VNIVERSITAT DE VALÈNCIA

Facultad de Ciencias de la Actividad Física y el Deporte

Departamento de Educación Física y Deportiva

Doctoral program: Actividad Física y Deporte
Regulated by Real Decreto 99/2011

DOCTORAL THESIS

THE EFFECT OF ARM-CRANK EXERCISE TRAINING ON POWER OUTPUT, SPIROMETRY AND CARDIAC FUNCTION AND LEVEL OF AUTONOMY IN PERSONS WITH TETRAPLEGIA.

EFECTO DEL ENTRENAMIENTO DE PEDALEO DE BRAZOS SOBRE LA ENTREGA DE POTENCIA, LA FUNCIÓN PULMONAR, LA FUNCIÓN CARDÍACA Y EL NIVEL DE AUTONOMÍA EN PERSONAS CON TETRAPLEJIA.

Author: **Sandra Sinz**

Director: **Dr. Gabriel Brizuela Costa**

Valencia, Spain, August 2021

Prof. Gabriel Brizuela Costa, PhD and Professor at the Department of Physical and Sports Education, University of Valencia Spain

DECLARES:

That the present dissertation with the title:

"Effect of an Arm-crank Exercise training on power output, spirometry and cardiac function and the level of autonomy in persons with tetraplegia"

Authored by Sandra Sinz and conducted under his direction, in his view, is submitted in fulfillment of the requirements for the degree of Doctor in Physical Activity and Sports Sciences.

And for the record, I sign the present document in Valencia, Spain on August 5th, 2021.

Prof. Gabriel Brizuela Costa, PhD.

Acknowledgements

To my Mentor Gabriel Brizuela, for his infinite pacience and for being the motor of an incredible visionary project that helped so many people gain more joy and confidence in their life

To my Co-workers Rafael Aranda and Ignacio Martinez-Navarro, for pushing our project ahead whenever needed!

Thanks to my Mom for bringing me up as the free spirit I am and to my grandma for her infinite love and cookie baking.

Gratitude to my long-term fiancé and father of my son, for teaching me tenaciousness and financially supporting my thesis.

INDEX

ABSTRACT

Introduction: Disability continues to be a barrier to the social, personal and educational development of people who have it. Several studies have shown that physical activity provides multiple benefits persons with spinal cord injury (SCI): improving exercise tolerance, muscular endurance, peak power output and oxygen consumption, but without the concurrence of central cardiovascular adaptations. There are few studies investigating the effects of cardiovascular exercise on heart rate variability (HRV) in persons with tetraplegia.

Objective: To study the effect of arm-crank exercise on the physiological response of persons with tetraplegia.

Method: This is a prospective, quasi-experimental study with an A-B applicability design, divided into two phases (pre and post-intervention), in which 11 persons with tetraplegia of traumatic origin participated. The experiment consisted of arm-crank exercise program (ACE), with a duration of 8 weeks and a frequency of twice a week. It was measured variables related with power output, spirometric and cardiac function, and level of autonomy.

Results: All functional and pulmonary variables showed significant differences in relation to the level of injury, with higher values for participants with a lower level of cervical SCI ($p < 0.05$). None of the VRC variables showed differences between high or low level of injury, neither in the “Pre” or in the “Post” time. Both the level of autonomy and the maximum power output were significantly correlated before ($p < 0.0001$) and after ($p < 0.0001$) of the training period.

Conclusion: A short-term training program with arm-crank exercise is sufficient to significantly improve pedaling power, lung function and heart rate variability in persons with cervical spinal cord injury, contributing to the improvement of their muscle, pulmonary and cardiovascular functions.

Key words: Disability, spinal cord injury, physical activity, pedaling, anaerobic performance, lung function, heart rate variability.

RESUMEN

Introducción: La discapacidad sigue siendo una barrera para el desarrollo social, personal y educativo de las personas con discapacidad. Se ha demostrado que la actividad física en la lesión medular mejora la tolerancia al ejercicio, la resistencia muscular, la resistencia máxima y el consumo de oxígeno, pero sin la concurrencia de adaptaciones cardiovasculares centrales. Los estudios que investigan los efectos del ejercicio cardiovascular sobre la variabilidad de la frecuencia cardíaca (HRV) en personas con tetraplejía son escasos.

Objetivo: Estudiar el efecto del ejercicio de pedaleo de brazos en la respuesta fisiológica de las personas con tetraplejía.

Método: Se trata de un estudio prospectivo cuasiexperimental con diseño de aplicabilidad A-B, dividido en dos fases (pre y postintervención), en el que participaron 11 personas con tetraplejía de origen traumático. El experimento consistió en un programa de ejercicios de pedaleo de brazo (ACE), con una duración de 8 semanas y una frecuencia de 2 veces por semana. Se midieron variables relacionadas con la producción de potencia, función espirométrica y cardiaca y nivel de autonomía.

Resultados: Todas las variables funcionales y pulmonares mostraron diferencias significativas en relación al nivel de lesión, con valores más altos para los participantes con niveles más bajos de lesión medular cervical ($p < 0{,}05$). Ninguna de las variables VRC mostró diferencias entre el nivel de lesión alto o bajo, ya sea en el tiempo "Pre" o "Post". Tanto el nivel de autonomía como la producción de potencia máxima se correlacionaron significativamente antes ($p < 0{,}0001$) y después ($p < 0{,}0001$) del período de entrenamiento.

Conclusión: Un programa de entrenamiento a corto plazo en ejercicio de pedaleo de brazos es suficiente para mejorar significativamente la potencia de pedaleo, la función pulmonar y la variabilidad de la frecuencia cardíaca, en personas con lesión medular cervical, lo que contribuye a mejorar su función muscular, pulmonar y cardiovascular.

PALABRAS CLAVE

Discapacidad, lesión medular, actividad física, pedaleo, rendimiento anaeróbico, función pulmonar, variabilidad de la frecuencia cardíaca.

RESUMEN AMPLIO

INTRODUCCIÓN

La lesión medular (LM) puede deberse a diferentes etiologías, puede causar parálisis en diferentes puntos y grados de extensión, pérdida de sensibilidad y disfunción de la vejiga, intestinal y sexual, además de importantes consecuencias psicológicas y socioeconómicas (Gifre, del Valle Gómez, Yuguero, Gil & Bosch, 2010).

La Organización Mundial de la Salud (OMS) estima que para 2020 la LM ocupará una de las cinco principales causas de discapacidad a nivel mundial (Strassburguer, Hernández & Barquín, 2004). La incidencia de la LM es variable entre países y entre regiones. A nivel europeo la incidencia de LM ha aumentado. Se estima que en España, se producen entre 12 a 20 nuevos casos por cada millón de habitantes cada año (Strassburguer et al., 2004).

La LM puede aparecer en cualquier nivel de la médula espinal, por lo que la ubicación y la gravedad de la lesión determinarán qué funciones del organismo se alterarán o perderán (Indakoetxea, 2003). Una paraplejia debida a LM implica una lesión a nivel de la columna dorsal o lumbar, causando parálisis de los miembros inferiores (Instituto nacional de desórdenes neurológicos y del movimiento, 2005; Henao-Lema & Pérez-Parra, 2010). Una tetraplejía con origen en LM provoca una pérdida de la función motora o sensorial de los miembros inferiores y superiores, así como alteraciones respiratorias en diferentes grados dependiendo de la lesión (Acevedo González, Fernando Varón, Berbeo Calderón, Feo Lee & Díaz Orduz, 2008).

La LM puede ser completa o incompleta. La LM completa da lugar a la desaparición de las funciones sensoriales y motoras voluntarias por debajo del nivel de la lesión, incluidos los segmentos sacros inferiores (S4 y S5). La LM incompleta es aquella en la que la persona presenta una determinada función motora o sensorial residual por debajo del nivel de la lesión (Alizadeh, Dyck, & Karimi-Abdolrezaee, 2019).

El cuadro clínico depende del grado y el nivel de la lesión. Una lesión completa implica la ausencia total de movilidad y sensibilidad en los segmentos sacros. La principal dificultad diagnóstica de la LM aparece en la identificación de su origen (especialmente en el caso de los no traumáticos) (van Middendorp, Goss, Urquhart, Atresh, Williams &schuetz, 2011). Esto es importante ya que, dependiendo de la causa, el tratamiento y el pronóstico pueden variar (Strassburguer et al., 2004).

Los estándares internacionales para la clasificación neurológica y funcional de la LM consisten en un sistema de clasificación ampliamente aceptado que describe el nivel y el grado de lesión basado en una examinación neurológica de la función motora y sensorial sistemática. Esta clasificación se conoce como la Escala de Medición de Discapacidad de la Asociación Americana de Lesiones de la Médula Espinal (ASIA o Escala de ASIA) (American Spinal Injury Association / International Medical Society of Paraplegia, 1992).

El uso de métodos de diagnóstico por imagen dependerá del diagnóstico más relevante establecido clínicamente con la intención de dar prioridad al tratamiento de las lesiones más graves. Estos métodos incluyen: a) radiografías simples, b) Tomografía computarizada (TC), c) Resonancia magnética (RM), d) En casos de disección arterial traumática: angiografía por TAC, angiografía por resonancia o angiografía por sustracción digital (Boleaga, 2007).

En cuanto al tratamiento, el manejo de la LM comienza en el mismo lugar donde ocurre la lesión y debe cumplir estrictamente con los protocolos de Soporte Vital De Trauma Avanzado (ATLS) (Galvagno et al., 2019). Hay tres objetivos fundamentales en la escena del trauma: prevenir lesiones adicionales, mantener una adecuada oxigenación y perfusión, a través de maniobras de reanimación (Schmidt et al., 2009).

La prevención de complicaciones médicas en pacientes con LM es de gran importancia, ya que representan alrededor del 30 % de las hospitalizaciones en estos pacientes. El monitoreo posterior es realizado por especialistas en fisiatría y columna vertebral, que han diseñado programas para combatir la pérdida funcional (Brenes, 2016). El objetivo general del tratamiento fisioterapéutico de la médula espinal lesionada es lograr el mayor grado de independencia y bienestar de los pacientes, normalizar el tono muscular, mantener y mejorar el movimiento y el rango articular de las extremidades afectadas, corregir las deformidades osteomioarticulares y prevenir complicaciones de salud, desarrollar la fuerza muscular en las extremidades superiores, además de mejorar el equilibrio en sentarse y estar de pie (Quel de Oliveira et al. , 2017).

En las últimas décadas algunos investigadores plantearon la hipótesis de que la mejora de la fuerza después de realizar un programa de entrenamiento se debe principalmente al aumento de la activación de las unidades motoras de los músculos entrenados, acompañado gradualmente por el aumento de la masa muscular (Hakkinen 1994).

La actividad física y el deporte adaptado contribuyen en la rehabilitación a nivel terapéutico, recreativo o competitivo, debido a que promueven el esfuerzo para restaurar una capacidad disminuida, la normalización del estilo de vida de una persona con discapacidad; mejora la autonomía personal o la capacidad de actuar sobre sí mismo sin depender de los demás; la integración social, y la promoción de la igualdad social; impulsando y aumentando el deseo de superación personal; colaborando en la supresión de barreras arquitectónicas, psicológicas y sociales; y mejorando la autoestima y el desarrollo personal (Montero-Ordoñez et al., 2017).

Debido a lo antes mencionado, las personas con discapacidad física deben realizar actividad física adaptada, que requiere supervisión en algunos casos (Capó-Juan et al., 2017). En este caso se debe tener en cuenta que más del 80 % de las personas con parapléjia sufren lesiones irreversibles que impedirían en el futuro una restauración de la movilidad de sus miembros inferiores, que necesita dispositivos ortopédicos y suficiente desarrollo muscular en los brazos y tronco, ya que estos suplantan la inactividad de los miembros inferiores (de la Cuerda & Vázquez , 2012).

Para abordar estas particularidades, se debe comenzar por profundizar en la rehabilitación física para posteriormente basar el diseño de un programa de ejercicios físicos terapéuticos para la rehabilitación de los pacientes con LM

(Behrman et al., 2017). El papel del rehabilitador es, entre otros, crear situaciones que estimulen la implementación de habilidades de aprendizaje; estimular al paciente a realizar ejercicios físicos terapéuticos y promover actividades de la vida diaria; así como animarlos a encontrar soluciones a los problemas que puedan surgir (Tse et al., 2018).

JUSTIFICACIÓN

La discapacidad sigue siendo un obstáculo para el desarrollo social, personal y educativo de las personas que la tienen (OMS, 2011a, 2013). La importancia del deporte para estas personas ha sido analizada desde diferentes aspectos. El deporte se convierte en una herramienta de inclusión socioeducativa pero también hay que tener en cuenta las barreras que se presentan (Queen, 2014).

La actividad física proporciona múltiples beneficios para las personas con LM, siempre que se adapte a las circunstancias del paciente y se tengan en cuenta diversos factores limitantes (Warburton et al., 2011).

Los programas de entrenamiento realizados por personas con tetraplejia muestran mejoras en la tolerancia al ejercicio, la resistencia muscular, la resistencia máxima y el consumo de oxígeno sin la concurrencia de adaptaciones cardiovasculares centrales. Sin embargo, se pueden demostrar adaptaciones periféricas, que serán de notable importancia para mejorar la calidad de vida de estos pacientes (Chicharro et al., 2003).

La frecuencia cardíaca (FC) es uno de los parámetros más utilizados para evaluar la actividad cardíaca (Rodas, Pedret Carballido, Ramos, & Capdevila, 2008). El análisis de la variabilidad de la frecuencia cardíaca (VFC) se utiliza típicamente como método no invasivo para cuantificar el control que el sistema nervioso autónomo ejerce sobre la dinámica de la frecuencia cardíaca (Akselrod et al., 1981; Malik et al., 1996).

En personas con LM el uso de la VFC presenta un buen modelo porque la interrupción de las vías eferentes del sistema nervioso altera el equilibrio normal del sistema nervioso autónomo, lo que se refleja en los patrones de VFC (Myers, Lee, & Kiratli, 2007a). Sin embargo, los estudios que investigan los efectos del ejercicio cardiovascular sobre la VFC en personas con tetraplejia son escasos, y generalmente están relacionados con la marcha asistida por tapiz rodante o el entrenamiento ortostático (Millar, et al., 2009; Ditor et al., 2005a).

Por lo tanto, dada la falta de estudios al respecto, es necesario conocer la respuesta de VFC en personas con tetraplejia, así como en el efecto del ejercicio sobre los parámetros de los PFC, especialmente durante la recuperación, después del ejercicio.

OBJETIVOS

Objetivo general

- Estudiar el efecto del programa de entrenamiento de pedaleo de brazos sobre la respuesta fisiológica, la capacidad funcional y la autonomía de las personas con tetraplejia.

Objetivos específicos

- Analizar los cambios en la tasa de trabajo máxima antes y después de practicar un programa de ejercicio de pedaleo de brazos en personas con tetraplegia.
- Analizar los cambios en los parámetros respiratorios antes y después de practicar un programa ejercicio de pedaleo de brazos en personas con tetraplejia.
- Analizar los cambios en la VFC antes y después de practicar un programa ejercicio de pedaleo de brazos en personas con tetraplejia.
- Analizar los cambios en la capacidad funcional y la autonomía después de practicar un programa ejercicio de pedaleo de brazos en personas con tetraplejia.

MÉTODO

Se realizó un estudio prospectivo cuasi-experimental con diseño de aplicabilidad A-B dividido en dos fases (pre y post-intervención).

El comienzo

El Proyecto se inició en 2009 en la Universitat de València, Facultad de Ciencias de la Actividad Física y el Deporte.

Desarrollo del experimento

El experimento consistió en un programa de entrenamiento en ejercicio de pedaleo de brazos (ACE), realizado en un ergómetro estacionario adaptado. Las primeras mediciones se realizaron una semana antes del inicio del estudio (Semana 0). Dos sesiones de medición tuvieron lugar durante la misma semana pero no el mismo día, en las que se registró el cuestionario del Índice de Función de Tetraplejia (QIF), el registro de la frecuencia cardíaca, las variables de espirometría y la potencia máxima del ACE. Las mediciones se repitieron al final del programa de ejercicios (Semana 9).

El entrenamiento se llevó a cabo durante un período de 8 semanas, dos veces por semana, pero nunca en días consecutivos. La duración del ejercicio en cada sesión fue de 15 a 20 minutos en las dos primeras semanas, de 20 a 30 minutos durante la tercera y cuarta semana, aumentando a 30 a 40 minutos desde la quinta semana hasta el final del programa de entrenamiento.

Participantes

Veinticinco personas que viven en la ciudad de Valencia y sus alrededores expresaron su voluntad de participar en el proyecto. Se incluyeron pacientes diagnosticados con LM, que no practicaban deporte de forma regular y estaban dispuestos a asistir al gimnasio de la universidad dos veces por semana, durante dos meses. Se excluyeron las personas con LM cervical baja y función de tríceps y las que practicaban deporte o actividad física regularmente (una vez a la semana o más), pacientes con enfermedad cardiovascular y otras patologías que pudieran afectar la adherencia al estudio, los individuos a los que estaba contraindicado el ejercicio físico, sujetos con deficiencias cognitivas o mentales, pacientes con alteraciones degenerativas u osteoarticulares de las extremidades superiores y pacientes con complicaciones tegumentarias (úlceras).

En total participaron 11 sujetos (8 hombres y 3 mujeres, masa corporal = 72,3 ± 13,4 kg y edad = 36,5 ± 10,0 años), todos ellos con tetraplejia de origen traumático (5 con LME entre C4-C5 y 6 entre C6-C7, niveles A y B de ASIA).

Variables

Las variables investigadas en este estudio fueron la máxima potencia mecánica (POTENCIA P (W)), el Índice de función de cuadriplejia (QIF), Capacidad vital (VC), Capacidad vital forzada (CVF), ventilación voluntaria máxima (MVV), variabilidad de la Frecuencia Cardíaca (HRV), Frecuencia cardíaca en resposo (HR), Desviación estándar de los valores instantáneos de frecuencia cardíaca (ETS HR), Raíz cuadrada de las diferencias cuadradas medias entre intervalos RR sucesivos (RMSSD), intervalos RR de baja frecuencia (LF), intervalos RR de alta frecuencia (HF), potencia total (HRVPower), y relación entre potencias LF y HF (LH/HF).

Instrumentos de medida

El PPOWER se midió utilizando un ergómetro de brazo SCIFIT PRO1 (SCIFIT Systems Inc., Tulsa, OK, USA), adaptado para personas con tetraplejia. La prueba consistió en cinco intentos de 10 s para aplicar su máxima potencia de ACE, tratando de aumentar su cadencia de pedaleo contra la resistencia aplicada por el ergómetro, con períodos de descanso de 3 a 5 minutos entre intentos para evitar la fatiga.

Se registró la señal de Frecuencia Cardíaca durante un período de descanso de 10 minutos como la primera prueba de cada sesión de medición, con el participante sentado en su propia silla de ruedas en condiciones de calma y relajación, tanto como fuera posible. Los parámetros de HRV se calcularon con el paquete de software Kubios HRV 2.0. Los datos fueron sometidos a un análisis espectral de la transformada de Fourier (FFT), tomando las bandas de frecuencias generalmente recomendadas (Task Force, 1996): alta frecuencia (HF) de 0,15 Hz a 0,4 Hz; baja frecuencia (LF) de 0,04 Hz a 0,15 Hz; y frecuencia muy baja (VLF) de 0,03 Hz a 0,04 Hz.

Todas las variables de espirometría se midieron utilizando un espirómetro Fukuda Sangyo ST-250 (Fukuda Sangyo Inc., Japón).

El nivel de autonomía se medio por el cuestionario del índice de función de la tetraplejia (QIF), que es un cuestionario con una escala ordinal de 37 ítems (rango de 0 a 100 %), que mide el rendimiento humano en términos de la capacidad para realizar las actividades de la vida diaria y puntúa cada actividad de 0 (asistencia total) a 4 (autonomía total). Esta escala se ha desarrollado específicamente para personas con tetraplejia, y es sensible a los efectos de la rehabilitación y el entrenamiento físico (Gresham et al., 1986; Anderson et al., 2008). La escala incluye evaluaciones de la alimentación, las actividades en la cama, el aseo, el baño, las transferencias, el vestido, la movilidad en silla de ruedas, el manejo de la vejiga y el intestino, y la comprensión del cuidado personal. Se utilizó una traducción al español realizada por los autores de la escala QIF original (Gresham et al., 1986; Marino et al., 1993) (véase el Apéndice).

Tratamiento de datos

Se verificó la normalidad de todas las variables mediante el test de Kolmogorov-Smirnov. Cuando las distribuciones fueron sesgadas se aplicaron estadísticas paramétricas para las comparaciones. Todos los análisis estadísticos se realizaron utilizando el paquete Statgraphics Plus (v. 5,1), con un nivel alfa establecido en 0,05.

RESULTADOS

Variables funcionales y pulmonares

Todas las variables funcionales y pulmonares mostraron diferencias significativas ($p < 0,05$) entre el nivel de lesión, con valores más altos para las participantes con menor nivel de LME cervical (QIF: 202 % pre y 200 % post, POTENCIA P: 255 % pre y 207 % post, VC: 21 % pre y 30 % post, CVF: 33 % pre y 34 % post y MVV: 9 % pre y 30 % post).

El nivel de autonomía, medido por QIF, no mostró cambios significativos de "Pre-entrenamiento" a "Post-entrenamiento", y no se detectó interacción ($p = 0,7833$) entre ambos factores.

En cuanto al factor TIEMPO, sólo el PPOWER y el MVV mostraron diferencias significativas ($p < 0,05$) entre la medición pre y post, resultando siempre en valores más altos después del programa de entrenamiento de la ECA. La mejora en PPOWER fue de 52 % para "LME superior" y 31 % para "LME inferior".

La MVV mejoró un 1% para "LME superior" y un 20% para "LME inferior". Por otra parte, se detectó una interacción significativa para el PPOWER ($p = 0,0315$) explicando el mayor aumento del mismo para la LME superior (52 %) que para una lesión más baja (el 31%) y para la MVV ($p = 0,0361$) explicando un mayor aumento de la MVV para la LME inferior (20 %) que para una lesión más alto (el 1%). VC y FVC mostraron una tendencia ligera pero ninguna significativa ($p = 0,1360$ y $p = 0,1746$, respectivamente) a aumentar después del programa ACE.

HRV Variables

La LME mostró aumentos significativos ($p = 0,0145$) después del programa ACE (81 % para LME superior y 124 % para LME inferior). HRVPOWER también mostró aumentos significativos ($p = 0,0295$) después del programa (156 % para LME superior y 78 % para LME inferior). En la misma dirección, la STDHR mostró una tendencia fuerte pero no significativa ($p = 0,0675$) a aumentos después del programa ACE (23 % para LME superior y 13 % para LME más baja). Contrariamente a las variables funcionales y pulmonares, ninguna de las variables de VFC mostró diferencias entre el nivel de lesión alto o bajo, ni en el tiempo "Pre", ni en el tiempo "Post". No se detectó interacción entre los factores TIME e INJLEVEL para ninguna variable HRV.

Relación QIF-PPOWER

QIF y PPOWER fueron correlacionados perceptiblemente antes ($r = 0,8830$ $p < 0,0001$) y después ($r = 0,8645$; $p < 0,0001$) el período de entrenamiento. El modelo de regresión lineal simple mostró que PPOWER explicaba el 74,42 % de la varianza de QIF.

DISCUSIÓN

Los resultados muestran que el entrenamiento de la ACE tiene un efecto positivo sobre el rendimiento y sobre los sistemas pulmonar y cardiovascular de las personas con tetraplejia.

