopatía y Terapia Manual** (2)
- **Patología Molecular Humana** (2)
- **Psicología General Sanitaria** (1)

(1) *Presencial* (2) *Semipresencial*

MÁS INFORMACIÓN: 968 27 88 01 · ucam.edu

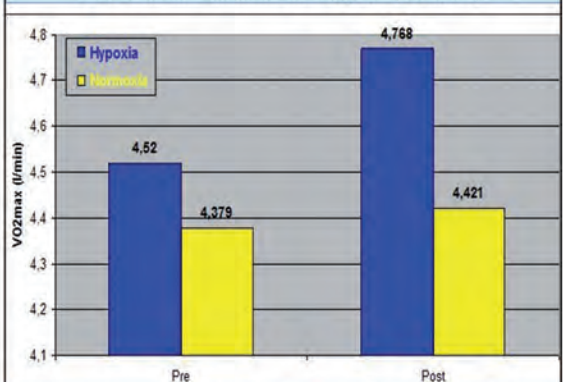
EJERCICIO EN HIPOXIA PARA LA MEJORA DEL RENDIMIENTO

BIOALTITUDE® V100

20 kilos

Válido para realizar Ejercicio en Hipoxia

Influencia del Entrenamiento en Hipoxia sobre la Evolución del Consumo Máximo de Oxígeno (VO2max)



Basado en el estudio de **Dufour y col**: Exercise training in normobaric hypoxia in endurance runners. I. Improvement in aerobic performance capacity. Publicado en el ***Journal of Applied Physiology***

Influencia del Entrenamiento en Hipoxia
sobre el Tiempo Límite de Ejercicio a Alta Intensidad

Gráfico elaborado en base a los datos del estudio de Ponsot y col, "Exercise training in normobaric hypoxia in endurance runners. II. Improvement of mitochondrial properties in skeletal muscle" publicado en el Journal of Applied Physiology, 2006

Datos Técnicos - Bioaltitude® V100

HIPOXIA: Flujo: 40 - 100 L/min - Concentración de O2: 8,5% - 20%
Flujo promedio máximo: 100 L/min. Flujo pico máximo: 140 l/min
HIPEROXIA: Flujo: 0 - 15 L/min - Concentración de O2: 70% - 93%
TIPO DE HIPOXIA: Dormir / Reposo / Ejercicio / Sprints repetidos (RSH)
MÉTODO: Separación del aire por método físico
AIRE HIPERÓXICO: Sí. hasta 15 L/min
MEDIDAS / PESO: 34,4 x 30,6 x 56,5 cm / 20 Kg
NIVEL SONORO: <50 dB
BOLSA DE EXPANSIÓN: Incluida. 60 litros de capacidad. Opcional hasta 240 litros.
TUBOS: 2 x 3 m
GARANTÍA: 3 años o 5000 horas, en nuestras instalaciones
MANTENIMIENTO: Mínimo (limpieza de filtros y reemplazo filtro Hepa cada 6 meses)

60 Litros

15 Litros

120 Litros

BIOAltitude® by BIOLaster®

www.biolaster.com

943 300 813 | 639 619 494