Efecto del ejercicio sobre la funcionalidad

Un resultado esperado es la diferencia en el pre-entrenamiento de PPOWER, que es 255% más alto en personas con el LM cervical de nivel inferior (C6-C7) que en pacientes con el LM de nivel más alto (C4-C5). Este hallazgo concuerda con otros trabajos publicados (Morgulec, 2005), y podría explicar los diferentes niveles de funcionalidad y autonomía en todo el grupo de participantes para quienes la LM de nivel inferior implica niveles inferiores (un tercio) de autonomía como mostró QIF.

La potencia máxima aumentó durante el período de 8 semanas del programa de entrenamiento ACE para todos los participantes. La mejora media del 36 % para todo el grupo podría considerarse notable en comparación con el 13,7 % reportado por McLean y Skinner (1995), y también con la mejora del 20,2 % notificada por Valent et al. (2009) y el 23,8 % por Di Carlo (1988). Esta mejora en la potencia máxima sería el resultado de una mayor eficiencia mecánica bruta debido a una mejor coordinación de brazos y hombros en lugar de una ganancia en la fuerza muscular durante el ejercicio ACE (De Groot et al., 2003; Valent et al., 2009).

Aunque todos los participantes aumentaron su potencia máxima, los resultados de la puntuación QIF no mostraron un aumento estadísticamente significativo en la capacidad de realizar actividades cotidianas. El tiempo parece ser esencial en este proceso para que el individuo pruebe nuevas actividades como las transferencias, el vestirse, la movilidad en silla de ruedas y el cuidado personal, que requieren rangos más amplios o nuevos patrones de movimiento, y eventualmente alcanzan un mayor nivel de autonomía individual y de funcionalidad medida por la puntuación QIF. Otros autores (Dallmeijer et al., 2001; Dallmeijer, et al., 2004) sugieren que el aumento de la potencia máxima de las personas con tetraplejia bien podría estar relacionado con la mejora de sus capacidades funcionales y el aumento de la autonomía individual. De hecho, de acuerdo con las conclusiones de Anderson et al. (2008), hubo diferencias significativas en las puntuaciones de QIF entre los dos grupos con diferentes niveles de LM cervical. Como los participantes con LM más bajo tenían puntuaciones más altas de QIF que los participantes con LM más alta, se asume que la funcionalidad probablemente podría mejorarse si la salida de potencia aumentada se podría aplicar a las capacidades de la vida diaria. Sin embargo, sería necesario tratar de cambiar los hábitos de la persona, para lo cual probablemente sería necesario más de 8 semanas para realizar nuevas actividades de la vida diaria. Todas estas mejoras deberían afectar positivamente su calidad de vida en diferentes áreas (Giacobbi et al., 2008).

En referencia a lo anterior, y en base a los resultados preliminares obtenidos con los mismos participantes del estudio y publicados por Brizuela et al., (2010), un factor que podría ser fundamental en este proceso es el tiempo que el individuo tiene para aplicar tales ganancias de fuerza a las actividades de la vida diaria, y de esta manera poder probar nuevas actividades de cuidado personal , como vestirse o ducharse, y la movilidad, como moverse en sillas de ruedas, o incluso, eventualmente, lograr un mayor nivel de autonomía y funcionalidad individual según lo medido por el QIF. Por esta razón, una intervención más larga o una medición tardía posterior al entrenamiento pueden ser necesarias para observar mejoras significativas en esta variable.

Efecto del ejercicio sobre el sistema respiratorio

El hecho de que en la situación del pre-entrenamiento, el grupo con LM inferior mostró valores medidos más altos de VC, FVC y MVV en comparación con el grupo con LM más alta, puede reflejar los diversos niveles funcionales de los músculos respiratorios. Los resultados espirométricos también muestran que después del período de entrenamiento de la ACE hay un aumento significativo en la MVV, una variable que se ha demostrado que se ve afectada en los trastornos neuromusculares (Linn et al., 2001; Rochester y Esaú, 1994; Rutchik et al., 1998; Tow et al., 2001). Eso es probablemente debido al aumento general de la función de algunos músculos esqueléticos que están implicados en la respiración. Nuestros resultados están de acuerdo con Valent et al. (2009) que no detectaron aumentos en la CVF (no informaron mediciones de VC) pero contrariamente a los de Crane et al. (1994) que informaron mejoras en la CVF para personas entrenadas con tetraplejia. Esta última discrepancia podría deberse a que en el Crane et al. (1994), los participantes eran personas sin discapacidad.

De acuerdo con nuestros hallazgos parece que las personas con LM cervical nivel más baja pueden tener mayores adaptaciones pulmonares al entrenamiento ACE que personas con LM de un nivel más alto. Esta diferencia debe tenerse en cuenta al programar el entrenamiento con ejercicios y evaluar el rendimiento y también al estudiar epidemiología o procesos respiratorios en personas con LM cervical.

6. Efecto del ejercicio sobre HRV

La falta de diferencias encontradas en nuestro estudio al comparar la HRV entre el nivel "Superior" e "Inferior" de LM cervical, puede apoyar la hipótesis de que ambos grupos tienen el mismo grado de lesión a la vía simpático-arenal descendente. Sin embargo, los participantes de ambos grupos tienen vías aferentes y eferentes vagales intactas. Otros autores como Ditor et al., (2005), encontraron una reducción significativa en la relación LF/HF, como resultado de una disminución significativa de la potencia en la LF y un aumento no significativo de la potencia en la HF.

Curiosamente, los resultados preliminares publicados por Brizuela et al., (2010) muestran un aumento concomitante de la potencia espectral en LF y HF, mientras que estudios anteriores, como Ditor et al., (2005), muestran unánimemente una reducción de potencia en LF después de diferentes programas de actividad física. Sin embargo, debido a que las personas con tetraplejia se ven privadas de una inervación eferente amigable en el sistema cardiovascular, los cambios en los componentes de la LF de la VFC también pueden ser regulados por la rama parasimpática en esta población (Takahashi et al., 2007). Con base en esta teoría, se pudo afirmar que el aumento de la LF y la HF se debió en ambos casos a una mejora en la modulación vagal de la dinámica de la FC.

Todas las diferencias autonómicas podrían explicar por qué la respuesta de la frecuencia cardíaca al ejercicio agudo se altera en las personas con LM. Ni el aumento de la frecuencia cardíaca al inicio del ejercicio, ni la frecuencia cardíaca máxima durante varios modos de ejercicio es tan alta como en las personas sin LM (Di Carlo, 1988; Takahashi et al., 2004). Se necesita más investigación para describir completamente el efecto del ejercicio prolongado sobre este equilibrio, principalmente la HRF.

Los valores basales de HRF obtenidos en este estudio son similares a otros datos publicados con personas con LME cervical (La Fountaine, Wecht, Spungen &bauman, 2010; Millar et al., 2009; Takahashi et al., 2007; Wecht, Weir, & Bauman, 2006). El hallazgo principal del actual estudio es que ocho semanas del entrenamiento ACE para las personas con LM son suficientes mejorar perceptiblemente HRV total, medido en el dominio de la frecuencia (HRVPOWER y LF). Los hallazgos difieren parcialmente de los estudios informados anteriormente, tal es el caso del estudio de Millar et al. (2009); la diferencia con dicho estudio podría ser porque todos nuestros participantes tenían una LM cervical entre C4 y C6, mientras que su muestra era bastante heterogénea (LM entre C5 y T10). El programa de ejercicio de la presente investigación, junto un periodo de tratamiento más prolongado (16 vs 12 sesiones de entrenamiento, 8 vs 4 semanas), pueden explicar la razón porque no encontraron diferencia significativa en ningún índice de HRC lineal ni de dominio de frecuencia). Además, el estudio de Ditor et al. (2005) fue de una muestra pequeña y heterogénea (6 sujetos, C4-T12), y esto podría haberles impedido encontrar cambios estadísticamente significativos en sus mediciones de HRV. De hecho, cuando agruparon a los participantes de acuerdo con su respuesta de la FC a la capacidad ambulatoria, los datos sugirieron una disminución selectiva, aunque no estadísticamente significativa, inducida por el entrenamiento en la relación LF/HF para los respondedores (es decir, aquellos que mostraron una mayor respuesta de la FC a la deambulación).

Curiosamente, los resultados de nuestra muestra mostraron aumentos en la LF, mientras que los estudios anteriores han sido unánimes en informar que no hay cambios o una reducción en la potencia de la LF después del entrenamiento (Ditor et al., 2005a; Ditor et al., 2005b; Millar et al., 2009). Aunque tal aumento en la potencia de la LF sería atribuible a una mejora de la actividad simpática en personas sin LM (Task Force, 1996), teniendo en cuenta que las personas con tetraplejía se ven privadas de la inervación eferente simpática neural al sistema cardiovascular (Bunten et al., 1998; Grimm et al., 1997), podría decirse que el aumento en el componente de LF de HRV es producido principalmente por una vía parasimpática y no por vía simpática, como se sugirió anteriormente (Takahashi et al. 2007). Los aumentos de LF de los participantes del presente estudio se debían probablemente a una mejora en la modulación vagal de la dinámica de la FC.

El aumento de la VFC después del período de entrenamiento de la ACE es especialmente interesante si se toma cuenta que la HRV se ha relacionado inversa o directamente con una variedad de condiciones clínicas, como la edad, el estado inflamatorio, el potasio sérico bajo, la diabetes mellitus, la disfunción renal, la enfermedad arterial coronaria y especialmente la insuficiencia cardíaca, que se asocia más significativamente con la disminución de la VFC (Almoznino-Sarafian et al. , 2009). Si tenemos en cuenta que las personas con LME tienen disfunción autonómica y mayor riesgo de enfermedad cardiovascular (Claydon & Krassioukov, 2008; Garshick et al., 2005; Myers, Lee & Kiratli, 2007) los resultados presentados en este estudio serían especialmente relevantes para conservar la función cardiovascular en personas con LM, en aquellas con LM cervical superior, e incluso sin ninguna mejora en la funcionalidad diaria.

Conclusiones

En el presente estudio se demostró que el ejercicio de pedaleo de brazos tiene un efecto positivo en la respuesta fisiológica de las personas con tetraplejia.

Los cambios en el PPOWER indican que la potencia máxima del brazo aumentó un 36% durante el período de 8 semanas del programa de entrenamiento ACE para todos los participantes.

Los cambios significativos fueron encontrados en parámetros respiratorios después de practicar un programa del ejercicio de la brazo-manivela. Todos los parámetros respiratorios de los participantes mejoraron después de la intervención de 8 semanas. El grupo SCI mostró mayores valores medidos de VC, CVF y MVV que el grupo LM superior, en la situación de pre-entrenamiento. Esto puede reflejar los diferentes niveles funcionales de los músculos respiratorios.

Los valores de la HRV en personas con tetraplejia fueron diferentes después de programa del AS. El LF mostró aumentos significativamente después del programa ACE (81% para el SCI más alto y el 124% para el SCI más bajo). Ni la frecuencia cardíaca aumenta al inicio del ejercicio, ni la frecuencia cardíaca máxima durante varios modos de ejercicio es tan alta como en las personas sin LME.

Las personas con LM de alto nivel conservan la capacidad de realizar adaptaciones positivas en la función cardíaca autónoma y la función respiratoria en respuesta a un período de entrenamiento de ACE, a pesar de que no hay una mejora inmediata en su funcionalidad diaria. Los niveles de funcionalidad y autonomía en los participantes con LM más baja son menores (un tercio) que los encontrados en los participantes con LME más alta.

LIST OF ABBREVIATIONS AND ACRONYMS

ACE: Armcrank Exercise.

ACSM: American College of Sports Medicine.

AD: autonomic dysreflexia

ASIA: American Spinal Cord Injury Association.

ASPAYM: Association of persons with spinal cord injury or other physical disability.

ATLS: Advanced Trauma Life Support.

CT: Computed tomography.

CNS: Central Nervous System.

CO: cardiac output.

FEV-1: forced expiratory volume**.**

FFT: Fast fourier transform.

FVC: Forced vital capacity.

HCF: forced life capacity.

HF: high frequency.

HR: heart rate.

HRV: Heart rate variability.

HRVPower: total power.

IMSOP: International Medical Society for Paraplegia.

LF: low frequency.

LH/HF: Ratio between LF and HF powers.

LM: Lesión medular.

LSD-MRT: least significant difference multiple range test.

MRI: Magnetic resonance imaging.

MVV: Maximum voluntary ventilation.

PFC: Prefrontal cortex

PNS: Peripheral nervous system.

QIF: Quadriplegia Index of Function.

RMSSD: root of the mean squared differences between successive RR intervals.

SCI: Spinal Cord Injury.

STD HR: Standard deviation of instantaneous heart rate values.

VC: Vital capacity.

VS: systolic volume.

W: POWER.

WHO: World Health Organization.

LIST OF TABLES

LIST OF FIGURES

1.INTRODUCTION

1.1. Origin of the work

Studying at the University of Sports Science at Cologne was my purpose; I really loved it. I re-connected with my youth as cyclist and started racing again by the age of thirty. For my Erasmus, I choose a winter semester in Valencia because at that time the CEAR track cycling training took place at the velodrome of Valencia. I had a great time and interesting classes at University, managed to train with the CEAR training group, learned a lot of Spanish and came back with strong legs and an invitation to participate in a study on field-testing protocols for Cyclists at the University of Valencia the following winter. Equipped with a DAAD grant, I followed this call, went to Valencia again, participated in the field testing study and used the date to write my master thesis and to finish my studies in Cologne in 2004. As I had made the connection to Professor Gabriel Brizuela, who was very active in several straightforward and well thought-through investigation projects, I felt motivated to start my doctorate studies in Valencia with Professor Brizuela being my mentor for this thesis project, which we started in 2009 and which consisted in the development of an exercise methodology to improve the functional characteristics of people with disability. I collaborated in the development of the project "Tetraplegia and Exercise" of the Physical Education and Sports Department and participated in the development of the Collaboration Agreement between the Universidad de Valencia, Estudi General, and TetraSport Association. To earn a living, I monitored courses of Indoor Cycling, Pilates and Nordic Walking with freelance accounting for the department of Sports Service the University of Valencia, which organizes and coordinates the physical and sports activities carried out at the University of Valencia. Its task is primarily aimed at members of the university community although, in many of its activities, all citizens can participate by paying the established fees. With my coordinator, I introduced the activity of Nordic Walking at UV.

However, with this way of life I encountered difficulties to manage finances and time restrictions and in 2014 decided to stop all other activities and focus on advancing the thesis, to do the literature analysis and present research results at international events and establish contacts that could help us with the publication of our article. It is therefore that I finally conclude to write this thesis memory ten years after we started the initial study.

1.2. Spinal Cord Injury

The Nervous System consists of nervous tissue, its main function being communication between the different regions of the body, which depends on the physical, chemical and morphological properties of neurons. Anatomically the nervous system is subdivided into the Central Nervous System (CNS) and the Peripheral Nervous System (SNP). The CNS consists of a portion contained in the Skull, the Brain, and another lodged in the vertebral canal, the Spinal Cord. In turn, the Brain includes the Brain, Brain Stem and Cerebellum. On the other hand, the PNS is composed of the nerves (and their associated ganglia) that put the CNS in communication with the external environment: cranial nerves (if they originate from the Brain), spinal (or spinal) nerves, which originate from the spinal cord) and its associated nodes; a ganglion corresponds to a cluster of neurons outside the CNS (Snell, 2010).

The spinal cord is the part of the CNS that lodges in the vertebral canal from the foramen magnum to the upper edge of the body of the second lumbar vertebra (L2). It has a cylindrical shape and its external appearance is whitish because it is superficially composed of myelinated nerve fibers. Its length varies in different individuals, but in general, an average of 45 cm is observed. Its width is changing according to the amount of fibers carried by its tracts (Snell, 2010). At the cervical level, precisely where the roots that make up the brachial plexus originate, the spinal cord is noticeably flattened anteroposterior, forming a fusiform thickening, the largest in the spinal cord: cervical thickening (C3-T2). Likewise, at the lower thoracic and lumbar level, where the lumbosacral plexus originates, the spinal cord presents lumbar thickening (L1-S3). The lower end of the spinal cord ends in a cone shape - the medullary cone. A thin band of fibrous tissue, the *filum terminale*, advances in the middle of the cauda equina until it joins the periosteum on the back of the coccyx. The *filum terminale* is an extension of the pia mater that indicates the regression path of the spinal cord and has the function of fixing the lower end of the spinal cord (Gregory, 2008).

The spinal cord, like the brain, is enveloped by the meninges: dura, arachnoid, and piamater. In a cross section, it is observed that the spinal cord consists of an H-shaped central region called gray matter, and a whitish-looking peripheral region called white matter (Snell, 2010). The relatively thin posterior extensions that almost reach the posterior lateral sulcus are called the posterior horns; Wide, rounded anterior extensions are called anterior horns. The three-dimensional arrangement of the anterior and posterior horns forms true columns that run through the spinal cord to constitute the gray anterior and posterior columns. The posterior horns, functionally somatosensory, are made up of sensory neurons that receive impulses that come from the posterior roots. The anterior horns, functionally somatomotor, are made up of motor neurons whose axons exit through the anterior roots (Porth, 2006).

Spinal cord injury (SCI) can be defined as damage to the spinal cord, of any aetiology, which can cause paralysis at different points and degrees of extension, loss of sensation and bladder, intestinal and sexual dysfunction, in addition to significant psychological and socioeconomic consequences (Gifre, del Valle Gómez, Yuguero, Gil & Bosch, 2010). SCI lead to the alteration or destruction of neurons in the spinal cord itself (Hagen, Rekand, Gilhus, & Grønning, 2012). They are often devastating in nature as they are associated with life-threatening complications and a loss of functional independence. SCIs can be permanent or temporary, depending on the type of injury (Hickey, 2009).

The World Health Organization (WHO) estimates that by 2020 the SCI will occupy one of the five main causes of disability worldwide. Hospitalization costs during the first year due to SCI are estimated to average between € 60,000 and € 100,000 with approximate direct costs / year of € 12,000-20,000 (Strassburguer, Hernández & Barquín, 2004). Approximately 53% of SCI cases occur in adolescents or young adults between 16 and 30 years of age; Most of these injuries are due to motor vehicle accidents, falls, attacks with physical violence (such as gunshot wounds) and sports injuries (Nayduch, 2011).

The incidence of SCI is variable between countries and between regions. Wyndaele and Wyndaele (2006), in a systematic review of scientific publications between 1977 and 2006 on the incidence, prevalence and epidemiology of SCI worldwide, conclude that the global incidence ranges between 10.4 and 83 per million inhabitants per year, and the prevalence between 223 to 755 per million inhabitants. Mazaira et al., (1998) estimate that in developed countries the incidence of SCI varies in a range between 9 and 53 per million inhabitants. Every year 12,000 new cases occur in North America (DeVivo, Go & Jackson, 2002), current estimates suggest that the annual incidence of spinal cord injuries in the United States is around 40 cases per million (Krause & Broderick, 2004). The incidence of SCI in Europe has increased. In Spain, the estimate is by 12-20 new cases per million inhabitants each year (Strassburguer et al., 2004).

The SCI can be classified according to the type of injury in (Nayduch, 2011 Witiw & Fehlings, 2015):

- Concussion: is a picture of intense shaking or shaking of the spinal cord that can lead to temporary functional loss over a period ranging from several hours to several weeks.
- Compression: occurs at the time of injury and comes accompanied by distortion of the normal curvature of the spine.
- Contusion: is a blow to the spinal cord that can cause bleeding and edema inside. Necrosis may be due to compression secondary to edema or to direct tissue injury. Fractures, dislocations, and direct trauma to the spinal cord can lead to a contusion.
- Laceration: is a tear of the spinal cord that is accompanied by a permanent injury; contusion, edema, and spinal compression accompany laceration.
- Transection: consists of a complete or incomplete section of the spinal cord. Upper cervical spinal transections (above the C4 level) lead to loss of respiratory control and death in cases where adequate diagnosis and treatment are not rapidly established.

- Hemorrhage: can take place after trauma inside or around the spinal cord, and it became an irritating element of the tissue that, in addition, compresses the spinal cord itself and the nerve roots.
- Injury to the blood vessels supplying the spinal cord, such as the anterior spinal artery or the two posterior spinal arteries, causes ischemia and possibly necrosis. Prolonged ischemia and necrosis can be the cause of permanent deficits.

1.2.1 Tetraplegia and Paraplegia

Injuries can appear anywhere in the spinal cord, so the location and severity of the injury will determine which functions of the organism will be altered or lost (Indakoetxea, 2003). Paraplegia is called the involvement of the lower limbs in lesions below the last cervical vertebra (National Institute of Neurological Disorders and Stroke, 2005; Henao-Lema & Pérez-Parra, 2010). Tetraplegia is a cervical spinal injury produced by SCI that causes a loss of motor or sensory function of the lower and upper limbs, as well as respiratory alterations to different degrees depending on the injury (Acevedo González, Fernando Varón, Berbeo Calderón, Feo Lee & Diaz Orduz, 2008).

1.2.2 Complete or Incomplete Injury

The SCI can be complete or incomplete. Complete SCI results in the disappearance of voluntary sensory and motor functions below the level of the injury, including the lower sacral segments (S4 and S5). In cases of complete SCI, the alterations that occur below the level of the lesion are as follows (Hagen et al., 2012):

• Paralysis of all voluntary muscles.

• Disappearance of all medullary reflexes.

• Loss of painful perception, sensitivity to light rubbing, proprioception and corresponding sensitivities to temperature and pressure.

• Absence of somatic and visceral sensations.

• Loss of sweating capacity (function of the autonomic nervous system).

• Bowel and bladder dysfunctions.

The patient may experience pain in the area of the injury because there is an area of increased sensitivity called hyperesthesia, immediately above the level of the injury (Stampas & Tansey, 2014). There is generally no chance of recovery in cases where an SCI is accompanied by complete loss of neurological function and when the patient does not experience any type of recovery during the first 24 hours after trauma (Strassburguer et al, 2004).

Spinal shock is the response of the spinal cord to injury. Spinal shock is characterized by a complete, albeit temporary, loss of sensory, motor, reflex, and autonomic nervous system functions below the level of the injury (Ziu & Mesfin, 2020). Examples are the following: acid paralysis, disappearance of skin reflexes and deep tendon reflexes, loss of bladder tone and disappearance of peristalsis, sweating and erection of hair, and vasomotor tone (Strassburguer et al, 2004). The recovery of function is announced by the reappearance of the bladder tone, by hyperreflexia and by the sacral reflexes. Acid paralysis evolves into a picture of spasticity and hypertonia. In cases, where after resolution of spinal shock the patient does not show a recovery of motor and sensory functions, SCI is considered complete (Ziu & Mesfin, 2020).

Neurogenic shock is seen in spinal cord injuries that occur above the T6 level. The signs are evident below the level of the injury due to the interruption of the sympathetic nervous system, which causes the parasympathetic nervous system to act without any kind of opposition. Autonomic nervous system dysfunction is characterized by systemic hypotension (vasodilation with decreased venous return), hot, dry skin, and bradycardia. The patient's body temperature is lower than normal due to the loss of the connection between the hypothalamus and the sympathetic nervous system. Body temperature responds to room temperature (poikilothermia) (Dave & Cho, 2020).

Incomplete SCI is that SCI in which the patient presents a certain residual motor or sensory function below the level of the injury (Alizadeh, Dyck, & Karimi-Abdolrezaee, 2019). In incomplete SCI, there are possibilities for improvement or resolution (Strassburguer et al, 2004).

Table 1 shows a list of incomplete SCI syndromes together with their clinical manifestations (Hayes, Hsieh, Wolfe, Potter, Delaney, 2000).

Table 1. Main characteristics of incomplete SCI syndromes.

Syndrome	**Clinical manifestations**	**Causes**
Central Cord	• More intense motor deficit in the upper extremities than in the lower ones. • Variable loss of sensation (more pronounced in the upper extremities). • Variable bowel and bladder dysfunction.	• The underlying cause is trauma or a picture of edema in the central part of the spinal cord, usually in the cervical segment due to hyperextension injuries.
Anterior cord	• Loss of perception of pain and temperature, and disappearance of motor function below the level of the injury. • Sensitivities for light touch, position, and vibration remain intact.	• Hyperextension injuries associated with fracture-dislocation of a vertebra. • Injury to the anterior spinal artery.
Brown-Séquard syndrome **(lateral cord)**	• Ipsilateral paralysis or paresis together with ipsilateral loss of sensitivities corresponding to touch, pressure and vibration. • Contralateral loss of pain and thermal sensitivity.	• Transverse hemi section of the spinal cord (transection of the cord). • It is generally due to a stab or firearm injury, with fracture-dislocation of the unilateral joint process.
Medullary cone	• Dysfunction of the lower extremities, generally with weakness or flaccid paralysis in said extremities. • Early loss of bladder and anal sphincter function. • Male sexual dysfunction. • Loss of the Achilles reflex. • Variable loss of sensation, possible "saddle" anesthesia. • Pain is infrequent.	• Falls. • Vertebral trauma, such as subluxation or dislocation with involvement of the L1, S4-5 nerve roots.
Horse tail .	• Weakness or flaccidity in the lower extremities with at least a partial preservation of sensitivity. • The pain is often intense, asymmetrical, and radicular. • Absence of the patellar reflex and	• Large disc herniation. • Epidural hematoma. • Trauma

	Achilles. • Loss of bladder and bowel control; "saddle" anesthesia, urinary retention is common.	

1.2.3 The influence of the Level of Injury

The clinical picture depends on the degree and level of the injury. A complete injury implies the total absence of mobility and sensitivity in sacral segments. However, it may have some degree of partial sensory and / or motor preservation two or three dermatomes below the level of the lesion. On the contrary, in an incomplete lesion there is a variable degree of function in the sacral segments (Matthew & Matthew, 2017). In order to facilitate the understanding of the different clinical pictures after SCI, here are some examples: damage to the anterior region of the spinal cord causes paralysis and loss of the ability to distinguish pain and changes in temperature; Injury at the central level affects the arms more than the legs; Damage to the right or left spinal cord causes paralysis on the same side of the lesion with loss of sensitivity to pain and temperature on the contralateral side and loss of proprioception (Strassburguer et al., 2004).

1.3 Diagnostic tests for first time evaluation

SCI can be due to multiple causes; reason why the main diagnostic difficulty appears in the identification of its origin (especially in the case of non-traumatic ones) (van Middendorp, Goss, Urquhart, Atresh, Williams & Schuetz, 2011). This is important since, depending on the cause, treatment and prognosis may vary. For example, an SCI due to compression by an intramedullary abscess (infectious process) does not have the same treatment or prognosis as a metastatic SCI (neoplastic process), although both present as SCI incomplete level D8 as a consequence of primary diagnosis (Strassburguer et al., 2004). It is also important to make the differential diagnosis with the various degenerative pathologies of the nervous system that, primarily or secondarily, could present with an SCI; such as multiple sclerosis, motor neuron diseases (amyotrophic lateral sclerosis, progressive bulbar paralysis, and progressive muscular atrophy, among others), peripheral polyneuropathies (Guillain Barré syndrome, hereditary neuropathies, post-polio syndrome, and critical state polyneuropathy). In all these cases, it is important to identify if the pathology affects the spinal cord or not and, in the first case, to identify the moment in which it does (Weidner, Rüdiger & Tansey, 2017).

The international standards for the neurological and functional classification of SCI consist of a widely accepted classification system that describes both the level and degree of injury based on a neurological examination of systematic motor and sensory function. This classification is known as the American Spinal Cord Injury Association (ASIA) Disability Measurement Scale, or the ASIA Scale. It was initially approved by the International Medical Society for Paraplegia (IMSOP) in 1992 (American Spinal Injury Association / International Medical Society of Paraplegia, 1992). It was subsequently revised in 1996, in 2000, and the last one in 2006. The examination for the neurological and functional classification of SCI has two components (sensory and motor), each of which is evaluated separately. always supine. When the patient cannot be fully assessed for any reason (for example, due to a fracture) the sensitive point or key muscle that cannot be assessed should be recorded as NT (Non-Testable). It is important to mention that this scale allows the registration of necessary and optional elements. To complete the registration format of the ASIA Scale, it is necessary to evaluate motor function in 10 myotomes from C5 to T1 and from L2 to S1 and of sensory function in the 28 dermatomes from C2 to S5. This examination is carried out systematically always on both sides of the body (van Middendorp et al., 2011).

1.3.1 Neurological evaluation

The examination for the neurological and functional classification of SCI has two components (sensory and motor), each of which is evaluated separately, always in the supine position (Holtz & Levi, 2010). When the patient cannot be fully assessed for any reason (for example, due to a fracture) the sensitive point or key muscle that cannot be assessed should be recorded as NT (Non-Testable). It is important to mention that this scale allows the registration of necessary and optional elements. To complete the registration format of the ASIA Scale, it is necessary to evaluate the motor function in 10 myotomes from C5 to T1 and from L2 to S1 and the sensory function in the 28 dermatomes from C2 to S5 (van Middendorp et al., 2011). This examination is carried out systematically always on both sides of the body. With respect to the necessary records of sensory function, two aspects of sensitivity are explored: prick sensitivity and light sensitivity (Strassburguer et al., 2004). The appreciation of the prick, or light touch, at each of the key points is rated separately on a three-point scale (American Spinal Injury Association / International Medical Society of Paraplegia, 1992):

- 0: Absent.
- 1: Damaged (partial or altered appreciation, including hyperesthesia).
- 2: Normal.
- NT: No Testable.

For the evaluation of motor function, the necessary registration requires the exploration of the strength of the right and left key muscles that correspond to each of the ten myotomes mentioned. Each key muscle must be evaluated in a craniocaudal sequence. Muscle strength is graded on a six-point scale (American Spinal Injury Association / International Medical Society of Paraplegia, 1992):

- 0: Total paralysis.
- 1: Visible or palpable contraction.
- 2: Active movement, completing the arc of mobility eliminating the force of gravity.
- 3: Active movement, completing the arc of mobility against the force of gravity.
- 4: Active movement, completing the arc of mobility against moderate resistance.
- 5: Active movement, completing the arc of mobility against total resistance.
- NT: No Testable.

A muscle with a score of 3 is considered “normal” if it is immediately above 4-5 (American Spinal Injury Association / International Medical Society of Paraplegia, 1992). In addition to evaluating motor and sensory function, it is essential to perform a rectal examination to check motor function or sensation at the mucocutaneous junction of the anal region. The presence of any of these can mean a preservation of the sacred "function"; whereby, the injury would be light incomplete (Strassburguer et al., 2004).

As mentioned at the beginning of the section, the sensory level and the motor level correspond to the most caudal segment of the spinal cord with normal sensory or motor function on both sides of the body. For those segments in which the motor function cannot be evaluated (C4, T2-L1 and S2-S5), it is assumed that the motor level is the same as the corresponding sensitive level considered as light normal (Strassburguer et al., 2004).

Table 2 describes the Degree of Involvement of SCI according to the ASIA Scale (American Spinal Injury Association / International Medical Society of Paraplegia, 1992).

Table 2. Degree of involvement of SCI according to the ASIA Scale.

A	Complete: There is no preservation of sensory or motor function in the sacral segments S4-S5.
B	Incomplete: preservation of sensory function below the neurological level that extends to the S4-S5 sacral segments with absence of motor function.
C	Incomplete: preservation of motor function below the neurological level and more than half of the key muscles below the neurological level have a degree less than 3 (degree 0-2).
D	Incomplete: preservation of motor function below the neurological level and at least half of the key muscles below the neurological level have a degree equal to or greater than 3.
And	Normal: normal sensory and motor function.

1.3.3 Image diagnostics

The use of diagnostic imaging methods will depend on the most relevant diagnosis established clinically with the intention of giving priority to the treatment of the most severe lesions. The different diagnostic methods currently available represent valuable paraclinical support with information based on the confirmation or exclusion of the clinically defined diagnostic possibility (s). Sometimes the choice of a method depends on its immediate or immediate availability. The experience gained by the medical personnel in charge of patients with SCI usually requires: a) plain radiographs, b) Computed tomography (CT), c) Magnetic resonance imaging (MRI), d) In cases of traumatic arterial dissection: CT angiography, resonance angiography or digital subtraction angiography (Boleaga, 2007).

Plain radiography is the most commonly available diagnostic method. Their informative contribution is useful for the initial definition of the diagnosis by evidence or exclusion and for the subsequent decision-making and can be supplemented with CT and MRI. However, fractures, dislocations, subluxations or indirect signs of ligament injury are evaluated adequately with this inexpensive and simple method (Boese & Lechler, 2013).

As for CT, its speed of performance offers advantages in non-cooperative patients. CT is a method of optimal specificity and diagnostic sensitivity in acute trauma. It offers the possibility of obtaining reshaped images that provide additional information. Another of its advantages is that it has no limitation for the use of life support elements during the study (assisted ventilation, defibrillator, etc.). Less cost than an MRI. Especially with hematomyelia in the acute phase of trauma, the current CT arrangement with multiple detector techniques offers the advantage to obtain images with multiplanar, sagittal, coronal and oblique reconstruction, as well as three-dimensional reconstruction, to achieve an optimal evaluation of the conditions of the spine, the spinal canal, the intervertebral and spinal cord discs. (Liu et al., 2000).

Among the limited indications for using MRI in acute trauma is a possible contusion or section of the spinal cord and epidural hematoma. Acute quadriparesis or quadriplegia requires early demonstration of a possible compressive effect and edema of the spinal cord. The diagnostic definition of acute spinal cord compression must be resolved with an urgent surgical procedure in order to eliminate or reduce compressive and hypoxic-ischemic sequelae. In the chronic phase, MRI shows myelomalacia, adhesions, syringomyelia, or medullary atrophy. MRI can identify unexplained neurological lesions on CT and radiographs (Shepard & Bracken, 1999). It is an useful method for an optimal evaluation by imaging a) spinal canal, b) spinal cord injury, c) intervertebral discs, d) search for spinal hematomas, e) ligaments, f) other findings such as medullary cysts, myelomalacia, medulla anchored and spinal compression (Liu et al., 2017).

1.4 Treatment

The management of the SCI begins in the same place where it happens and must strictly comply with the Advanced Trauma Life Support protocols (ATLS) (Galvagno et al., 2019). There are three fundamental objectives in the trauma scene: to prevent additional injuries, to maintain adequate oxygenation and perfusion, through resuscitation maneuvers. It is also crucial to make a timely and adequate transfer to a referral center that provides a multidisciplinary team of professionals and the necessary technology to respond to the therapeutic requirements of this type of patient (Schmidt et al., 2009).

Maintaining adequate oxygenation is essential, since it significantly attenuates additional damage due to ischemia resulting from the initial injury. On the other hand, patients with cervical lesions have immediate compromise in respiratory volumes due to the variable compromise of the thoracic musculature. Closely related to the severity of MRT and systemic involvement are respiratory complications. Respiratory failure and associated infectious processes can be prevented by proper airway management and bronchopulmonary hygiene therapy (Nockels, 2001).

It is vitally important to maintain adequate perfusion in order to optimize the control of the mechanisms of secondary spinal cord injury. Because patients who suffer SCI are generally framed within polytrauma, these patients have two potential causes of hemodynamic compromise: hypovolemia and neurogenic shock, both of which consist in loss of vasomotor tone due to generalized hypotension because of the trauma (Nockels, 2001).

Subsequently, the pharmacological intervention is carried out. Steroids are one of the main drugs used in the management of these patients. The precise mechanisms of the neuroprotective effect of steroids aren´t fully understood. However, it is suggested that they inhibit lipid peroxidation and inflammatory cytokines, modulate the immune-inflammatory cellular response, improve vascular perfusion, and prevent calcium entry and accumulation into cells. Methyl-prednisolone (MP) appears to be the most effective compared to other glucocorticoids (Liu et al., 2019).

Gangliosides are glycolipids highly expressed in the cell membranes of the CNS. A neuroprotective effect has been described in its use in experimental animal models based on the theory that it increases neuronal growth and plasticity, inhibits excito-toxicity and prevents apoptosis. However, there is no evidence to support the routine use of gangliosides in SCI or to rule out a harmful effect in patients in whom they could be used (Xu et al., 2015). Naloxone, a nonspecific opiate receptor antagonist, was investigated intensively in the 1980s after studies in animals that demonstrated its effect in decreasing the severity of neurogenic shock and improving blood flow in the spinal cord without being able to reproduce it. There is a recent report of the appearance of severe spasticity associated with the use of naloxone infusion in patients with SCI (Brackett et al., 2007). From the theoretical point of view, calcium channel blockers have a potential effect in the treatment of SCI. In fact, experimental studies observe an increase in spinal blood flow. However, since there is a potential risk of hypotension with the detriment that it can produce in the general conditions of the patient, its use is not recommended (Pointillart et al., 2000).

Currently, research programs and lines continue to be developed that seek a better understanding of the pathophysiology of SCI and potential interventions not yet widely described (Witiw & Fehlings, 2015). As the field continues to evolve, drug treatments, in combination with cell therapies and other technology-driven interventions play an important role in the evolving management of SCIs (Hachem et al., 2017).

Stem cell therapies have shown significant potential for regeneration after SCI. Various differentiating and multipotent cell types (e.g. neural precursor cells, Schwann cells, neurons, etc.) have been examined in preclinical and clinical trials and are believed to act through multiple mechanisms, including cell replacement, the release of neurotrophic factors and immunomodulation (Levi et al., 2019). Another novel method in the management of patients with SCI is the use of biodegradable polymer scaffolds and hydrogels. These are believed to provide structural support, guide cell migration and neurite growth, and facilitate the delivery of therapeutic agents in the context of SCI (Zweckberger et al., 2016).

The prevention of medical complications is of great importance, which represent about 30% of hospitalizations in these patients. Subsequent monitoring is done by physiatry and spinal specialists, with programs designed to combat functional loss (Brenes, 2016). Conventional physical rehabilitation to strengthen muscles, improve range of motion, and induce cardiorespiratory load is increasing with technologies (Behrman et al., 2017). New measures, such as electro stimulation, adaptive equipment, etc., are tested, trying to perform maximum possible function, limit progression and decrease paralysis, to reintegrate patients into their daily lives. For example, electro stimulation stimulates the muscle distally and it is useful in intact lower motor neurons to strengthen the muscle, improve heart condition, facilitate erection and control pain. They also serve to improve bowel and bladder function and reduce complications (Boland et al., 2011).

Physiotherapeutic treatment of SCI has the general to achieve the highest degree of independence and well-being of the patient, normalize muscle tone, maintain and improve movement and joint range of affected limbs, correct osteomyoarticular deformities and prevent health complications, develop muscle strength in upper limbs and improve balance in sitting and standing (Quel de Oliveira et al., 2017).

1.5 Consequences

1.5.1 Autonomic dysfunction

SCI disrupts the crucial "crosstalk" between the spinal autonomic nervous system and the supraspinal control centers. Thus, SCI can cause not only motor paralysis, but also potentially fatal deficiencies in many autonomic functions including, but not limited to, blood pressure regulation. Despite the detrimental consequences of autonomic dysregulation, the management and recovery of autonomic functions after SCI have been little explored (Krassioukov et al., 2020).

Autonomic dysfunction or autonomic dysreflexia (AD) is a life-threatening emergency that occurs in persons with SCI at the T6 level and higher, but has been reported in patients with SCI as low as T8-T12.3-5. AD is a medical emergency defined as a sudden and significant increase in systolic and diastolic blood pressure that can present with bradycardia or tachycardia (Koyuncu & Ersoz, 2017). It is caused by any noxious or non-noxious stimulus below the level of injury. Up to 80% of AD episodes are caused by a full bladder or by intestinal distention or irritation; however, many other conditions can precipitate the episodes, including a pressure injury or other skin problem, tight clothing or footwear, ingrown toenails, kidney stones or urinary tract infection, hemorrhoids, a hidden bone fracture, or a painful medical procedure. (Morita et al., 2010).

The cardinal finding of AD is an elevation of systolic blood pressure of at least 20 mm above the usual Hg, which can be accompanied by severe headache, profuse sweating above the level of injury, blurred vision, piloerection and / or anxiety (Krassioukov et al., 2012). Less severe AD episodes may present with sweating only and piloerection or even be asymptomatic. It is vitally important that any physician caring for persons with SCI can identify, evaluate, and treat AD as unrecognized and poorly treated episodes have serious consequences, such as intracranial hemorrhage, retinal detachments, seizures, cardiac arrhythmias and death (Wan & Krassioukov, 2014).

1.5.2 Urinary dysfunction

Isolated lesions of the neurological pathways that innervate the bladder can affect one or more aspects of its physiology, be it its filling, storage or emptying phase, depending on the affected nerve area and the nature of the bladder injury. When the SCI occurs above the C3 level, most die immediately or prior to medical attention, when medical attention is achieved, the patient presents, from the voiding point of view, involuntary bladder contractions with coordinated function of the sphincter (Panicker et al., 2015). The sensitivity and function of the striated sphincter may be preserved but delayed; these lesions may present initially or late without subsequent improvement in detrusor areflexia, or the opposite effect with subsequent incontinence due to hyperactivity of the same. If the SCI occurs between levels from T6 to S2 and is complete, initially they show involuntary bladder contractions and lack of sensitivity, with synergy of the smooth sphincter, but dyssynergia of the striated sphincter, urinary retention may occur due to hyperactivity of the external sphincter or incontinence due to overactivity of the bladder musculature. In lesions below the S2 level, bladder areflexia is the behavior to observe, with a progressive loss of bladder capacity, while the striated sphincter remains with a continuous residual tone (Moslavac et al., 2014).

The patient with voiding pathology secondary to spinal cord injuries should be comprehensively evaluated with the preparation of an adequate clinical history and a correct physical examination. The medical history should always include data about the mechanism of spinal cord injury, date, treatments, surgeries, medication, lifestyle, quality of life and survival expectations. From the urological perspective, voiding habits, detecting whether it is a retentions or incontinence pathology, if there is sensitivity, information on bladder emptying (catheterization) (Solano & San Roman 2013).

1.5.3 Intestinal dysfunction

Recent research suggests that the management of intestinal problems is a major source of concern for patients with SCI and can significantly alter quality of life. The most common gastrointestinal symptoms found were constipation and fecal incontinence, reported by 46% and 41%, respectively. Abdominal bloating was reported in 22% and gastrointestinal pain (abdominal, rectal or anal pain) was reported by 33% of patients (Leitón et al., 2015).

1.5.4 Sexual function

The sexual nature of a person is in his mind, and it is not altered by a spinal cord injury. Individuals with SCI continue to express sexual desire and remain sexually active. However, both men and women with spinal cord injuries report a decrease in sexual desire, as well as the frequency and satisfaction of sexual activity. For persons with spinal cord injuries, resuming sexual life is one of their priorities, being even as important as optimizing the function of the upper limbs and anal and bladder continence, all with the aim of improving their quality of life (Castillo & Tapia, 2012).

The alteration of sexual function is due to the disruption of the sexual response mediated by the brain and spinal cord. In the male, it can be altered, manifesting itself with erection, ejaculation and orgasmic perception problems that cause a change in the patient's sexual behavior. In women, it is less studied but follows a physiological sequence similar to that of men. The main problem is genital orgasmic awareness (Latella et al., 2019). Women often report decreased sexual arousal and orgasmic problems, with lack of vaginal lubrication being the main sexual dysfunction in women (Alexander et al., 2011). Psychological and emotional factors play an important role in the sexual response cycle of women. One of the main complaints of women is the dissatisfaction of the partner. The majority of persons with SCI are of reproductive age and in their time of greatest sexual activity. Adolescents face the belief that they are not sexually active, but have the same interests as other adolescents even though their social and sexual opportunities are limited by their motor impairments. Having altered sexual function does not mean that it is abolished (Deforge et al., 2004).

1.5.5 Adaptation of the nervous system

Spasticity develops gradually over several months after an SCI. Immediately after SCI there is a "spinal shock" phase, in which functions from the level of spinal injury down are suppressed. It is characterized by muscle paralysis, sagging and loss of osteotendinous reflexes. According to some theories, alpha motor neurons are hypo excitable due to the loss of supraspinal excitatory stimuli, causing hyperpolarization of motor neurons (Hiersemenzel et al, 2000).

Weeks later this stage is modified giving way to Upper Motor Neuron Syndrome. As the name suggests, Upper Motor Neuron Syndrome is due to an injury to the upper motor neurons. These include inhibitory (lateral reticulospinal tract) and excitatory (medial and vestibuloespinal reticulospinal tract), which descend into the spinal cord to control reflex spinal activity. There is a balance of the system between excitatory and spinal inhibitory pathways in different areas of it, so that an injury can affect some tracts and others may not, thus causing a variety of clinical patterns in this type of patients (Hiersemenzel et al, 2000).

The clinical characteristics of Upper Motor Neuron Syndrome are divided into two large groups: negative phenomena and positive phenomena. Negative phenomena are characterized by causing the reduction of motor activity, such as weakness, loss of skill and fatigue. However, these phenomena can be improved with adequate rehabilitative intervention. Positive phenomena are often disabling and more difficult to intervene. Functionally, there is an increase in muscle activity, positive Babinski sign, clonus, spasticity, flexor and extender spasms and hyperexcitability of tendon reflexes (Sheean, 2002).

Hyperexcitability of spinal reflexes forms the basis of most positive signs of Upper Motor Neuron Syndrome. These exalted reflexes can be divided into two groups: proprioceptive reflexes that include stretch reflexes (tonic and phase) and cutaneous/nociceptive. encompassing the extender and flexor reflexes and the knife phenomenon. The last three positive characteristics are manifestations of Upper Motor Neuron Syndrome that are pressed when the supraspinal pathways are affected as in brain damage.

Spasticity is one of the most important signs of Upper Motor Neuron syndrome. It is defined as a form of hypertonia due to increased speed-dependent stretch tonic reflexes.

Although there is not yet a well-defined model of human spasticity, all studies seem to point out that the pathophysiology of human spasticity is multifactorial. There may be primary mechanisms directly caused by motor system injury, and compensatory secondary mechanisms. Thus, any change in neural and biomechanical systems is important in determining which of the neural control mechanisms is poor contributing to movement disorder. The mechanisms of spasticity in brain damage and spinal injury are thought to be different. The greatest contribution to spasticity in spinal injury lies in neural mechanisms; in contrast, in brain damage, alteration in the con retractable properties of muscle plays a leading role in the development of spasticity (Elbasiouny et al, 2009).

Spasticity is a relevant example of plastic changes occurring at the spinal level after central injuries, and knowledge of its pathological mechanisms can provide important keys to its effective treatment. The main alterations underlying spasticity are increased muscle contractile tone and hyperactivity of spinal myostatic reflexes, either due to the release of downward control or as an adaptation of reflexes to the lack of supraspinal control (Nielsen et al, 2005). Reflected hyperexcitability develops over months after primary central injury and involves mechanisms of adaptation in the spinal neural circuits flowing to the lesion. What is unclear is the functional meaning of spasticity or its role in voluntary movements.

As for supraspinal alterations, higher motor neurons send fibers, both excitatory and inhibitory, that descend through the spinal cord to control the activity of spinal motor neurons, pre-neuron neurons and spinal reflexes. Supraspinal pathways include the cortico-spinal (or pyramidal) pathways and the corneal-trunk-spinal pathways. Animal studies have shown that pure lesions of the polyhedral pathway produce mild motor deficits (pure pyramid syndrome), but do not trigger spasticity or muscle hyperactivity. Upper moto neuron syndrome, with its negative and positive phenomena, is largely due to the dysfunction of the cornice-trunk-spinal pathways, with contribution of the corticospinal pathways more importantly in primates and humans (Sherman et al, 2000).

Historical experiments conducted by Magoun et al, (1946) showed that decirification stiffness and spasticity depended not only on the abolition of inhibitory supraspinal influences, but also on other downward pathways facilitating spinal reflex responses. The main tract that inhibits spinal reflex activity is the lateral reticular fascicle, which originates from bulbar reticular formation and descends through the lateral funiculus, near the lateral corticospinal fascicle. Therefore, lesions affecting this area will often cause mixed pyramidal and reticule spinal dysfunction. The inhibitory bulb reticular region is influenced by motor cerebral cortex, cerebellum anterior lobe, and basal nodes. The excitatory pathways also originate in the trunk of the brain. The main one is the medial reticular fascicle, coming from the pontine region of reticular formation, while the pscicular folliespinal fascicle does not seem as important in the production of spasticity (Navarro, 2009).

The fact that there is a balanced system of inhibition and arousal and that the descending pathways are located in different areas of the spinal cord, provides explanations for variations in the clinical pattern and pathology of spinal or cerebral spasticity depending on the level of injury of the upper moto neuron (Sheean, 2002). Bulbar reticular formation is under continuous facilitator control of the motor cortex, which therefore increases orders to inhibit muscle tone to the spinal cord in parallel with voluntary motor activity orders. An injury of the cortico-bulbar fibers, at the level of the cortex or internal capsule, eliminates this cortical facilitation, leading to a slight reduction of inhibitory influences and a supremacy of excitatory at the spinal level. On the other hand, spinal injury affecting the lateral but not medial funicle will leave distal spinal activity completely uninhibited, leading to significant spasticity and hyperreflexia. In complete spinal cord injuries, spinal reflex circuits lose all upper control, both inhibitor and exciter, and become hyperactive to stimulation.

As for the contribution of motor cerebral cortex, there appear to be diverse influences depending on the motor areas (Clemente, 1978). Thus, experimental lesions delimited to the precentral cortex result in contralateral flaccid paralysis, accompanied by hypotonia and hyporeflexia. For their part, lesions confined to area 6 determine spasticity without noticeable paralysis.

They also occur to alterations of the spinal reflexes within which they are located:

- Alterations of short latency reflexes in spasticity

These reflexes are mediated by the fibers IA, ranging from muscle spindles to the spinal cord, where they produce excitation of stretched muscle motor neurons and inhibition of motor neuron antagonist muscle. In the clinic it is possible to study this type of reflexes by electrophysiological assessment of reflex H and reflex T. Both reflex circuits are monosynaptic, although it has been shown that reflex H also has a polysynaptic component (Burke, 1985).

Several inhibitory pathways contribute to the control of the activity of spinal motor neurons in relation to postural maintenance and voluntary movements. Among them, there is evidence that inhibitory interneurons responsible for the mechanisms of presynaptic inhibition, reciprocal inhibition, recurrent inhibition and autogenic inhibition play a role in the physiopathology of spasticity.

The causes of hyperactivity of these reflexes have been investigated in subjects with spinal and brain injuries, resulting in several theories in this regard:

- Hyperactivity of fusimotor neurons (gamma motor neurons), which inert muscle fibers. However, this theory was rejected when studying muscle spindles in individuals with spinal cord injury, where no increase in fusimotor fiber activity was observed during spasticity (Dietz, 2007).
- Axonal shoots. After a spinal injury, the terminations of damaged axons in spinal neurons degenerate. After a few weeks of injury, the remaining afferent fibers branch into the spinal parenchyma, performing new synapses within the vacant space, trying to improve the effectiveness of spinal connections (Krenz & Weaver, 1998).
- Reduction of presynaptic inhibition of fibers Ia. According to some studies in subjects with spastic spinal injury, in which a vibratory stimulus has been applied to the Achilles tendon, recording the H reflex shows a decrease in vibratory inhibition (Calancie, 1993). This loss of inhibition could be directly related to spasticity.

The application of vibration to the muscular tendon excites the primary afferences of muscle spindles, but not the secondary ones (Burke et al, 1976). When vibration is applied to the tendon on a stretched muscle, it decreases the stretch reflex, as vibration blocks the arousal of the afferent IA and promotes presynaptic inhibition IA. In hemiplegic patients with spasticity, an absence of the inhibitory effect of vibration on the short latency stretch reflex (mediated by Afferents IA) has been demonstrated, confirming a reduced inhibition capacity of the monosynaptic reflex. But on the other hand, it increases the amplitude of the long-latency reflex (mediated by the afferents II), indicating a disinhibition of these afferents in patients (Nardone & Schieppati, 2005).

Modulation of H reflex during muscle contraction is also altered in subjects with incomplete spinal injury; the H reflex disappears, for example, during the standing position, but is slightly diminished in the gait relative to healthy subjects (Yang et al,1991). This lack of reflex modulation during gait probably contributes to the spastic gait of subjects with incomplete spinal injury.

- Decreased dissynaptic reciprocal inhibition. Crone et al (1994) studied patients with multiple sclerosis finding that fiber-mediated dyssinaptic inhibition was abolished in lower limbs. In individuals with incomplete spinal injury, this type of inhibition is decreased, they are unable to suppress H reflex when antagonistic muscles are activated by showing abnormal coactivation of these muscles during isometric contractions (Boorman et al, 1996).

- Disinhibition of group II afferent pathways, responsible for acting on afferent flexor reflexes (Maupas, 2004). Recent studies have shown that there is a facilitation of excitatory interneuron transmission coactivated by afferences II and A in patients with spastic hemiplegia producing spastic dystonia in anti-gravity muscles (Rémy-Néris et al, 2003).

- Increased excitability of motor neurons. It has been confirmed in spastic individuals, in subjects with SCI an increase in the maximum H/M maximum ratio has been observed (Delwaide, 1993). This increase in excitability is attributed to intrinsic alterations in the properties of motor neurons, in which there is persistent activation of internal currents and depolarization of the membrane (Li et al, 2004) observed in a model of spinalized rats. These currents, controlled by the brainstem through the downward fibers, are uncontrolled, leaving motors and cylinders to shoot prolongedly through the IA fibers.

In general, in spasticity situations all inhibition mechanisms at the medullary level are decreased or abolished, there is a deficit of modulation of the inhibitory pathways, so subjects with spasticity have an incoordination of antagonist-agonist muscles that prevents movement.

In relation to the sensory-motor functions that may undergo recovery processes after SCI vary widely, being able to encompass everything from simple activities, such as spinal monosynaptic reflexes, to the most complex functional patterns, such as locomotion. This limited restoration of neurological functions takes place in most patients (60-80%) with incomplete motor SCI (Fawcett et al., 2007), is most likely during the subacute phase of the injury, and relates to a process of spontaneous plasticity (Fawcett et al., 2007; Gomez-Soriano et al., 2010). Several neurophysiological studies prove the existence of some spontaneous recovery of voluntary motor function measured through the ASIA impairment scale (Maynard et al., 1997). For example, Fawcett et al., found that approximately 15-40% of individuals diagnosed with ASIA B evolved into ASIA C, compared to 40% of ASIA B lesions, which evolved to ISSA D, and 60-80%of SIA CAs that progressed to ASIA D (Fawcett et al., 2007).

In this way, it is thought that this process is the joint result of several phenomena, both short and long term, which are due to the immediate loss of excitability and connectivity in spinal neurons, followed by the development of physiological and morphological compensation mechanisms (Rossignol et al., 2007). An example of a compensation mechanism is the preservation of certain projections belonging to motor neuro control systems, such as spinal control, pyramidal and extrapyramidal downstream tracts, and ascending tracts (sensory afferents).

In recent decades some researchers hypothesized that the improvement in strength after performing a training program is mainly due to the increase in the activation of the motor units of the trained muscles, accompanied gradually by the increase in muscle mass. It has also been shown that the improvement of strength production in man is determined not only by the increase in AST and the distribution of the fibers of the participating muscle groups, but also by the magnitude of muscle mass activation (neural factors) (Hakkinen 1994).

It has been seen that subjecting a group of people to 12 weeks of intensive training produced a significant increase in maximum strength without changes in muscle mass (deVries, 1968). Results of the same type have been obtained when only one leg is trained and in subsequent measurements improvements have also been recorded in the uneded piema without evidence of hypertrophy (Moritani & deVries, 1980). Also, after 6 weeks of training, greater increases in strength production were observed, when it was analyzed with a family measurement methodology. These studies suggest that training-induced increases in strength are associated with a process of adaptation in the nervous system, either by an increase in the activation of the agonist musculature or by changes in the activation patterns of the antagonist musculature (Komi, 1986). Adaptations of the nervous system to strength training occur both in transmission from the central nervous system and in reflex-type responses at the level of the spinal cord. In addition, a feedback of both nerve centers originates from the peripheral sensory receptors. In this scheme it is observed that the training of the maximum and explosive strength will produce specific adaptations in all the structures of the nervous system, as well as in the muscle tissue itself (Enoka, 1988).

1.6 Physical activity and it´s health influences

There are different definitions and judgments about physical activity, but in general, all of them revolve around the increase in energy expenditure or metabolic rate above baseline, which include various aspects, variables and categories such as age, interest and culture to which the individual belongs (Vidarte et al., 2011).

The World Health Organization (WHO) (2010) considers it as the factor that intervenes in the state of people's health, and defines it as the main strategy in the prevention of obesity, understanding it as “any body movement produced by skeletal muscles and that produces an energy expenditure above the basal metabolic rate. It includes daily routine activities, such as housework and work”.

An important position that defines and classifies physical activity is that carried out by the American College of Sports Medicine (ACSM) (2009), which states that once the individual moves voluntarily, their metabolism increases because of muscular activity, luckily you are already doing a physical activity that becomes the basis of the intensity levels of it. From this perspective, getting up and walking are exactly the same physical activity for both a severely limited heart disease and an athlete, but with the difference that for the heart disease this activity represents 100% of their capacity, while for the athlete does not exceed more than 10% (Tikkanen et al., 2018). A level higher than physical activity is physical exercise, which includes a physical activity program that has programmed and continuous objectives, for which an exercise prescription is necessary. This is where fitness is included, retaken as the last level of sport that has the same components of physical exercise, but with competition variables, which can be also regulated and occupational (Erickson et al., 2014).

Physical activity, from health and therapy, has become today an ideal element to prevent some diseases in their appearance or development, to combat the sequelae or the way in which diseases affect the quality of life. It could be assumed that physical activity occupies a privileged place within the preventive, therapeutic and rehabilitative context, for professions other than Physical Education, such as nursing, physiotherapy and medicine, among others. This, because the subject (patient) evaluates his intervention processes based on the possibilities of movement that he performs after the injury or disease process has occurred, taken as a reference (Nelson et al., 2007).

Worldwide, physical activity assumed in its integral context is currently the key strategy for all health professionals who in one way or another seek to improve people´s quality of life conditions. From a public health perspective, Life is a basic and collective element that can undergo important changes especially in regard to diseases resulting from inappropriate lifestyles and unhealthy behaviors (Bangsbo et al., 2019).

Prolonged sedentary lifestyle leads to a marked and progressive reduction in muscle mass, decrease of strength, flexibility and balance. It has been shown that regular physical activity, with stimuli of at least three times a week, promotes significant differences in the indexes that predict body fat, significantly reduces the risks of contracting diseases such as coronary diseases, hypertension, resistance to insulin, dyslipidemia, etc., and positively influences aspects of the quality of life of individuals (Tremblay et al., 2010).

1.6.1 Physical activity and SCI

Adapted sport is a fundamental part of therapeutic physical culture. However, participation in sport, recreation and therapeutic exercise is commonly restricted after spinal injury (Chan et al., 2016). Adapted Physical Activity is defined as "any movement, physical activity and sport in which special emphasis is placed on the interests and abilities of persons with limiting conditions, such as disability, health problems or the elderly" (DePauw & Doll Tepper [1989, p. 96).

The term adapted physical activity should not only be understood as a body of interdisciplinary knowledge, belonging to the Sports Sciences, but also as a theoretical framework of reference for the research, programming and design of successful strategies to facilitate access to the practice of physical and sports activity for persons with disability. Recently, Hutzler (2008, p. 184) understands this body of knowledge as "a set of knowledge that encompasses the physical activities carried out by persons with disability, the service delivery systems developed to ensure the participation of such persons, a professional specialization that attracts professionals from pedagogical and academic disciplines, and a field of academic study."

The areas of application of adapted physical activity are therefore varied, such as therapeutic, recreational, educational, competitive (Sanz & Reina, 2012) and associative, understood this as sports physical activity promoted and organized by the association movement of disability (especially active in our country) and mainly oriented to health, recreation and sports initiation. These areas offer new opportunities for the development of activities and the promotion of the participation of persons with disability in sports activities, at all levels. In this sense, the current “Classification of Functioning, Disability and Health”, promulgated by the World Health Organization (WHO, 2001), represents a true homogenization of terminology and updates the perspective of disability as a personal element or characteristic that conditions health but does not have to involve a disease. This classification is a real approximation to all areas affecting people's health conditions, and is very relevant to addressing the overall analysis of health promotion/disease prevention for everyone, not just those with a disability, from a bio-psycho-social perspective. This approach is very suitable to address the different approaches of research in adapted physical activity and adapted sports (Perez, 2006; Hutzler, 2008).

Adapted sport, as another part of the adapted physical activity, encompasses all those sports modalities that adapt to the collective of persons with some type of disability, either because a series of adaptations and / or modifications have been made to facilitate the practice of that group, or because the structure of the sport itself allows its practice (Hernández, 2000; Perez, 2003; Queen, 2010). In this way, some conventional sports have adapted a number of parameters to be able to adapt to the needs of the collective that will practice it (e.g. wheelchair basketball) and, in other cases, the sport has been designed based on the needs and specificities of disability (e.g. goalball for persons that are visually impaired) (Pérez Tejero et al., 2012).

A fundamental feature of adapted sport is the concept of functional classification: the athlete is classified according to his ability to move when it comes to the practice of a particular sport (Tweedy & Vanlandewijck, 2010). Definition of the minimum disability to compete in a certain adapted sport is therefore necessary (notion of "minimal handicap") and has to be distinguished from the "functional potential" of the athlete. The purpose of a sports classification is to allow each competitor, regardless of the severity of the disability, to compete fairly with the rest of the athletes, with a similar skill/disability (Ritcher et al., 1992). In addition, these sports rankings should also stimulate the participation of people with disability in competitive sport while preventing the sporting abandonment of athletes with severe disability levels (Vanlandewijck & Chappel, 1996).

Despite the above, this still remains a controversial issue today. The trend in recent years has been the genesis of classification systems based on parameters of functionality applied to sport, and not so much on a diagnostic categorization of disability, so that performance is based on skill not disability (Tweedy & Vanlandewijck, 2010; Arroyo, 2011). However, this type of classification has harmed the participation of persons with severe disability at elite sports competitions (DePauw & Gavron, 2005). Additionally and as consequence of this organizational competition model, it has impacted changes in the organizational model of adapted sport. Now the changing trend is that adapted sports athletes of the highest level begin to integrate into their respective sports federation and no longer depend organically on a multisport federation that brings together a certain group of disabilities (Tejero et al., 2012).

Both special physical education and adapted sport contribute to rehabilitation at a therapeutic, recreational or competitive level, because they promote the continuous effort of avoiding or restoring a diminished capacity, the normalization or process of such of making the way of life of a person with a disability normal; enhance personal autonomy or ability to act on oneself without dependence on others; social integration, i.e. reducing situations of disability by encouraging change and promoting social equality; boost and enhance the desire for self-improvement; collaboration in the suppression of architectural, psychological and social barriers; improving self-esteem and personal development (Montero-Ordoñez et al., 2017).

66% of persons with SCI have overweight or obesity and have a high risk of premature mortality due to respiratory, cardiovascular or urogenital diseases, as well as a tendency to hypertension and cardiovascular diseases. This loss of health and physical condition due to SCI can be the result of the paralysis of the muscles necessary to do physical exercise voluntarily, but in many cases, it is simply a consequence of adopting a sedentary lifestyle, reducing their functional status, their participation, their autonomy and finally their quality of life (Brizuela et al., 2016).

Despite the fact that for persons with SCI, the benefits of regular physical exercise are much more relevant than for the rest of the population, they continue to make up the most sedentary and inactive portion of the population, since they have numerous additional problems to access the practice of physical exercise (Machač et al., 2016).

Persons with physical disability should engage in adapted physical activity, requiring supervision in some cases. Patients with SCI will require short-term physiotherapy treatment (strategies against pains, strategies against cardio-respiratory, digestive and urinary complications, and strategies to maintain tonicity) and long-term physiotherapy strategies, educational-therapeutic measures and treatment modalities. Adapted physical activity to improve mood, health-related quality of life, self-esteem and level of well-being (Capó-Juan et al., 2017).

1.6.2 Competitive Sports for persons with disability.

Sport for persons with disability is a social phenomenon with very recent origin. Although physical activity, sport and motoric games begin with mankind himself, as far as persons with disability are concerned, their history is less extensive. It can be considered that after the first and Second World War, due to the high number of mutilated persons, the first steps of practicing of sports by persons with discapacities began (Montero-Ordoñez et al., 2017).

Some countries promote innovation, research and development policies in Paralympic sport. The worldwide popularity of adapted physical activity was doubtless inspired by competition (Capó-Juan et al., 2017). Currently the three best-known sporting events are: the Paralympic Games, the Special Olympics World Games and the Deaflympics. Persons with a disability have been able to compete in the Paralympic Games since 1960, the year in which 23 countries joined the event in the city of Rome. 175 countries participated in the 2016 games in Rio de Janeiro, 4,350 athletes in 22 sports: athletics, wheelchair basketball, boccia, cycling, SR fencing, soccer-5, soccer-7, goalball, judo, weightlifting, horse riding, swimming, rowing, table tennis, wheelchair tennis, archery, olympic shooting, wheelchair rugby, sailing and sitting volleyball, canoeing and triathlon. The Paralympic Games clearly manage to develop programs that facilitate the process of integration of these formerly SCI patients into society (Torralba, 2012).

Any adapted physical activity can be performed in a playful and / or competitive way and is preferably done in group in order to stimulate and promote healthy socializing in community. The determining factor when choosing which sporting activity for patients with SCI depends on: external factors like climatic conditions, geographic location of residence, habitual residence, accessibility, political-social strategies and internal factors like personal interests and tastes, level of injury and patient capacities, socio-economic situation, and others (Capó-Juan et al., 2017).

In recent years a paradigm shift has occurred from rehabilitation to enabling; however, there are still points to improve in relation to physical activity adapted to patients with SCI. The educational-therapeutic measures will be essential in any program in which the physiotherapist participates, in this way, the patient with SCI will be ergonomically advised in sports practice. The collaboration of other professionals in the field of physical activity and adapted sport will also be essential in this work, based on transdisciplinary models (Capó-Juan, 2016).

The participation of SCI patients in exercise activities may also require special adaptation equipment and, in some cases, the use of electric current, either with or without computerized control. Despite these limitations, there is considerable evidence that recreational and therapeutic exercise improves the physical health and emotional well-being of persons with spinal cord injuries (Nash, 2005).

Traditionally, what has been done to improve the quality of life and autonomy of persons with a tetraplegia was to improve functional independence through compensatory exercise programmes, such as overuse of senior members. This is not the most suitable way to exercise, because it does not enhance the plasticity of the tissue that has not been damaged by the injury and neither the neuroplastic capacity of the spinal cord (Galea et al., 2013). Before prescribing physical activity one of the most important points to consider is knowing the severity (level) of the injury and whether it is a complete or incomplete SCI. According to Chicharro et al., (2008), in patients with complete injury, confirmed over years, the physical activity prescription has to incorporate compensational exercises for function that has been lost due to the injury. However, if it is an incomplete injury the prescription of physical activity will seek to improve the functional capacity, through motor learning based on functional taras (motor patterns).

Exercise should consist of stretching, aerobic exercise and muscle strengthening. People who have undergone SCI should do stretching exercises regularly to prevent and treat stiff muscles and joints (Mulroy et al., 2011). A good flexibility program consists of stretching the main muscle groups, the shoulders, hips, knees and ankles, because those are common areas of stiffness after an SCI. Muscle strengthening can be done on the same day with aerobic exercise or on a different day, but is not recomended within aerobic exercise time (Eitivipart et al., 2019).

Persons with SCI have a "circulatory hypokinesia" that generates a buildup of venous blood in the lower limbs and often in the lower part of the trunk, due to the low movement of these limbs as well as limited control of the nervous system especially the sympathetic nervous system, below the level of the injury (Hopman et al., 2002). This alteration depends on the level of spinal injury and, studied in athletes with paraplegia, is related to a decrease in cardiac output (CO). Similarly, the systolic volume (VS) is normally reduced for athletes with SCI, most likely because the deficit venous return does not favor ventricular filling (Hopman et al., 1994). However, when exercise intensity is submaximum and the level of SCI relatively low (lower than T6-T7), VS deficiency can be offset by increased heart rate (FC), provided that the nice inervation of the heart remains intact (Hopman et al., 1993). On the contrary, when the intensity of exercise is close to the maximum, the decrease in venous return, cardiac preload and finally VS, causes a reduction in the ability to transport oxygen to tissues, limiting aerobic power and ultimately athletic performance, in endurance tests (Hopman, 1994).

Persons with dorsal or cervical SCI show a reduction in lung ventilation capacity, with a reduction of all lung volumes and capacities, especially FEV-1 (forced expiratory volume) and HCF (forced life capacity), progressively reducing after injury and generating predisposition to respiratory tract infections

(Martínez & López, 2014; Ovechkin et al., 2010). When SCI is located above T1, but below C4, the scalen muscles, pectorals, trapezium and steroncleidomastoid, play an essential auxiliary role, next to the diaphragm (Bach, 2006), to compensate for the paralysis of the intercostal and abdominal muscles (Costly et al., 2002). Similarly, the difference in measured aerobic power between persons with high and low LM, reaching double, persons with paraplegia, VO_2max (maximum oxygen consumption or aerobic power) of persons with tetraplegia (Haisma et al., 2006) is reflected. The same is true if a complete SCI is compared against an incomplete SCI, the decrease in active muscle mass, as well as the decrease in the aforementioned cardiovascular response in persons with complete SCI, may explain this difference. In parallel, when it comes to high-intensity physical exercise, for short periods, the magnitude of the anaerobic power generated shows an inverse relationship to the level of SCI, as well as to the degree of affectation (Slater & Meade, 2004). It should be noted that this type of high-intensity exercise, unlike aerobic exercise, does not generate a relevant demand on the cardiorespiratory system. Considering that respiratory system diseases and their complications have a very important impact on the health of persons with SCI, their prevention, as well as the search for better respiratory function, should be a clear goal in any rehabilitation and sports training program (Brizuela et al., 2016).

Finally, muscle strength training, aimed at seeking a balance between the different muscle groups, could be a good recommendation to follow in these patients, since the imbalance seems to be one of the determining factors for the appearance of alterations of the upper train of athlete's wheelchair users, detecting a lower strength of aduction, internal rotation, and external rotation, in those who present shoulder compression syndrome (Lemos et al., 2020).

1.7 Coaching persons with paraplegia and tetraplegia

It must be taken into account that the paraplegic patient in more than 80% of cases suffers from irreversible injuries that would prevent in the future a restoration of the mobility of their lower limbs, which needs orthopedic devices and sufficient muscle development for walking powerful for arms and trunk that supplants the inactivity of the lower limbs (de la Cuerda & Vázquez, 2012).

To address the particularities of the treatment of spinal cord injuries as a precedent of physical rehabilitation through various technologies and techniques, one should begin by deepening physical rehabilitation to later base the design of a program of therapeutic physical exercises for the rehabilitation of patients that favors their self-validation (Behrman et al., 2017). In this sense, the purpose of the rehabilitation of patients with SCI is aimed at: founding an interdisciplinary process centered on the patient, comprehensive and coordinated, establishing physical motor functional activities with an intervention and early prophylaxis to prevent new complications, acquire new information that provides the patient with the appropriate means to achieve independence, achieve functional, physical or verbal independence, and the necessary equipment to facilitate this independence, in addition to obtaining and maintaining a satisfactory reintegration into society (Morawietz & Moffat, 2013).

The goal in young patients is to achieve complete function without limitations and, in older patients, to regain the ability to perform as many daily activities as possible. In each case it is necessary to determine the functional objectives of each patient according to the affected spinal cord level (neurological level). The functional potential also depends on other factors such as: age, associated diseases, existing technical means and motivation of the patient (Akkurt et al., 2017).

In the most immediate phase after the injury, rehabilitation plays a very important role, at the beginning it should be aimed basically at the prevention of respiratory and circulatory complications, and the care of pressure areas, an assessment must be made to have an objective measurement initial functions, identify the aspects that present possibilities to pose specific problems and promote prophylactic treatment. Respiratory treatment, maintenance of joint range in all joints and maintenance-strengthening of the totally or partially innervated muscles are very important. Rehabilitation of paraplegic patients should begin as soon as possible. The decrease in complications is directly related to the care received immediately after the spinal cord injury; This begins gradually and over time the number of hours per day is progressively increased (van der Scheer et al., 2017).

The role of the rehabilitator is, among others, to create situations that stimulate the implementation of learning skills; stimulate the patient to perform therapeutic physical exercises and promote activities of daily living; as well as to encourage them to find solutions to problems that may arise. In the initial phase, exercises are performed in bed and progression takes place according to the adaptation the patient presents. In this phase, you are often in pain, easily fatigued, and confused by the same effects of physical rehabilitation. The principles of sports training and the basic principles of rehabilitation acquire a very important role, of which they are used: the principle of progressive increase of loads, principle of cyclical organization of loads, systematization and affordability, to mention a few. The assisted passive, active and active mobilization of the joints is essential, since it allows avoiding contractures, pain and functional limitation of the affected joints and preventing atrophies and weakness in the uninjured muscles (Tse et al., 2018).

2. JUSTIFICATION

Disability remains a barrier to the social, personal and educational development of persons with disability (WHO, 2011a, 2013). “Disability is now a phenomenon increasingly conceived as a result of the disadvantage in participating in equal opportunities in society", considering self-esteem to be basic in the integral development of any individual, particularly in the emotional aspect for the best quality of life (Huete Garcia, 2013.pag 20).

The importance of sports for persons with disability has been analyzed from different aspects. Authors such as (Segura et al., 2013) have analyzed the beliefs and attitudes about sport adapted for persons with disability and as well from stigma towards people who realize it (Ferrante, 2014).

From the premise of international agencies (UNICEF-UN-UNESCO, 2004) it is stated, that the development of physical activity and sport is a right for All without discrimination, as well as it is recognized that practicing physical activity and sport can contribute various individual and social benefits.

Sport becomes a tool for socio-educational inclusion but we must also see the barriers that are the same for persons with disability. (Queen, 2014). For example, the perception of Paralympic athletes and the counterproductive view of Paralympic games for disability (Braye, Dixon, & Gibbons, 2013). From this perspective, we must motivate persons with disability to carry out sports activities for overcoming barriers (Peers, 2009; Wedgwood, 2013).

Physical activity provides multiple benefit for persons with SCI, whenever performed adapted in accordance to the subject and taken into account various limiting factors (Warburton et al., 2011).

- On a physical level:
  - Changes on different organs and body systems:
    - On skeletal musculature: increases the volume and number of muscle fibers that causes the improvement of strength and endurance. It also improves oxygenation and facilitates the elimination of lactic acid, thus favoring muscle metabolism.

  - On the circulatory system: there is a cell increase in erythrocytes and hemoglobin, which improves oxygen supply to tissues, decreasing recovery time after exertion.
  - On the respiratory system: increases vital capacity and oxygen uptake capacity, thus improving the breathing rate at rest and during exercise.
  - On the Nervous System: enhanced nerve regulation improves the coordination of movements.
  - On the metabolic system: regulates glandular, toroidal and adrenal function, due to better glucose regulation. Fat deposits are reduced.
  - On the cardiovascular system: blood pressure values are lowered and cardiac hypertrophy occurs.
- Changes in motor deficit alterations:
  - On muscle tone: variations and regulation of the tone according to the position and activities to be developed so that the action is effective.
  - On posture: functionality is sought by taking the most appropriate position possible when performing the proposed activities.
  - On movement: improves the fluidity of movement and regulates alterations typical of different types of deficit.
  - On balance: improved balance in both static and dynamic.

- At the psychomotor level: persons with SCI who perform physical activity improve the knowledge of their own body, viso-motor coordination, spatial and temporal orientation and consequently, skill.

- At the psychosocial level: physical activity in these users can affect in many personal and social aspects that they had blocked.

Training programs performed by persons with a tetraplegia show improvements of exercise tolerance, muscle endurance, peak endurance and oxygen consumption without the concurrence of central cardiovascular adaptations. However, peripheral adaptations can be demonstrated, which will be of remarkable importance for improving quality of life (Chicharro et al., 2003).

When exercise is performed in the sitting position, FC is usually limited to about 120 ppm, and cardiac output, systolic volume and blood pressure often offer values below what would be expected for certain oxygen consumption values (Figoni,1993).

Heart rate is one of the most commonly used parameters for assessing heart activity. Heartbeats occur at a variable frequency, during rest, i.e. the time in milliseconds between two beats varies beat-by-beat (Rhodes, Pedret Carballido, Ramos, & Capdevila, 2008). Heartbeat intervals show, with each other, slight differences in duration that result in changes in heart rate. These changes follow certain repeat patterns, so shortening and prolongation of intervals are repeated cyclically (Migliaro & Contreras, 2005). Heart rate variability analysis (HRV) is typically used as a non-invasive method to quantify the control that the autonomous nervous system exerts on heart rate dynamics (Akselrod et al., 1981; Malik et al., 1996), and allows to obtain indicators that relate to health in the general population, which are sensitive to physiological and psychological disorders (Ortis et al., 2008).

HRV is more evident at rest than in exercise. As discussed above in a general way, HRV is a marker of autonomic activity, i.e. the higher the oscillation of resting heart rate, the greater the vagal participation. A reduction in vagal tone and consequently HRV is linked to autonomic dysfunction, chronic-degenerative diseases and increased risk of mortality (Tapanainen et al., 2002).

The activity of the autonomous nervous system in persons with tetraplegia is depressed but maintains homeostasis (Wang et al., 2000), because whenever sympathetic decentralization happens, the functioning of FC by the autonomous system regarding is carried out by the parasympathetic nervous system (Takahashi et al., 2004). A large number of researches in recent years used HRV to assess the autonomic balance in various chronic diseases, including neuromuscular diseases, diabetic neuropathy and SCI. For SCI, using HRV represents a good model because the disruption of the efferent friendly pathways that inert the cardiovascular nervous system alters the normal balance of the autonomous nervous system, which is reflected in HRV patterns (Myers, Lee, & Kiratli, 2007a).

Nevertheless, studies investigating the effects of cardiovascular exercise on HRV in persons with tetraplegia are still scarce, and generally related to rolling tapestry-assisted walking or orthostatic training (Millar, et al., 2009; Ditor et al., 2005a). Given the lack of studies in this regard, investigation of the response of HRV in persons with tetraplegia as well as on the effect of exercise on the parameters of PFCs, especially of the time of inmediate recovery after exercise are necessary.

3. OBJECTIVES

3.1 General objective

- Study the effect of arm-crank exercise program on the physiological response, functional capacity and autonomy of persons with tetraplegia.

3.2 Specific objectives

- Analyze changes in Peak Power Output before and after practicing an arm-crank exercise program in persons with tetraplegia.
- Analyze changes in respiratory parameters before and after practicing an arm-crank exercise program in persons with tetraplegia.
- Analyze changes in HRV before and after practicing an arm-crank exercise program in persons with tetraplegia.
- Analyze changes in functional capacity and autonomy after practicing an arm-crank exercise program in persons with tetraplegia.

4. METHOD

It is a quasi-experimental prospective study, which consists of a series of repeated observations on the subjects participating in the study. An intervention with several variable has been applied, to subsequently make periodic measurements and quantify the effects of such intervention on the sample studied.

An A-B applicability design has been used, as the study is divided into two phases (pre and post-intervention), performing measurements in each of the phases, so that the results of the effectiveness of the intervention can be predicted. This design allows identifying the effectiveness of the intervention, monitoring the evolution of the patient and subsequently extrapolate and replicate the results of the intervention scenarios in relation to physical activity and sport.

4.1 The Start

The Project started in 2009 at the University of Valencia, faculty of physical activity and sport. To find participants we contacted with ASPAYM Comunidad Valenciana, a non-profit organization of persons with SCI or severe physiological disability, which was inaugurated in 1982 with the aim to improve life and integration of this group of the population. All of its members were invited to find persons with tetraplegia who had previously engaged in little or no activity and who were willing to participate in the study

4.2 Development of the experiment

The first step was the development of an armcrank ergometer. A commercial indoor bicycle was used, its frame cut and mounted onto a table. Specific handgrips were mounted instead of the pedals, which allowed attaching the hands with micro belts because the participants had no handgrip ability.

The experiment consisted of Armcrank Exercise (ACE) training, performed on an adapted, stationary, and mechanically braked armcrank ergometer (Figure 1).

Figure 1. Special adjustable hand grips designed for persons without grip ability and mounted onto the custom designed armcrank ergometer.

This machine was equipped with a pair of grips specially designed for persons without grip ability adjustable in different ways to the dimensions and characteristics of the participant's hands and wrists.

The first measurements for all the participants were made one week before the beginning of the study (Week 0). Two measurement sessions took place during the same week but not the same day, in which Quadriplegia Index of Function (QIF) questionnaire, heart rate recording, spirometry variables, and maximum ACE power output were measured. The same researcher explained carefully to every participant each item of the QIF scale, and scored the corresponding item.

The complete series of measurements was repeated after the end of the exercise program (Week 9), again split over two days, following the same order and schedule (in particular, the time of the heart rate measurement).

The training was carried out over an 8-week period, twice a week, but never on consecutive days. The duration of the exercise in each session was from 15 to 20 minutes in the first two weeks, from 20 to 30 minutes during the third and fourth week, rising to 30 to 40 minutes from the fifth week until the end of the training program. Instructions to the subjects were to keep a constant cadence throughout the training session at the maximum intensity they would be able to maintain until the end of the exercise.

Each participant was asked to choose a resistance that he or she could maintain during the proposed duration in response to his or her own sensations. Participants were able to speak during the entire exercise, which indicates that the exercise is of light to medium aerobic intensity (Figure 2).

Figure 2. Adjustable-height armcrank ergometer as used for training.

4.3 Participants

Study participants were selected for non-probabilistic, causal or incidental sampling, in which the sample was not randomly selected.

Twenty-five people living in and around the city of Valencia expressed their willingness to participate in the project. A total of 11 of them met the inclusion and exclusion criteria and therefore were chosen from this group, ensuring the objectivity, continuity and relevance of the study, and being able to obtain reliable and valid able results (externally and internally). Inclusion criteria were that participants had to be spinal injury diagnosed, not play sport on a regular basis and be willing to come to the university gym twice a week for two months. Selection was homogenous concerning the lesion level. Five persons were with SCI between C4-C5 and six persons with SCI between C6-C7.

Persons with triceps function and those who practiced sport or physical activity regularly (once a week or more), patients with cardiovascular disease and other pathologies that could affect adherence to the study, individuals to whom physical exercise was contraindicated, subjects with cognitive or mental impairments, patients with degenerative or osteoarticular alterations of the upper limbs and patients with tegumentary complications (ulcers) were excluded.

The study involved 11 participants (8 men and 3 women, body mass = 72.3 ± 13.4 kg and age = 36.5 ± 10.0 years), all of them with traumatic-origin tetraplegia (5 with SCI between C4-C5 and 6 between C6-C7, ASIA levels A and B) (Table 3).

Table 3. Characteristics of the sample: variance / mean and standard deviation of age, body mass and years since the injury.

	Higher (C4-C5)	**Lower (C6-C7)**
Age SCI (years)	12.6 ± 12.9	13.5 ± 8
Age (years)	34.2 ± 12.7	38.3 ± 7.8
Body mass (Kg)	68.7 ± 11.5	75.3 ± 15.2

All 11 participants had functional biceps and deltoid muscles, but different levels of motor ability. They could voluntarily bend their elbows, but not extend them against gravity or opposition. None of them had grip ability (ability to grasp or hold objects by flexing the fingers).

All participants were informed of the possible beneficial effects and risks of their participation in the study, and gave their written consent to take part in the research project as well as for the results and conclusions to be published. University Ethics Committee approval was obtained in order to perform the study and it conformed to the principles outlined in the declaration of Helsinki.

4.4 Variables

The variables investigated in this study were (Table 4):

Table 4. Variables included in the study.

Variable	**Definition**	**Unit of measurement**	**Variable type**
PPOWER (W)	Maximum mechanical power (short and maximum) that subjects can produce while pedaling.	Watt.	Quantitative.
QIF	Quadriplegia function index that measures the level of autonomy of patients and allows for small significant changes in patients with tetraplegia (Marino et al., 1993).	9 categories with daily life activities, in which each motor task is assigned a score of 0 to 4 points, with 4 being maximum independence. The total can add up to 200 points, of which 180 refer to functional tasks and 20 points to personalcare.	Quantitative.
Spirometry variables			
VC	Vital capacity is the volume of gas that can be taken into the lungs in a full inhalation, starting from the resting inspiratory position. It is measured during normal exhalation. It measures the total inspiratory capacity, equal to the tidal volume plus the inspiratory reserve volume.	Milliliters.	Quantitative.

FVC	Forced vital capacity is the maximal volume of gas that can be exhaled from full inhalation by exhaling as forcefully and rapidly as possible. FVC is the total amount of air exhaled during the FEV test. The exhaled airflow may be measured during the first (FEV1), second (FEV2), and/or third seconds (FEV3) of the forced breath. It´s unit is liter per seconds.	Milliliters.	Quantitative.
MVV	Maximum voluntary ventilation is the volume of air expired in a specified period during repetitive maximal effort.	Seconds.	Quantitative.
HRV variables			
HR	Average heart rate of the five minutes recorded.	beats* min-1	Quantitative.
STD HR	Standard deviation of instantaneous heart rate values.	beats* min-1	Quantitative.
RMSSD	Square root of the mean squared differences between successive RR intervals.	ms.	Quantitative.
LF	Absolute power in the low frequency spectral components of RR intervals.	ms-2.	Quantitative.

HF	Absolute power in the high frequency spectral components of RR intervals.	ms-2.	Quantitative.
HRVPower	Absolute power in the high, low and very low frequency spectral components of RR intervals, also termed total power.	ms-2.	Quantitative.
LH/HF	Ratio between LF and HF powers.	Adimensional.	Quantitative.

4.5 Measurement Instruments

PPOWER was measured during short anaerobic exercise using a SCIFIT PRO1 (SCIFIT Systems Inc., Tulsa, OK, USA) arm ergometer, adapted with a pair of the same grips specially designed for persons with tetraplegia as were used for the training sessions. This ergometer provides a wide range of adjustable crank heights and lengths to allow pedaling as in the training sessions (Figure 3). The participants pedaled seated on their wheelchairs, with their trunk strapped to their wheelchair back, and the wheelchair itself firmly strapped to the base of the ergometer. The pedaling axis was set at the level of the participant's chest, always lower than their shoulder height. The ergometer data was logged on a computer via an RS232 connection at a sample generated by the ergometer of 1 Hz.

Figure 3. Fully adjustable adapted ergometer used to measure the ACE power output.

The test consisted of five 10 s attempts to apply their maximum ACE power, trying to increase their pedaling cadence against the resistance applied by the ergometer, with 3 to 5 min rest periods between attempts so as to avoid fatigue. Before testing all participants had a good warm up.

The heartbeat signal during a resting period of 10 minutes was recorded as the first test of each measurement session, with the participant seated on his or her own wheelchair in conditions to calm down as much as possible. We therefore provided a very quiet room with dimly lit light, and ambient temperature set at 22°C. As recommended (Ditor et al., 2005), for all the participants, these measurements were made with the bladder almost empty. Signals were recorded with a Polar RS800 monitor (Polar Electro, Finland) in RR (beat-to-beat) mode. The records were logged onto the computer through an infrared interface (Polar IR), using the Polar Precision Performance software package (version 3).

The HRV parameters were calculated with the Kubios HRV 2.0 software package, analyzing only the last five minutes of the record in order to ensure stability of the heart rate data. After appropriate filtering, correction, and detrending according recommendation by the manufacturer (Tarvainen et al., 2002), the data was subjected to a fast Fourier transform (FFT) spectral analysis, taking the usually recommended frequency bands (Task Force, 1996): high frequency (HF) from 0.15 Hz to 0.4 Hz; low frequency (LF) from 0.04 Hz to 0.15 Hz; and very low frequency (VLF) from 0.03 Hz to 0.04 Hz.

All spirometry variables were measured using a Fukuda Sangyo ST-250 spirometer (Fukuda Sangyo Inc., Japan). The same technician calibrated the spirometer daily and tested all the participants from a seated position. Reproducibility standards were those established by Miller et al. (2005).

For the VC, FVC, and MVV tests, the maneuvers were explained and demonstrated to the participants following the recommended procedures (Miller et al., 2005). Belts or pant waists were loosened, and nose clips were worn. For the VC measurements, the participants were encouraged to inhale completely and exhale maximally, and sustain the effort for at least 6 s or longer. For the FVC test the instructions were to inhale completely and then exhale the air out, again trying to do it maximally and sustain the effort for at least 6s or longer. These two tests were repeated three times. For the MVV test, the instructions were to perform at least three resting tidal breaths followed by breathing as rapidly and deeply as possible for 12 s. This test was carried out once only with each participant.

4.6 Data treatment

All variables were checked for normality using the Kolmogorov-Smirnov test. When the distributions were skewed or heteroskedastic (LF, HF, and HRVPOWER), they were log-transformed, yielding transformed data with a normal distribution (La Fountaine et al., 2010), and thus allowing parametric statistics to be applied for comparisons. Nonetheless, the results for these variables will be expressed in terms of the raw data for greater clarity and to allow comparison with other studies.

An ANOVA was applied to all the variables, including TIME and INJLEVEL as factors. The interaction between the aforementioned two factors was analyzed, and a linear regression analysis was performed between QIF and PPOWER.

A least significant difference multiple range test (LSD-MRT) was used to detect or confirm significant differences between the levels of the factors. All statistical analyses were done using the Statgraphics Plus package (v. 5.1), with an Alpha level set at 0.05.

5. RESULTS

5.1 Functional and pulmonary variables

All functional and pulmonary variables showed significant differences ($p < 0.05$) between level of injury, with higher values for the participants with the lower level of cervical SCI (QIF: 202 % pre and 200 % post, PPOWER: 255 % pre and 207 % post, VC: 21 % pre and 30 % post, FVC: 33 % pre and 34 % post and MVV: 9 % pre and 30 % post).

Level of autonomy, measured by QIF, was not significantly changed from “Pre-training” to “Post-training” by the ACE program, and no interaction was detected ($p = 0.7833$) between both factors.

Regarding factor TIME, only PPOWER and MVV showed significant differences ($p < 0.05$) between pre and post measurement, resulting always in higher values after the ACE training program. Improvement in PPOWER: 52 % for “Higher SCI” and 31 % for “Lower SCI”.

MVV was improved 1% for “Higher SCI” and 20 % for “Lower SCI”. Moreover, it was detected significant interaction for PPOWER ($p = 0.0315$) explaining the higher increase in PPOWER for Higher SCI (52 %) than for Lower SCI (31 %) and for MVV ($p = 0.0361$) explaining a higher increase in MVV for Lower SCI (20 %) than for higher SCI (1 %).

In the same direction, VC and FVC showed a light but none significant tendency ($p = 0.1360$ and $p = 0.1746$, respectively) to increase after the ACE program (Table 5).

Table 5. Results of the comparison of the functional and pulmonary variables on the factors INJLEVEL (higher or lower level of cervical SCI) and TIME ("Pre" and "Post" the exercise program).

		Factor TIME	
Variable	**Factor INJLEVEL**	**Pre** (Mean ± SE)	**Post** (Mean ± SE)
QIF (%)	Higher (C4-C5)	19.67 ± 0.09	21.5 ± 0.09
	Lower (C6-C7)	59.4 ± 8.96	64.4 ± 8.96
	All participants	39.53 ± 6.03	42.95 ± 6.03
	Factor TIME	p = 0.5536	
	Factor INJLEVEL	p = < 0.0001	
	Factors Interaction	p = 0.7833	
PPOWER ($W \cdot kg^{-1}$)	Higher (C4-C5)	0.29 ± 0.04	0.44 ± 0.04
	Lower (C6-C7)	1.03 ± 0.07	1.35 ± 0.07
	All participants	0.66 ± 0.04	0.90 ± 0.04
	Factor TIME	p = < 0.0001	
	Factor INJLEVEL	p < 0.0001	
	Factors Interaction	p = 0.0315	
You (l)	Higher (C4-C5)	2.42 ± 0.18	2.49 ± 0.18
	Lower (C6-C7)	2.92 ± 0.29	3.23 ± 0.29
	All participants	2.67 ± 0.16	2.86 ± 0.17
	Factor TIME	p = 0.1360	
	Factor INJLEVEL	p < 0.0001	
	Factors Interaction	p = 0.2388	
FVC (l)	Higher (C4-C5)	2.27 ± 0.16	2.38 ± 0.16
	Lower (C6-C7)	3.01 ± 0.25	3.18 ± 0.25
	All participants	2.64 ± 0.14	2.78 ± 0.15
	Factor TIME	p = 0.1746	
	Factor INJLEVEL	p = < 0.0001	
	Factors Interaction	p = 0.6599	
MVV (l)	Higher (C4-C5)	74.44 ± 6.39	74.83 ± 6.39
	Lower (C6-C7)	81.39 ± 9.15	97.45 ± 9.15
	All participants	77.92 ± 5.44	86.14 ± 5.44
	Factor TIME	p = 0.0280	
	Factor INJLEVEL	p = 0.0001	
	Factors Interaction	p = 0.0361	

5.2 HRV Variables

LF showed significant increases (p = 0.0145) after the ACE program (81 % for Higher SCI and 124 % for lower SCI). HRVPOWER also showed significant increases (p = 0.0295) after the program (156 % for Higher SCI and 78 % for lower SCI). In the same direction STDHR showed a strong but none significant tendency (p = 0.0675) to increases after the ACE program (23 % for Higher SCI and 13 % for lower SCI). Contrarily to functional and pulmonary variables, any of the HRV variables showed differences between high or low injury level, neither in the "Pre" time, nor in the "Post" time. There was not detected interaction between factors TIME and INJLEVEL for any HRV variable (Table 6)

Table 6. Results of the comparison of the HRV variables on the factors INJLEVEL (higher or lower level of SCI) and TIME ("Pre" and "Post" the exercise program).

		Factor TIME	
Variable	**Factor INJLEVEL**	**Pre** (Mean ± SE)	**Post** (Mean ± SE)
HR (min^{-1})	Higher (C4-C5)	74.50 ± 2.82	71.74 ± 2.82
	Lower (C6-C7)	71.69 ± 3.09	68.78 ± 3.09
	All participants	73.09 ± 2.09	71.74 ± 2.09
	Factor TIME	p = 0.3450	
	Factor INJLEVEL	p = 0.3360	
	Factors Interaction	p = 0.9793	
STDHR (min^{-1})	Higher (C4-C5)	2.07 ± 0.19	2.54 ± 0.19
	Lower (C6-C7)	2.02 ± 0.21	2.29 ± 0.21
	All participants	2.04 ± 0.14	2.42 ± 0.14
	Factor TIME	p = 0.0675	
	Factor INJLEVEL	p = 0.4432	
	Factors Interaction	p = 0.6108	
RMSSD (ms)	Higher (C4-C5)	17.45 ± 5.80	31.11 ± 5.80
	Lower (C6-C7)	17.74 ± 6.35	18.60 ± 6.35
	All participants	17.60 ± 4.30	24.85 ± 4.30
	Factor TIME	p = 0.2398	
	Factor INJLEVEL	p = 0.3208	
	Factors Interaction	p = 0.2987	
LF (ms^{-2})	Higher (C4-C5)	204.54 ± 75.56	370.24 ± 75.56
	Lower (C6-C7)	169.37 ± 82.77	379.30 ± 82.77
	All participants	186.95 ± 56.04	374.77± 56.04
	Factor TIME	p = 0.0145	
	Factor INJLEVEL	p = 0.3939	
	Factors Interaction	p = 0.8758	
HF (ms^{-2})	Higher (C4-C5)	181.48 ± 202.19	641.99 ± 202.19
	Lower (C6-C7)	128.27 ± 221.49	158.85 ± 221.49
	All participants	154.88 ± 149.95	400.42 ± 149.95
	Factor TIME	p = 0.2311	
	Factor INJLEVEL	p = 0.9762	
	Factors Interaction	p = 0.8934	
HRVPOWER (ms^{-2})	Higher (C4-C5)	422.15 ± 241.09	1082.73 ± 241.09
	Lower (C6-C7)	351.98 ± 264.10	627.58 ± 264.10
	All participants	387.07 ± 178.80	855.15 ± 178.80
	Factor TIME	p = 0.0295	
	Factor INJLEVEL	p = 0.5892	
	Factors Interaction	p = 0.8983	
LF/HF	Higher (C4-C5)	2.21 ± 0.56	2.89 ± 0.56
	Lower (C6-C7)	2.78 ± 0.61	3.63 ± 0.61
	All participants	2.50 ± 0.41	3.26 ± 0.41
	Factor TIME	p = 0.1995	
	Factor INJLEVEL	p = 0.2717	
	Factors Interaction	p = 0.8819	

5.3 QIF-PPOWER relationship

QIF and PPOWER were significantly correlated before ($r = 0.8830$ $p < 0.0001$) and after ($r = 0.8645$; $p < 0.0001$) the training period. The simple linear regression model showed PPOWER to explain 74.42 % of the variance of QIF.

6. DISCUSSION

Our results show that ACE training has a positive effect on armcrank performance and on the pulmonary and cardiovascular systems of persons with tetraplegia.

6.1 Effect of exercise on functionality

One expected result is the difference in pre-training PPOWER, which is 255% higher in persons with the lower level cervical SCI (C6-C7) than in those with the higher level SCI (C4-C5).

This finding, which seems obvious and is in agreement with other published work (Morgulec, 2005), could explain the different levels of functionality and autonomy in the entire group of participants for whom the lower-level SCI implies lower levels (one third) of autonomy as QIF showed.

Despite the pre-training differences, maximum armcrank power output increased during the 8-week period of ACE training program for all the participants. The average improvement of 36 % for the whole group could be considered notable compared with the 13.7 % reported by McLean and Skinner (1995), and also to the 20.2 % improvement reported by Valent et al. (2009) and the 23.8 % by Di Carlo (1988). Nonetheless, these differences in relative improvements between studies need to be taken with caution because different devices and protocols were used to measure the power output. This improvement in power output would be the result of improved gross mechanical efficiency due to a better arm and shoulder coordination rather than a gain in muscular strength (De Groot et al., 2003; Valent et al., 2009) during the ACE exercise.

Although all participants increased their power output, the QIF score results did not show statistically significant increase in the ability to perform everyday activities. At first sight, these results would seem contrary to the conclusions of other authors such as Gresham et al. (1986) and Anderson et al. (2008) who refer to the QIF scale as “sensitive to the effects of rehabilitation and physical training". Time seems to be essential in this process for the individual to try out such new activities as transfers, dressing, wheelchair mobility, and personal care, which require broader ranges or new patterns of movement, and eventually attain a higher level of individual autonomy and of functionality as measured by the QIF score. Other authors (Dallmeijer et al., 2001; Dallmeijer, et al., 2004) suggest that increasing the armcrank power output of persons with tetraplegia could well be related to improvement in their functional abilities and increased individual autonomy. In fact, in agreement with the conclusions of Anderson et al. (2008), there were significant differences in QIF scores between the two groups with different cervical SCI levels. As lower SCI level participants had higher QIF scores than the higher SCI level participants, we hypothesize that functionality could probably be improved if the increased power output could be applied to the daily life abilities. However, it would be necessary to try to change person's habits, for which it would probably be necessary more than 8 weeks to perform new activities of daily life. All these improvements should positively affect their quality of life in different areas (Giacobbi et al., 2008).

The preliminary results of this work showed that that an 8-week ACE training program can increase exercise capacity in persons with SCI. However, although all participants increased their power output, the findings in the QIF showed no scores representing a statistically significant increase in the ability to carry out daily life activities (Brizuela et al., 2010), counteracting Gresham et al., (1986) conclusions, who considers that as with any new functional assessment instrument, the merits of the QIF should be determined in the areas of validity, viability, acceptability, sensitivity and reliability. Gresham et al., (1986) and Anderson et al.,(2008) state that QIF appears to be useful for monitoring the functional progress of people with cervical SCI, and also demonstrated that it allows to evaluate the effectiveness of rehabilitation in neurologically stable patients and as a result measure in clinical trials similar to that performed in this work. In general, the conclusions of Gresham et al., (1986) and Anderson et al., (2008) indicate that QIF appears to be specifically useful for assessing the activities of daily life.

In reference to the above, and based on the preliminary results obtained with the same patients in this study and published by Brizuela et al., (2010), a factor that could be fundamental in this process is the time that the individual has to apply such strength gains to activities of daily living, and in this way be able to test new activities of personal care, such as dressing or showering, and mobility, such as getting around in wheelchairs, or even, eventually, achieve greater level of autonomy and individual functionality as measured by the QIF. For this reason, a longer intervention or a late post-training measurement may be necessary to observe significant improvements in this variable.

6.2 Effect of exercise on respiratory system

The fact that Lower SCI group showed higher measured values of VC, FVC and MVV than Higher SCI group, in the pre-training situation, may reflect the different functional levels of the respiratory muscles (Figure 4).

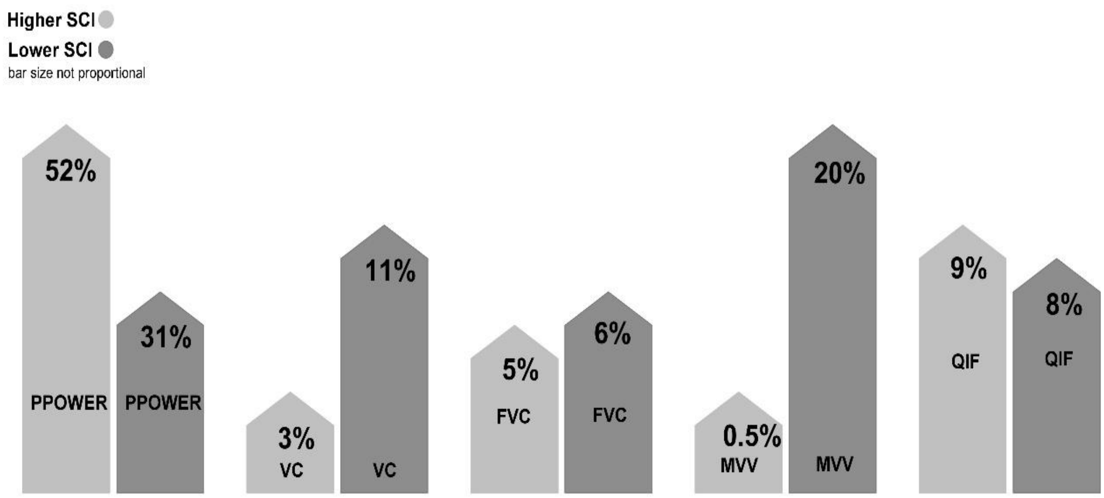

Figure 4. Improvement of functional and pulmonary variables.

The spirometric results also show that after the period of ACE training there is a significant increase in MVV, a variable that has been shown to be afected in neuromuscular disorders (Linn et al., 2001; Rochester & Esau, 1994; Rutchik et al., 1998; Tow et al., 2001). That is probably due to the general increase of function of some skeletal muscles that are involved in respiration. Nevertheless, more insight into the function of respiratory muscles might be gained from measuring inspiratory and expiratory pressures, since these are strongly affected in cervical SCI and would hence probably show greater improvement than volumes after a period of training. Our results are in agreement with Valent et al. (2009) who detected no increases in FVC (they did not report measurements of VC) but contrary to those of Crane et al. (1994) who reported improvements in FVC for trained persons with tetraplegia. This latter discrepancy could be because in the Crane et al. (1994), the participants were trained persons.

The bars in the figure 5 indicate the increase of HRV between “Higher” and “Lower” SCI groups, pre- and post-training. Based on our findings in a small group of novice exercisers where the “Lower” SCI group improved significantly MVV compared to the “Higher” SCI group it appears that persons with lower level cervical SCI may have greater pulmonary adaptations to ACE training than persons with higher level SCI. This difference should be taken into account when programming exercise training and evaluating performance and also when studying epidemiology or respiratory processes in cervical SCI.

6.3 Effect of exercise on HRV

The lack of differences found in our study when comparing HRV between “Higher” and “Lower” level of cervical SCI, may support the hypothesis that both groups have the same degree of lesion to the descending sympathoadrenal pathway (Figure 5). However, participants of both groups have intact vagal afferent and efferent pathways. HRV has been used to know the level at which persons with SCI are affected by the loss of autonomic balance and some authors found differences in baseline LF component when comparing persons with tetraplegia and paraplegia with persons without SCI (Bunten et al., 1998); however, other authors did not find differences in LF component nor in HF (Takahashi et al. 2007). However, other authors such as Ditor et al., (2005), found a significant reduction inthe LF/HF ratio, resulting from a significant decrease in power in LF and a non-significant increase in power in HF.

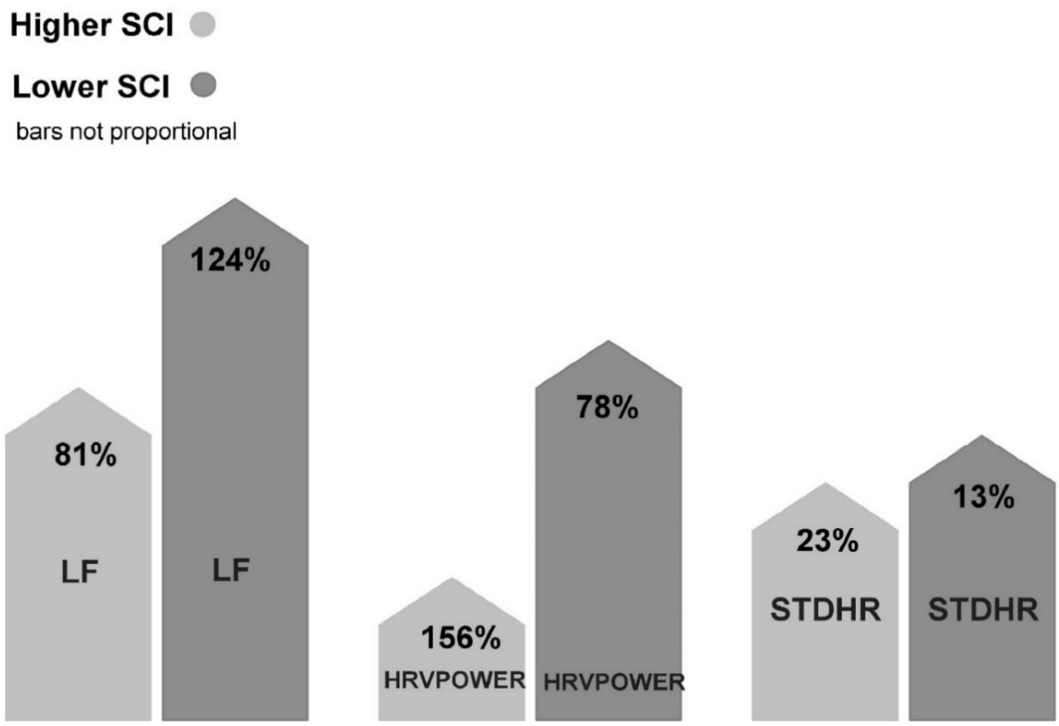

Figure 5. Improvement of HRV variables.

Interestingly, the preliminary results published by Brizuela et al., (2010) show a concomitant increase in spectral power in LF and HF, while previous studies, such as Ditor et al., (2005), unanimously show a reduction in power in LF after different physical activity programs. In the case of people without IBS, the increase in LF power together with an increase in the LF / HF ratio could generally be explained by an increase in the activity of the friendly branch (Task Force, 1996). However, because people with tetraplegia are deprived of friendly efferent innervation in the cardiovascular system, changes in the components of the HRV LF may also be regulated by the parasympathetic branch in this population (Takahashi et al., 2007). Based on this theory, it could be stated that the increase in LF and HF was due in both cases to an improvement in the vagal modulation of HR dynamics.

All the autonomic differences could explain why heart rate response to acute exercise is altered in persons with SCI. Neither heart rate increase at the onset of exercise, nor peak heart rate during several exercise modes is as high as in persons without SCI (Di Carlo, 1988; Takahashi et al., 2004). More research is needed to fully describe the effect of prolonged exercise on this balance, mainly the HRV.

Baseline values of HRV obtained in this study are similar to other data published with persons with cervical SCI (La Fountaine, Wecht, Spungen & Bauman, 2010; Millar et al., 2009; Takahashi et al., 2007; Wecht, Weir, & Bauman, 2006). The main finding of the present study is that eight weeks of ACE training for persons with SCI are sufficient to significantly improve overall HRV, measured in the frequency domain (HRVPOWER and LF). Our findings partially differ from previously reported studies. The disagreement with the Millar et al. (2009) study could be because all our participants had a cervical SCI between C4 and C6, whereas their sample was fairly heterogeneous (SCI between C5 and T10). Our different mode of exercise, together with our longer treatment (16 vs 12 training sessions, 8 vs 4 weeks), may explains the reason because they did not find significant difference in any linear nor frequency domain HRV index, while we did (although they found a trend to increase HF). In addition, the Ditor et al. (2005) study was of a small, heterogeneous sample (6 subjects, C4-T12), and this might have precluded them from finding statistically significant changes in their HRV measurements. Indeed, when they grouped the participants according to their HR response to ambulatory ability, the data suggested a selective, although not statistically significant, training-induced decrease in the LF/HF ratio for responders (i.e., those who showed a greater HR response to ambulation).

Interestingly, our results showed increases in LF, whereas previous studies have been unanimous in reporting no changes or a reduction in LF power after training (Ditor et al., 2005a; Ditor et al., 2005b; Millar et al., 2009). Although such an increase in LF power would be attributable to an enhancement of sympathetic activity in non-SCI persons (Task Force, 1996), taking into account that persons with tetraplegia are deprived of neural sympathetic efferent innervation to the cardiovascular system (Bunten et al., 1998; Grimm et al., 1997), we suggest that the rise in the LF component of HRV could be produced mainly by parasympathetic and not by sympathetic outflow, as previously suggested (Takahashi et al. 2007). LF increases of the participants of our study would then probably due to an enhancement in vagal modulation of HR dynamics.

The increased HRV after the period of ACE training is especially interesting if we take into account that HRV has been inversely or directly related to a variety of clinical conditions, such as age, inflammatory status, low serum potassium, diabetes mellitus, renal dysfunction, coronary artery disease and specially heart failure, which is most significantly associated with decreased HRV (Almoznino-Sarafian et al., 2009). If we take into account that persons with SCI have autonomic dysfunction and increased risk of cardiovascular disease (Claydon & Krassioukov, 2008; Garshick et al., 2005; Myers, Lee & Kiratli, 2007) our results would be especially relevant to conserve cardiovascular function in persons with SCI, even in those with higher cervical SCI, and even without any improvement on daily functionality.

7. CONCLUSIONS

In the present study, each of the objectives set was met. Arm pedaling exercise was shown to have a positive effect on the physiological response of people with tetraplegia.

The changes in PPOWER before and after practicing an arm-crank exercise program in persons with tetraplegia indicate that arm's peak power output increased 36% over the 8-week period of the ACE training program for all participants.

Significant changes were found in respiratory parameters after practicing an arm-crank exercise program. All participants' respiratory parameters improved after the 8-week intervention. The SCI group showed higher measured values of VC, FVC and MVV than Higher SCI group, in the pre-training situation. This may reflect the different functional levels of the respiratory muscles.

Resting HRV values in persons with tetraplegia were shown to be different from values after ACE program. LF showed significant increases after the ACE program (81% for the highest SCI and 124% for the lowest SCI). Neither heart rate increases at the onset of exercise, nor peak heart rate during several exercise modes is as high as in persons without SCI. More research is needed to fully describe the effect of prolonged exercise on this balance, mainly the HRV.

In relation to functionality, it was concluded that persons with high-level SCI retain the ability to make positive adaptations in autonomous heart function and respiratory function in response to an ACE training period, even though there is no immediate improvement in their daily functionality. The levels of functionality and autonomy in participants with "Lower" SCI are lower (one third) than those found in participants with "Higher" SCI as demonstrated in the QIF.

7.1. Recommendations

Based on our findings in a small sample of participants stationary ACE training appears a safe and effective method to practice healthy aerobic exercise in persons with tetraplegia. Beginners, persons with the lowest physical capacities, and especially vulnerable participants should be supervised by skilled professionals who need to carefully monitor and adjust the loads (volume and intensity of the work) to the individual's capacities. In addition, as training advances, it is highly recommendable to motivate the subjects to overcome their individual and previous physical limits, and to attempt to improve their fitness in order to avoid health problems and enlarge their quality of life. Finally, it must be taken into account that this kind of exercise could represent a first step on the path to using a real handcycle as a daily mobility device, with the consequent gain of even a small amount of independence.

7.2. Limitations of the study and future research

More insight into the function of respiratory muscles might be gained from measuring inspiratory and expiratory pressures, since these are strongly affected in cervical SCI and would hence probably show greater improvement than volumes after a period of training.

Due to the small sample size it is also necessary to conduct similar research with a larger sample of persons with tetraplegia in order to analyze the effect of this kind of exercise on a broader spectrum of this population, classifying the participants by different levels of SCI, age, age of injury, gender, and other individual characteristics.

Very little information exists about the long-term effects of armcrank pedaling training in persons with SCI, and especially in those with tetraplegia, possibly because this activity is relatively novel.

8. SCIENTIFIC AND SOCIAL CONTRIBUTIONS

8.1 Scientific contributions

- **First contribution: Publication of partial data at 2010 in the Ricyde journal: Brizuela, G.; Sinz, S.; Aranda, R.; Martínez, I. (2010). Efecto del pedaleo de brazos sobre el sistema cardiorrespiratorio de las personas con tetraplejia. Ricyde. 21, 6: 297-310.**

Ricyde is an International Journal of Sports Sciences, a periodical with the aim of publishing only original works that help to deepen the various dimensions of physical activity and sports sciences.

The article was written in an initial phase of the project, very motivated by the good results of the participants and with great enthusiasm to move forward. It was a great motivation to see our first article accepted so quickly.

- **Second contribution: Participation in the annual congress of the European College of Sport Science (ECSS) at 2016: "Crossing Borders Through Sport Science".**

I made the choice of going to the ECSS congress 2016 because of my love for this very well organized event since my participation as student volunteer when my University hosted this congress in Cologne 2004.

The ECSS congresses are immensely rich in content, thematically exhaustingly informative, exiting and very interesting.

During the four congress days, I emerged fully into the congress topics. I found so many topics of my interest that I had difficulties to schedule all the events in my day. I found the organization of rooms slightly challenging and too many topics running parallel, so searching for the rooms I missed some bits of the content. However, the selection of content was magnificent and I found myself asking questions during the sessions and participated in discussions where I felt my opinion seen and accepted.

I learned a lot about the latest investigation tendencies, got to know colleagues, had interesting discussions and was very motivated to continue my work. I very much recommend the yearly ECSS congresses as the scientific qualification of the participants is a set point, Europe wide and worldwide.

- **Third contribution: Poster presentation in the annual congress of the European College of Sport Science (ECSS) at 2016 "Crossing Borders Through Sport Science":** "**Effect Of A Stationary Armcrank Pedaling Training Program On The Level Of Autonomy, Anaerobic Performance, Spirometric Function And Heart Rate Variability In Persons With Tetraplegia".**

The poster presentations were well-organized, scheduled 2min mini presentation with 2min questions afterwards. Everyone interested was standing around the presenter and his/her poster in a small circle.

During previous poster presentations, I found myself helping some colleagues from china with English language difficulties to make their speech easier understandable by asking directed questions. I also had made myself visible during the sessions by asking questions and participation in discussions.

My Poster had a good design, caught attention and brought a lot of attendance to the presentation. My speech was well accepted. In the question part, a discussion came up about "the impact on society we would wish this project to have".

We would wish to draw attention to the problem of lack of sports facilities accessible to persons with tetraplegia with high lesion levels. In addition, to the lack of knowledge that such training could help them improve their lives and wellbeing nevertheless their high lesion level.

Participating for me was a very motivating and positive experience and it brought us the interest of several magazine publishers' one of which published our article in 2019.

- **Fourth contribution: Publication of abstract in the annual congress of the European College of Sport Science (ECSS) at 2016**: **"Effect Of A Stationary Armcrank Pedaling Training Program On The Level Of Autonomy, Anaerobic Performance, Spirometric Function And Heart Rate Variability In Persons With Tetraplegia".**

At each congress, part of the application process for presentations is to hand in an abstract of your project. The ECSS publishes all abstracts in a “book of abstracts” which can be purchased during the event. It helps to look up fellow researchers and their projects during and after the congress. It is read by publishers who are interested in contacting with authors. Furthermore, the abstract can now also can be cited, as the book of abstracts is a published work.

- **Fith contribution: Participation in the Cell Symposia 2017 in Gothenburg: “Exercise Metabolism”.**

The choice of attending “Cell Symposia” was due to strong interests I have in muscle cell physiology, what happens in the cell during exercise.

The Congress Cell Symposia in Gothenburg was the perfect fusion of what I´ve done so far with what I wished to do in the future. It was all about adaptive processes to training – from a medical perspective.

I attended each of the three conference days fully and with great joy. The first day, at the beginning, the topics seemed difficult to follow but by the end of the first day, I had gotten used to the new medical expressions and the frequent exposition of photos of de-sectioned mice. On the second day, I especially enjoyed the session of Luc van Loon from Maastricht University, Netherlands about Skeletal muscle conditioning to anabolic stimuli. Luckily, on the last day, we were placed on the same table at lunch and I was able to speak to him for a while. I also spoke a longer time to Francesca Amati from Universite de Lausanne, Switzerland. The lunch event was very inviting and held in a fish museum, which made getting in touch with people very easy. Overall, the congress setting was great.

I wanted to get to know the latest tendencies of this area of expertise and the people working in it and this congress fulfilled all those expectations. I would very much like to attend another likewise congress to freshen up contacts in the future.

- **Sixth contribution: Presentation of poster in the Cell Symposia 2017 in Gothenburg: “Tetraplegia: Adaptive response to stationary**

armcrank pedaling exercise, comparing different lesion levels in persons with a tetraplegia".

With the experience of the ECSS congress, for Cell Symposia my focus of our study was to compare the impact of the exercise on the group with the lower lesion vs the group with the higher lesion, so I could point out that nevertheless (or even though) the higher lesion, the benefits of physical activity are still very relevant. Therefore, in my application for the poster presentation I choose the title, "tetraplegia: Adaptive response to stationary arm crank pedaling exercise – comparing different lesion levels in persons with tetraplegia".

Participating for me was a very motivating but the concept of how the poster presentations were organized was not good and only well know investigations were discussed.

I hardly reached interest for my poster. In the end, I was happy to have participated though also a little bit disappointed and would prefer to "only participate" next time and concentrate on taking in information and making contacts.

- **Seventh contribution: Publication of the final results in the European Journal of Sport Science 2019: Brizuela, G.; Sinz, S.; Aranda, R.; Martínez, I. (2019). The effect of arm-crank exercise training on power output, spirometry and cardiac function and level of autonomy in persons with tetraplegia. European Journal of Sport Science. DOI: 10.1080/17461391.2019.1674927**

The article was published on the ECSS 2016 Vienna. The European Journal of Sport Science (EJSS) is the official Medline – and Impact Factor–listed journal of the European College of Sport Science. The editorial policy of the Journal pursues the multi-disciplinary aims of the College: to promote the highest standards of scientific study and scholarship on respect of the following fields: (a) Applied Sport Sciences; (b) Biomechanics and Motor Control; (c) Physiology and Nutrition; (d) Psychology, Social Sciences and Humanities and € Sports and Exercise Medicine and Health. The Journal also aims to facilitate and enhance communication across all sub disciplines of the sport sciences.

It´s a blessing to see our study concluded with this article publication and soon my final thesis hand in.

8.2 Social contributions

In this moment that I close the memory of my doctoral thesis project, it is May 2021 and a lot of time has passed since our initial study in 2009, which is the one I described above. A lot has happened in the meantime…

Our study participants were very delighted by what they had experienced and pressure was high on our professor to continue the project in some way, which he did, for some time, in the laboratory-gym at the Faculty.

Word by mouth brought us more and more people interested and each of them had different impairments. Now it was interesting if our findings of cardiorespiratory and muscular improvements to the physical fitness of persons with a high lesion could translate in the same way to other types of disability. Would everyone have improvement in his/her daily life activities and personal autonomy?

This motivated our experimental tetraplegic gym to continue with a follow up study with a much larger number of participants and not only persons with a tetraplejia due to medular lesion, but with other physical deficiencies. This was the beginning of a project named TETRASPORT.

The objectives of this new project were:

- To analyze the long time efect of physical exercise as it is handcrank ergometer cycling, muscular training and flexibility exercises on the health and personal autonomy of the participants,
- Develop a training schedule of physical exercises which can be aported to gyms and municipal sports centers which show interest and wish to offer this kind of activities.

The offer

What initially had started as an offer of physical activity only for persons with a tetraplegia then incorporated persons with different kind of impairment, mainly of the nervous system, like cerebral palsy, cerebellar ataxias, multiplesclerosis and neuromuscular disorders. In the end we were able to include everyone who had suffered cerebrovascular accidents.

First, an experimental gym was installed, starting with the study participants, then more people were added, then children with different types of affectation ... not only spinal cord injury, but also cerebral palsy, spina bifida and other neuromuscular affectations.

Our equipment remained simple, the most important being a handcycle, complemented by a variety of ordinary gym equipment, adapted to the needs of the persons with discapacities with unsofisticated material like anklets and rubber bands. Inexpensive ordinary gym equipment that can be easily used in many cases are dumbbells o weighted wristbands.

The fundamental exercise was ACE, static handcycling with an adapted bicyle indoors which was combined with muscle strength training with elastic bands, alternated with mat exercises and movement video games for exercises for muscle strengthening, flexibility, coordinacion and agility. Everything adapted to the initial condition of the person, his/her body composition and disability level additionally to the training objectives he/she wishes to achieve.

In regard to training frequency we took the general recommendation of initial training intervals of 60 to 90 minutes, twice or three times per week. Progressively the frequency of training can be altered to three or four times per week, alternating the kind of exercises in each training intervall.

Handbike rides outdoors complemented the activities, for which we dispose of different types of bicycles like tricycles and handbikes which adapt to the interests, likes and needs of the participants. The more consistency and fun, the quicker the success would show.

Complementary to the gym activity the group integration of persons with disability was fomented with activities of social or playful character: these are musical activities, group excursions, video game championships, Adapted Chi-kung, Quad-Rugby, bicycle excursions to the old trainlines of Valencia, education about nutrition, and many more. Every new activity is an incentive for the clients to remain hooked to the basic activity in the gym, which is the one that apports the most to his/her physical fitness and well being.

The gym we want to count on needs to be spacious regarding it´s floor dimensions and wheelchair accessibility, because many of the clients come in wheelchair and mostly in an electric one, which has even larger dimensions.

It is important to work with specialists of sports science, oriented towards adapted physical activity and multidisciplinary with physiotherapists oriented towards functionality. The attention to each client results slightly increased compared ordinary gyms. Additionally to basic assistance and individualized correction of the exercises it is recomendable to do valorations at the beginning and in defined time intervals adapting the training this way to the characteristics, necessities and objectives of each individual.

The excellent results obtained motivated to the foundation of Tetrasport Association in 2011, a non-profit association of public utility. It was created to promote adapted physical activity and to offer this type of service. TetraSport is born under the wings of the University of Valencia but with complete autonomy. The directory is formed of the very same participants of our inicial study who organized and given their knowledge, their workforce and experience of different areas to create this organization.

As a subsequent step was a contract between TetraSport Association and the university of Valencia, who offered facilities and workers (professors, students in practices, etc. In this way the incorporation of professors and investigators of different departments and different faculties, sports science, physiotherapy, psychology, sociology, etc… everything around Adapted Physical Activity.

As the number of participants was raising quickly, Tetrasport is in constant search to finding a place of mayor dimensions that´s payable or to amplify it´s services to different neighborhood areas in Valencia. The “how and where isn´t easy to manage”. Renting a commercial space big enough to install all gym activities there failed, due to the elevated costs and missing incoming finances.

At present Tetrasport has amplified it´s activities by installing in few facilities belonging to the Foundation “Deportiva Municipal”, of Valencia townhall. It´s opening was welcomed by a great number of persons with different type of disability who started to enjoy the benefits of sports practice now on a regular basis. We are in constant search of new accessible spaces allover Valencia and other different Spanish and European cities.

Nevertheless, national and international legislation protects the right of persons with disability to enjoy physical activity and sports; strict compliance is still missing as well concerning universal accessibility as well as actual offers of sports or physical activity for everyone. It´s incredible, but up to today there is NO offer of health promoting physical activity for persons with disability of high level, not on a private nor public level.

Public entities as well as private providers should support or create projects like ours; because the proof is, society needs it! The weekly increasing number of persons who wish to participate demonstrates the demand of such an offer. More publications and more voice are necessary, to increase public awareness and governmental support, in order to actually give Adapted physical activity the importance that it has.

This interesting perspective for professionals of sports science needs your support!

9. REFERENCES

Acevedo González, J., Fernando Varón, L., Berbeo Calderón, ME., Feo Lee, O., & Diaz Orduz, R. (2008). Pathological advances for understanding traumatic spinal injury. Bibliographical review. Rev Col Or Tra. 22 (4):272-81.

Akkurt, H., Karapolat, H. U., Kirazli, Y., & Kose, T. (2017). The effects of upper extremity aerobic exercise in patients with spinal cord injury: a randomized controlled study. European journal of physical and rehabilitation medicine, 53(2), 219–227.

Alexander, M. S., Rosen, R. C., Steinberg, S., Symonds, T., Haughie, S., & Hultling, C. (2011). Sildenafil in women with sexual arousal disorder following spinal cord injury. Spinal cord, 49(2), 273–279.

Alizadeh, A., Dyck, S. M., & Karimi-Abdolrezaee, S. (2019). Traumatic Spinal Cord Injury: An Overview of Pathophysiology, Models and Acute Injury Mechanisms. Frontiers in neurology, 10, 282.

American College of Sports Medicine ACSM Position stand on exercise and physical activity for older adults. (2009). Med Sie Sports Exerc.

American Spinal Injury Association/International Medical Society of Paraplegia (ASIA/IMSOP). (1992). International Standards for Neurological and Functional Classification of Spinal Cord Injury Patients, 1992 Revision. Chicago, IL: American Spinal Injury Association.

Anderson K., Aito S., Atkins M., Biering-Sorensen F., Charlifue S., Curt A., Ditunno J., Glass C., Marino R., Marshall R., Mulcahey M.J., Post M., Savic G., Scivoletto G., and Catz A. (2008) Functional recovery measures for spinal cord injury: an evidence-based review for clinical practice and research. J Spinal Cord Med 31: 133-144.

Arroyo, O. (2011). Sports medical classifications. In Book of Acts of the 49th Congress of the Spanish Society of Physical Medicine and Rehabilitation (SERMEF). Toledo: SERMEF. 13-15.

Bach, J. R. (2006). Prevention of respiratory complications of spinal cord injury: a challenge to “model” spinal cord injury units. The journal of spinal cord medicine, 29 (1): 3-4.

Bangsbo, J., Blackwell, J., Boraxbekk, C. J., Caserotti, P., Dela, F., Evans, A. B., Jespersen, A. P., Gliemann, L., Kramer, A. F., Lundbye-Jensen, J., Mortensen, E. L., Lassen, A. J., Gow, A. J., Harridge, S., Hellsten, Y., Kjaer, M., Kujala, U. M., Rhodes, R. E., Pike, E., Skinner, T., Viña, J. (2019). Copenhagen Consensus statement 2019: physical activity and ageing. British journal of sports medicine, 53(14), 856–858.

Behrman, A. L., Ardolino, E. M., & Harkema, S. J. (2017). Activity-Based Therapy: From Basic Science to Clinical Application for Recovery After Spinal Cord Injury. Journal of neurologic physical therapy: JNPT, 41 Suppl. 3 (Suppl. 3 IV STEP Spec Iss), S39–S45.

Boese, C. K., & Lechler, P. (2013). Spinal cord injury without radiologic abnormalities in adults: a systematic review. The journal of trauma and acute care surgery, 75(2), 320–330.

Boland, R. A., Lin, C. S., Engel, S., & Kiernan, M. C. (2011). Adaptation of motor function after spinal cord injury: novel insights into spinal shock. Brain: a journal of neurology, 134(Pt 2), 495–505.

Boleaga, B. (2007). Indications of imaging studies in cervical trauma. Ortho-tips Vol. 3 No. 3.

Boorman, G. I., Hoffer, J. A., Kallesoe, K., Viberg, D., & Mah, C. (1996). A measure of peripheral nerve stimulation efficacy applicable to H-reflex studies. The Canadian journal of neurological sciences. Le journal canadien des sciences neurologiques, 23(4), 264–270.

Brackett, N. L., Ibrahim, E., Krassioukov, A., & Lynne, C. M. (2007). Systemic naloxone infusion may trigger spasticity in patients with spinal cord injury: case series. The journal of spinal cord medicine, 30(3), 272–275.

Braye, S., Dixon, K. y Gibbons, T. (2013). “A mockery of equality”: an exploratory investigation into disabled activists’ views of the Paralympic Games. Disability & Society, 28(7), 984–996.

Brenes, Y. (2016). Acute spinal cord injuries. Medical Journal of Costa Rica and Central America LXXIII, (620) 645 – 652.

Brizuela, G., Sinz, S., Aranda, R., Martínez, I. (2010). Efecto del pedaleo de brazos sobre el Sistema cardiorrespiratorio de las personas con tetraplejia. Ricyde. 21, 6: 297-310.

Brizuela, G., Romero, J., Beltrán, J. (2016). Spinal cord injury and physical exercise: review from a sports perspective. Revista Española de Discapacidad, 4 (2): 163-185. Revista Internacional de Ciencias del Deporte, 21(6), 297- 310.

Brizuela, G., Sinz, S., Aranda, R., Martínez, I. (2019). The effect of arm-crank exercise training on power output, spirometric and cardiac function and level of autonomy in persons with tetraplegia. European Journal of Sport Science.

Burke, D. (1985). Mechanisms underlying the tendon jerk and H-reflex. In: P.J. Delwaide and R.R. Young, (eds). Clinical Neurophysiology in spasticity. Amsterdam: Elsevier, pp. 55-62.

Burke, D., Hagbarth, K. E., Löfstedt, L., & Wallin, B. G. (1976). The responses of human muscle spindle endings to vibration during isometric contraction. The Journal of physiology, 261(3), 695–711.

De Vrles, H. A (1968). Efficiency of electrical activity as a measure of the functional state of muscle tissue".Am. J. Phys. Med. 47, pp. 10-22.

Enoka, R. M. (1988). Muscle strength and its development: New perspectives. Sports. Med. 6, pp. 146-168.

Hood-John, M., Bennasar-Veny, M., Aguiló-Pons, A., & de Pedro-Gómez, J. (2017). Review of generic aspects about adapted physical activity in the person with spinal cord injury. Arch Med Sport, 34(2):100-104.

Hood-John, MA. (2016). Effectiveness of educational-therapeutic programs in physiotherapy. Rev Soc Esp Pain. 23(3):153-7.

Calancie, B., Broton, JG., Klose, KJ., & Traad, M. (1993). Evidence that alterations in presynaptic inhibition contribute to segmental hypo- and hyperexcitability after spinal cord injury in man. Electroencephalogr Clin Neurophysiol. 1993 Jun;89(3):177-86.

Castillo, J., & Tapia, C. (2012). Sexuality after spinal cord injury: characterization of the male population treated at the Hospital del Trabajador, Santiago, Chile. Rev Col Med Fis Rehab, 22(1): 32-43.

Clemente, CD. (1978). Neurophysiologic mechanisms and neuroanatomic substrates related to spasticity. Neurology, 28: 40-45.

Crane L., Klerk K., Ruhl A., Warner P., Ruhl C., & Roach K.E. (1994). The effect of exercise training on pulmonary function in persons with quadriplegia. Paraplegia 32: 435-441.

Crone, C., Nielsen, J., Petersen, N., Ballegaard, M., & Hultborn, H. (1994). Disynaptic reciprocal inhibition of ankle extensors in spastic patients. Brain: a journal of neurology, 117 (Pt 5), 1161–1168.

Chan, C. W., Eng, J. J., Tator, C. H., Krassioukov, A., & Spinal Cord Injury Research Evidence Team (2016). Epidemiology of sport-related spinal cord injuries: A systematic review. The journal of spinal cord medicine, 39(3), 255–264.

Chicharro, J., & Mojares,L. (2008). Exercise Physiology. Pan American Publishing House.

Dallmeijer A.J. and van der Woude L.H. (2001). Health related functional status in men with spinal cord injury: relationship with lesion level and endurance capacity. Spinal Cord 39: 577-583.

Dallmeijer, A.J., Zentgraaff, I.D., Zijp, N.I., & van der Woude, L.H. (2004). Submaximal physical strain and peak performance in handcycling versus handrim wheelchair propulsion. Spinal Cord, 42(2), 91-98.

Dave S & Cho JJ. (2020). Neurogenic Shock. [Updated 2020 Mar 28]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing.

Deforge, D., Blackmer, J., Moher, D., Garritty, C., Cronin, V., Yazdi, F., Barrowman, N., Mamaladze, V., Zhang, L., & Sampson, M. (2004).

Sexuality and reproductive health following spinal cord injury. Evidence report/technology assessment (Summary), (109), 1–8.

De Groot P.C., Hjeltnes N., Heijboer A.C., Stal W., and Birkeland K. (2003). Effect of training intensity on physical capacity, lipid profile and insulin sensitivity in early rehabilitation of spinal cord injured individuals. Spinal Cord 41: 673-679.

Delwaide, P. J., Pepin, J. L., & Maertens de Noordhout, A. (1993). Contribution of reticular nuclei to the pathophysiology of parkinsonian rigidity. Advances in neurology, 60, 381–385.

DePauw K. P. & Doll Tepper G. (1989). European perspectives on adapted physical activity. Adapted Physical Activity Quarterly, 6 (2), 95-99.

DePauw, K. P. & Gavron S. J. (2005). Disability sport (2nd ed.). Champaign, IL: Human Kinetics.

DeVivo, MJ., Go, BK., & Jackson, AB. (2002). Overview of the national spinal cord injury statistical center database. J Spinal Cord Med, 25 (4): 335-8.

DiCarlo S.E. (1988). Effect of arm ergometry training on wheelchair propulsion endurance of individuals with quadriplegia. Phys Ther 68: 40-44.

Dietz, V. (2007). Spastic movement disorder: impaired reflex function and altered muscle mechanics. Lancet Neurol. 6: 725-733.

Ditor, D.S.; Kamath, M.V.; MacDonald, M.J.; Bugaresti, J.; McCartney, N.; Hicks, A.L. (2005). Reproducibility of heart rate variability and blood pressure variability in individuals with spinal cord injury. Clin Auton Res. 15: 387–393.

Ditor, D.S., Kamath, M V., MacDonald, M J., Bugaresti, J., McCartney, N., & Hicks, A L. (2005). Effects of body weight-supported treadmill training on heart rate variability and blood pressure variability in individuals with spinal cord injury. Journal of Applied Physiology, 98(4), 1519.

Eitivipart, A. C., de Oliveira, C. Q., Arora, M., Middleton, J., & Davis, G. M. (2019). Overview of Systematic Reviews of Aerobic Fitness and Muscle

Strength Training after Spinal Cord Injury. Journal of neurotrauma, 36(21), 2943–2963.

Elbasiouny, S. M., Moroz, D., Bakr, M. M., & Mushahwar, V. K. (2010). Management of spasticity after spinal cord injury: current techniques and future directions. Neurorehabilitation and neural repair, 24(1), 23–33.

Erickson, K. I., Leckie, R. L., & Weinstein, A. M. (2014). Physical activity, fitness, and gray matter volume. Neurobiology of aging, 35 Suppl 2, S20–S28.

Expensive, A. T. et al. (2002). Respiratory physiotherapy protocol in the spinal spinal spinal cord injured. Physiotherapy, 24 (4): 181-189.

Fawcett, J. W., Curt, A., Steeves, J. D., Coleman, W. P., Tuszynski, M. H., Lammertse, D., Bartlett, P. F., Blight, A. R., Dietz, V., Ditunno, J., Dobkin, B. H., Havton, L. A., Ellaway, P. H., Fehlings, M. G., Privat, A., Grossman, R., Guest, J. D., Kleitman, N., Nakamura, M., Gaviria, M., … Short, D. (2007). Guidelines for the conduct of clinical trials for spinal cord injury as developed by the ICCP panel: spontaneous recovery after spinal cord injury and statistical power needed for therapeutic clinical trials. *Spinal cord*, *45*(3), 190–205.

Ferrante, C. (2014). Body, disability and stigma at the origin of the adapted sports field of the City of Buenos Aires, 1950-1961: a mere internalization of a devalued identity? História, Ciancias, Saúde – Manguinhos, Rio de Janeiro, 21(2), 421–437.

Galea, M. P., Dunlop, S. A., Davis, G. M., Nunn, A., Geraghty, T., Hsueh, Y. S., & Churilov, L. (2013). Intensive exercise program after spinal cord injury ("Full-On"): study protocol for a randomized controlled trial. Trials, 14, 291.

Galvagno, S. M., Jr, Nahmias, J. T., & Young, D. A. (2019). Advanced Trauma Life Support® Update 2019: Management and Applications for Adults and Special Populations. Anesthesiology clinics, 37(1), 13–32.

Giacobbi P.R., Jr., Stancil M., Hardin B., and Bryant L. (2008). Physical activity and quality of life experienced by highly active individuals with physical disability. Adapt Phys Activ Q, 25: 189-207.

Gifre, M., Valle Gómez, A., Yuguero, M., Gil, A., Bosch, PM. (2010). Improving the quality of life of people with spinal cord injuries: The transition from the rehabilitation center to everyday life from the perspective of users. Digital Athena: journal of thought and social research, (18), 3-15.

Gomez-Soriano J, Castellote JM, Perez-Rizo E, Esclarin A and Taylor JS. (2010). "Voluntary ankle flexor activity and adaptive coactivation gain is decreased by spasticity during subacute spinal cord injury." Exp Neurol, 224(2), 507-516.

Gregory, J. (2008). Spinal cord anatomy, localization, and overview of spinal cord syndromes. Continuum: Lifelong Learning Neurol;14(3).

Gresham G.E., Labi M.L., Dittmar S.S., Hicks J.T., Joyce S.Z., and Stehlik M.A. (1986). The Quadriplegia Index of Function (QIF): sensitivity and reliability demonstrated in a study of thirty quadriplegic patients. Paraplegia 24: 38-44.

Hachem, L. D., Ahuja, C. S., & Fehlings, M. G. (2017). Assessment and management of acute spinal cord injury: From point of injury to rehabilitation. The journal of spinal cord medicine, 40(6), 665–675.

Hagen, E. M., Rekand, T., Gilhus, N. E., & Grønning, M. (2012). Traumatic spinal cord injuries--incidence, mechanisms and course. Tidsskrift for den Norske laegeforening: tidsskrift for praktisk medicin, ny raekke, 132(7), 831–837.

Haisma, J. A., van der Woude, L. H., Stam, H. J., Bergen, M. P., Sluis, T. A., & Bussmann, J. B. (2006). Physical capacity in wheelchair-dependent persons with a spinal cord injury: a critical review of the literature. Spinal cord, 44(11), 642–652.

Hakkinen, K. (1994), Neuromuscular adaptation during strength training, aging, detraining, and immobilization. Critical Reviews in Physical and Rehabilitation Medicine. 14 (6), 161-198.

Hayes, K., Hsieh, J., Wolfe, D., Potter, P., Delaney, G. (2000). Classifying incomplete spinal cord injury syndromes: Algorithms based on the International Standards for Neurological and Functional Classification of spinal cord injury patients. Arch Phys Med Rehabil, 81:644-52.

Henao-Lema, CP., & Pérez-Parra, JE. (2010). Spinal cord injuries and disability: bibliographic review. Aquichan, 10(2), 157-172.

Hernandez F. J. (2000). Sport to serve diversity: adapted sport and inclusive sport, Apunts, Physical Education and Sports, (60), 46-53.

Hiersemenzel, L. P., Curt, A., & Dietz, V. (2000). From spinal shock to spasticity: neuronal adaptations to a spinal cord injury. Neurology, 54(8), 1574–1582.

Hickey, JV. (2009). The Clinical Practice of Neurological and Neurosurgical Nursing. 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins.

Holtz, A., & Levi, R. (2010). Spinal Cord Injury. New York: Oxford University Press.

Hopman, M. T., Groothuis, J. T., Flendrie, M., Gerrits, K. H., & Houtman, S. (2002). Increased vascular resistance in paralyzed legs after spinal cord injury is reversible by training. Journal of applied physiology (Bethesda, Md.: 1985), 93(6), 1966–1972.

Hopman, M. T. et al. (1993). Volume changes in the legs of paraplegic subjects during arm exercise. Journal of Applied Physiology, 75 (5): 2079-2083.

Hopman, M. T. et al. (1994). Properties of the venous vascular system in the lower extremities of individuals with paraplegia. Spinal Cord, 32 (12): 810-816.

Huete Garcia, A. (2013). The exclusion of the population with disability in Spain. Specific study based on the European Social Survey. Spanish Journal of Disability, I(2), 7–24.

Hutzler, Y. (2008). AFA as an evaluation and intervention tool: an IFAPA point of view. In Pérez, J. (coord.), Disability, quality of life and sports physical activity: the current situation looking to the future (pp. 181-207). Madrid: Directorate of General of Sports of the Community of Madrid.

Indakoetxea, M. (2003). Diagnostic protocol of paraplegia and tetraplegia. Medicine - Accredited Continuing Medical Training Program, 8(99), 5359–5361.

Krenz, N. R., & Weaver, L. C. (1998). Sprouting of primary afferent fibers after spinal cord transection in the rat. Neuroscience, 85(2), 443–458.

Komi, P. V. (1986). Training of muscle strength and power: interaction of neuromotoric, Hypertrophic and mechanical factors". Int. 1. Sports Med. (Suppl) 7, pp. 10- 15.

Koyuncu, E., & Ersoz, M. (2017). Monitoring development of autonomic dysreflexia during urodynamic investigation in patients with spinal cord injury. The journal of spinal cord medicine, 40(2), 170–174.

Krassioukov, A., Stillman, M., & Beck, L. (2020). Autonomic dysfunctions after a spinal cord injury: an overview for primary care physicians. Top Spinal Cord Inj Rehabil 26(2):123-127.

Krassioukov, A., Biering-Sorensen, C. F., Donovan, W., Kennelly, M., Kirshblum, S., Krogh, K., Alexander, M. S., Vogel, L., & And Wecht, J. (2012). International Standards to document remaining Autonomic Function after Spinal Cord Injury (ISAFSCI), First Edition 2012. Topics in spinal cord injury rehabilitation, 18(3), 282–296.

Krause, JS., & Broderick, L. (2004). Outcomes after spinal cord injury: comparisons as a function of gender and race and ethnicity. Arch Phys Med Rehabil, 85: 355-62.

La Fountaine, M.F., Wecht, J.M., Spungen, A.M., & Bauman, W.A. (2010). Intra-inter visit reproducibility of short-term linear and nonlinear measurement of heart rate variability in tetraplegia and neurologically intact controls. Physiological Measurement, 31(3), 363-374.

Latella, D., Maggio, M. G., Manuli, A., Militi, D., & Calabrò, R. S. (2019). Sexual dysfunction in male individuals with spinal cord iniury: What do we know so far? Journal of clinical neuroscience: official journal of the Neurosurgical Society of Australasia, 68, 20–27.

Leitón, A., Hu Liang, H., & Ramirez, J. (2015). Benefits of colostomy in the quality of life of the patient with chronic spinal injury and advantages of its realization laparoscopically. UCR School of Medicine Clinical Journal – HSJD, Vol 5 No V.

Lemos, J. R., da Cunha, F. A., Lopes, A. J., Guimarães, F. S., do Amaral Vasconcellos, F. V., & Dos Santos Vigário, P. (2020). Respiratory muscle training in non-athletes and athletes with spinal cord injury: A systematic review of the effects on pulmonary function, respiratory muscle strength and endurance, and cardiorespiratory fitness based on the FITT principle of exercise prescription. Journal of back and musculoskeletal rehabilitation, 33(4), 655–667.

Levi, A. D., Anderson, K. D., Okonkwo, D. O., Park, P., Bryce, T. N., Kurpad, S. N., Aarabi, B., Hsieh, J., & Gant, K. (2019). Clinical Outcomes from a Multi-Center Study of Human Neural Stem Cell Transplantation in Chronic Cervical Spinal Cord Injury. Journal of neurotrauma, 36(6), 891–902.

Li, Y., Harvey, P. J., Li, X., & Bennett, D. J. (2004). Spastic long-lasting reflexes of the chronic spinal rat studied in vitro. Journal of neurophysiology, 91(5), 2236–2246.

Liu, C. C., Theodorou, D. J., Theodorou, S. J., Andre, M. P., Sartoris, D. J., Szollar, S. M., Martin, E. M., & Deftos, L. J. (2000). Quantitative computed tomography in the evaluation of spinal osteoporosis following spinal cord injury. Osteoporosis international: a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA, 11(10), 889–896.

Liu, H. M., Dong, C., Zhang, Y. Z., Tian, Y. Y., Chen, H. X., Zhang, S., Li, N., & Gu, P. (2017). Clinical and imaging features of spinal cord type of neuro Behçet disease: A case report and systematic review. Medicine, 96(40), e7958.

Liu, Z., Yang, Y., He, L., Pang, M., Luo, C., Liu, B., & Rong, L. (2019). High-dose methylprednisolone for acute traumatic spinal cord injury: A meta-analysis. Neurology, 93(9), e841–e850.

Machač, S., Radvanský, J., Kolář, P., & Kříž, J. (2016). Cardiovascular response to peak voluntary exercise in males with cervical spinal cord injury. The journal of spinal cord medicine, 39(4), 412–420.

Magoun, H. W., & Rhines, R. (1946). An inhibitory mechanism in the bulbar reticular formation. Journal of neurophysiology, 9, 165–171.

Maynard, FM., Bracken, MB., Creasey, G., Ditunno, JF., Donovan, WH., Ducker, TB., Garber, SL., Marino, RJ., Stover, SL., Tator, CH., Waters, RL., Wilberger, JE., & Young W. (1997). "International Standards for Neurological and Functional Classification of Spinal Cord Injury. American Spinal Injury Association." Spinal Cord 35(5): 266-274.

Marino, R. J., Huang, M., Knight, P., Herbison, G. J., Ditunno, J. F., Jr, & Segal, M. (1993). Assessing selfcare status in quadriplegia: comparison of the quadriplegia index of function (QIF) and the functional independence measure (FIM). Paraplegia, 31(4), 225–233.

Martínez, P. Y. O. y López, J. A. H. (2014). Importance of physical exercise in the lung capacity of persons with spinal cord injury, a pedagogical proposition through the aquatic environment. Ibero-American Journal of Health Sciences, 3 (5): 1-9.

Matthew, E., & Matthew, M. (2017). Trauma: Spinal Cord Injury. Surg Clin N Am, 97; 1031–1045.

Maupas, E., Marque, P., Roques, C. F., & Simonetta-Moreau, M. (2004). Modulation of the transmission in group II heteronymous pathways by tizanidine in spastic hemiplegic patients. Journal of neurology, neurosurgery, and psychiatry, 75(1), 130–135.

Mazaira, J., Labanda, F., Romero, J., Garcia, ME., Gambarruta, C., & Sanchez, A. (1998). Epidemiology of spinal injury and ortros aspects. Rehabilitation (Madrid), 32: 365-72.

McLean K.P., & Skinner J.S. (1995). Effect of body training position on outcomes of an aerobic training study on individuals with quadriplegia. Arch Phys Med Rehabil 76: 139-150.

Miller M.R., Hankinson J., Brusasco V., Burgos F., Casaburi R., Coates A., Crapo R., Enright P., van der Grinten C.P., Gustafsson P., Jensen R., Johnson D.C., MacIntyre N., McKay R., Navajas D., Pedersen O.F., Pellegrino R., Viegi G., and Wanger J. (2005). Standardisation of spirometry. Eur Respir J 26: 319-338.

Montero-Ordoñez, L., Garcés-Quilambaqui, R., Rivas-Cun, H. (2017). Sports for disabled. An alternative for people with medular injury (part. II). OLYMPIA. Journal of the Faculty of Physical Culture of the University of Granma. Vol.14 No.43,. ISSN: 1817-9088. RNPS: 2067.

Morawietz, C., & Moffat, F. (2013). Effects of locomotor training after incomplete spinal cord injury: a systematic review. Archives of physical medicine and rehabilitation, 94(11), 2297–2308.

Morgulec N., Kosmol A., Vanlandewijck Y., and Hubner-Wozniak E. (2005). Anaerobic performance of active and sedentary male individuals with quadriplegia. Adapted Physical Activity Quarterly 22: 253.

Morltani, T. y DEVRlES, H. A (1979). Neural factors versus hypertrophy in the time course of muscle strength gain. Am. 1. Phys. Med. 58, pp. 115- 130.

Morita, M., Iwasaki, M., Okuda, S., Oda, T., & Miyauchi, A. (2010). Autonomic dysreflexia associated with Charcot spine following spinal cord injury: a case report and literature review. European spine journal: official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society, 19 (Suppl 2), S179–S182.

Moslavac, S., Dzidić, I., Moslavac, A., Vlahek, P., & Filipan, Z. (2014). Urinary tract dysfunction in spinal cord injury patients. Lijecnicki vjesnik, 136(5-6), 147–152.

Mulroy, S. J., Thompson, L., Kemp, B., Hatchett, P. P., Newsam, C. J., Lupold, D. G., Haubert, L. L., Eberly, V., Ge, T. T., Azen, S. P., Winstein, C. J., Gordon, J., & Physical Therapy Clinical Research Network (PTClinResNet) (2011). Strengthening and optimal movements for painful shoulders (STOMPS) in chronic spinal cord injury: a randomized controlled trial. Physical therapy, 91(3), 305–324.

Nardone, A., & Schieppati, M. (2005). Reflex contribution of spindle group Ia and II afferent input to leg muscle spasticity as revealed by tendon vibration in hemiparesis. Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology, 116(6), 1370–1381.

National Institute of Neurological Disorders and Stroke. (2005). Lesión de la médula espinal: esperanza en investigación. Department of Health and Human Services. Bethesda. National Institute of Health Publication. Available in: http://espanol.ninds.nih.gov/trastornos/lesión_de_la_medula_espinal.pdf

Navarro, X. (2009). Neural plasticity age nerve injury and regeneration. International Review of neurobiology. 87:483-505.

Nayduch, DA. (2010). Back to basics: Identifying and managing acute spinal cord injury. Sep;40(9):24-31; quiz 31-2. doi: 10.1097/01.NURSE.0000387151.39750.66. PMID: 20693929.

Nelson, M. E., Rejeski, W. J., Blair, S. N., Duncan, P. W., Judge, J. O., King, A. C., Macera, C. A., & Castaneda-Sceppa, C. (2007). Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. Medicine and science in sports and exercise, 39(8), 1435–1445.

Nielsen, J. B., Petersen, N. T., Crone, C., & Sinkjaer, T. (2005). Stretch reflex regulation in healthy subjects and patients with spasticity. Neuromodulation: journal of the International Neuromodulation Society, 8(1), 49–57.

Nockels R. P. (2001). Nonoperative management of acute spinal cord injury. Spine, 26(24 Suppl), S31–S37.

Of the Rope, R.C., & Vazquez, S.C. (2012). Neurorehabilitation, specific methods and evaluation of treatments. Spain: Editorial Médica Panamericana.

World Health Organization. (2001). International Classification of Functioning, Disability and Health. Geneva, Switzerland. Available in: https://www.imserso.es/InterPresent2/groups/imserso/documents/binario/435cif.pdf

Ovechkin, A. et al. (2010). Evaluation of respiratory muscle activation in individuals with chronic spinal cord injury. Respiratory physiology & neurobiology, 173 (2): 171-178.

Panicker, J. N., Fowler, C. J., & Kessler, T. M. (2015). Lower urinary tract dysfunction in the neurological patient: clinical assessment and management. The Lancet. Neurology, 14(7), 720–732.

Peers, D. (2009). (Dis)empowering Paralympic histories: absent athletes and disabling discourses. Disability & Society, 24(5), 653–665.

Perez, J. (2006). Disability and health, antagonistic? Proposals from physical sports activities. In Jiménez, A. and Atero, C. (eds.) International Physical Activity and Health Days "Ganasalud". Book of Minutes (pp. 396-417). Madrid: Ministry of Sports of the Community of Madrid.

Perez, J. (2003). Research in sports sciences applied to adapted sport. In Martínez, J.O. (ed.) I International Conference on Adapted Sport. Book of Acts (pp. 229-243). Malaga: Andalusian Institute of Sport.

Pérez Tejero, J., Reina Vaíllo, R., Sanz Rivas, D. (2012). The Physical Activity Adapted for people with disability in Spain: scientific perspectives and current application Culture, Science and Sport, vol. 7, No. 21, pp. 213-224.

Pointillart, V., Petitjean, M. E., Wiart, L., Vital, J. M., Lassié, P., Thicoipé, M., & Dabadie, P. (2000). Pharmacological therapy of spinal cord injury during the acute phase. Spinal cord, 38(2), 71–76.

Porth, CM. (2006). Essentials of Pathophysiology. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins.

Quel de Oliveira, C., Refshauge, K., Middleton, J., de Jong, L., & Davis, G. M. (2017). Effects of Activity-Based Therapy Interventions on Mobility, Independence, and Quality of Life for People with Spinal Cord Injuries: A Systematic Review and Meta-Analysis. Journal of neurotrauma, 34(9), 1726–1743.

Queen, R. (2010). Physical activity and sport adapted to the European Higher Education Area. Seville: Wanceulen.

Queen, R. (2014). Inclusion in adapted sport: two sides of the same coin. Psychology, Society, & Education, 6(1), 55–67.

Rémy-Néris, O., Barbeau, H., Daniel, O., Boiteau, F., & Bussel, B. (1999). Effects of intrathecal clonidine injection on spinal reflexes and human locomotion in incomplete paraplegic subjects. Experimental brain research, 129(3), 433–440.

Ritcher, K. J., Adams-Mushett, C., Ferrara, M. S. y McCann, B. C. (1992). Integrated swimming classification: A faulted system. Adapted Physical Activity Quarterly, 9, 5-13.

Rochester D.F., & Esau S.A. (1994). Assessment of ventilatory function in patients with neuromuscular disease. Clin Chest Med 15: 751-763.

Rossignol, S., Schwab, M., Schwartz, M., & Fehlings, M. G. (2007). Spinal cord injury: time to move?. The Journal of neuroscience : the official journal of the Society for Neuroscience, 27(44), 11782–11792.

Rutchik A., Weissman A.R., Almenoff P.L., Spungen A.M., Bauman W.A., & Grimm D.R. (1998). Resistive inspiratory muscle training in subjects with chronic cervical spinal cord injury. Arch Phys Med Rehabil 79: 293-297.

Sanz, D. & Reina, R. (2012). Basics and methodological bases of physical activities and sports adapted for people with disability. Barcelona: Paidotribo.

Segura, J., Martínez-Ferrer, J.O., Guerra, M. and Barnet, S. (2013). Beliefs about social inclusion and adapted sport of athletes, technicians and sports sports federation managers for people with disability. Ibero-American Journal of Exercise and Sport Psychology, 8(1), 120–144.

Sinz, S. (2016). Effect of a stationary armcrank pedaling training program on the level of autonomy, anaerobic performance, spirometric function and heart rate variability in persons with tetraplegia. 21th Annual Congress of the European College of Sport Science. Book of abstracts. ISBN 978-3-9818414-2-8.

Schmidt, O. I., Gahr, R. H., Gosse, A., & Heyde, C. E. (2009). ATLS(R) and damage control in spine trauma. World journal of emergency surgery: WJES, 4, 9.

Sheean, G. (2002). The pathophysiology of spasticity. Eur J Neurol. 9 (Suppl 1): 3–9.

Shepard, M. J., & Bracken, M. B. (1999). Magnetic resonance imaging and neurological recovery in acute spinal cord injury: observations from the National Acute Spinal Cord Injury Study 3. Spinal cord, 37(12), 833–837.

Sherman, S. J., Koshland, G. F., & Laguna, J. F. (2000). Hyper-reflexia without spasticity after unilateral infarct of the medullary pyramid. Journal of the neurological sciences, 175(2), 145–155.

Slater, D., & Meade, M. A. (2004). Participation in recreation and sports for persons with spinal cord injury: review and recommendations. NeuroRehabilitation, 19 (2): 121-129.

Snell, R. (2010). Clinical neuroanatomy. Seventh edition. Wolters Kluwer. Available in: http://med-mu.com/wp-content/uploads/2018/06/Snell-Neuroanatomy-7th-Edition.pdf

Solano, H., & San Roman, A. (2013). Impact of traumatic spinal cord injuries on bladder dynamics: follow-up prospects. Coluna/Column, 12(3), 242-245.

Stampas, A., & Tansey, K. (2014). Spinal Cord Injury Medicine and Rehabilitation. Seminars in Neurology, 34(05), 524–533.

Strassburguer, K., Hernandez, Y., & Barquín E. (2004). Medular Injury: Guide to the integral management of the patient with chronic LM. Association of Paraplegics and People with Great Physical Disability of the Community of Madrid (ASPAYM-Madrid). Available in:

https://www.aspaymmadrid.org/wp-content/uploads/2018/05/guia-manejo-integral-2013.pdf

Takahashi, M.; Matsukawa, K.; Nakamoto, T.; Tsuchimochi, H.; Sakaguchi, A.; Kawaguchi, K.; Onari, K. (2007). Control of heart rate variability by cardiac parasympathetic nerve activity during voluntary static exercise in humans with tetraplegia. Journal of Applied Physiology. 103: 1669–1677.

Tarvainen M.P., Ranta-Aho P.O., and Karjalainen P.A. (2002). An advanced detrending method with application to HRV analysis. IEEE Trans Biomed Eng 49: 172-175.

Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996). Heart rate variability: Standards of measurement, physiological interpretation and clinical use. European Heart Journal. 17: 354-381.

Tikkanen, E., Gustafsson, S., & Ingelsson, E. (2018). Associations of Fitness, Physical Activity, Strength, and Genetic Risk With Cardiovascular Disease: Longitudinal Analyses in the UK Biobank Study. Circulation, 137(24), 2583–2591.

Torralba, MA. (2012). The London Paralympics 2012: The Inclusion Games. Apunts Educ Fís Deportes. 110(4):7-10.

Tow A.M., Graves D.E., & Carter R.E. (2001). Vital capacity in tetraplegics twenty years and beyond. Spinal Cord 39: 139-144.

Tremblay, M. S., Colley, R. C., Saunders, T. J., Healy, G. N., & Owen, N. (2010). Physiological and health implications of a sedentary lifestyle. Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme, 35(6), 725–740.

Tse, C. M., Chisholm, A. E., Lam, T., Eng, J. J., & SCIRE Research Team (2018). A systematic review of the effectiveness of task-specific rehabilitation interventions for improving independent sitting and standing function in spinal cord injury. The journal of spinal cord medicine, 41(3), 254–266.

Tweedy, S.M. & Vanlandewijck, Y. (2010). International Paralympic Committee position stand-background and scientific principles of classification in Paralympic Sport. Br J Sports Med, 45: 259-269.

UNICEF-UN-UNESCO. (2004). Sport. recreation and play. Unicef.

Valent, L. J., Dallmeijer, A. J., Houdijk, H., Slootman, H. J., Janssen, T. W., Post, M. W., et al. (2009). Effects of hand cycle training on physical capacity in individuals with tetraplegia: a clinical trial. Phys Ther, 89(10), 1051-1060.

van der Scheer, J. W., Martin Ginis, K. A., Ditor, D. S., Goosey-Tolfrey, V. L., Hicks, A. L., West, C. R., & Wolfe, D. L. (2017). Effects of exercise on fitness and health of adults with spinal cord injury: A systematic review. Neurology, 89(7), 736–745.

Vanlandewijck, Y. C. & Chapel, R. J. (1996). Integration and classification issues in competitive sports for athletes with disability. Sport Science Review, 5(1), 65-88.

Vidarte, J., Velez, C., Sandoval, C., & Alfonso, M. (2011). Physical activity: health promotion strategy. Towards Health Promotion, Volume 16, No.1, 202 – 218.

Wan, D., & Krassioukov, A. V. (2014). Life-threatening outcomes associated with autonomic dysreflexia: a clinical review. The journal of spinal cord medicine, 37(1), 2–10.

Warburton, D. E. R., Jamnik, V. K., Bredin, S. S. D., McKenzie, D. C., Stone, J., Shephard, R. J., & Gledhill, N. (2011). Evidence-based risk assessment and recommendations for physical activity clearance. Applied physiology, nutrition, and metabolism = Physiologie appliquée, nutrition et métabolisme, 36 Suppl 1, S1-2.

Wedgwood, N. (2013). Hahn versus Guttmann: revisiting “Sports and the Political Movement of Disabled Persons.” Disability & Society, 29(1), 129–142.

Weidner, N., Rupp, R., & Tansey, K. (2017). Neurological Aspects of Spinal Cord Injury. Springer International Publishing.

Witiw, C. D., & Fehlings, M. G. (2015). Acute Spinal Cord Injury. Journal of spinal disorders & techniques, 28(6), 202–210.

World Health Organization (WHO). (2010). Global Recommendations on Physical Activity for Health. Available from: https://apps.who.int/iris/bitstream/handle/10665/44441/9789243599977_spa.pdf?sequence=1

Wyndaele, M., & Wyndaele, JJ. (2006). Incidente, prevalence and epidemiology of spinal cord injury: what learns a worldwide literature survey? Spinal Cord, 44: 523-9.

Xu, D., Yang, L., Li, Y., & Sun, Y. (2015). Clinical study of ganglioside (GM) combined with methylprednisolone (MP) for early acute spinal injury. Pakistan journal of pharmaceutical sciences, 28(2 Suppl), 701–704.

Yang, J. F., Fung, J., Edamura, M., Blunt, R., Stein, R. B., & Barbeau, H. (1991). H-reflex modulation during walking in spastic paretic subjects. The Canadian journal of neurological sciences. Le journal canadien des sciences neurologiques, 18(4), 443–452.

Ziu, E. & Mesfin, FB. (2020). Spinal Shock. [Updated 2020 Apr 28]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing. Available from: https://www.ncbi.nlm.nih.gov/books/NBK448163/

Zweckberger, K., Ahuja, C. S., Liu, Y., Wang, J., & Fehlings, M. G. (2016). Self-assembling peptides optimize the post-traumatic milieu and synergistically enhance the effects of neural stem cell therapy after cervical spinal cord injury. Acta biomaterialia, 42, 77–89.

10. APPENDIX

10.1 Spanish translation of the QIF questionnaire

Alimentación:

1. Bebe de un vaso o una taza.
2. Usa tenedor o cuchara.
3. Corta la comida (carne).
4. Se sirve bebidas.
5. Abre una caja de cartón o un tarro.
6. Unta mantequilla o paté en el pan.

En la cama:

7. Se cambia de boca arriba a boca abajo.
8. Se cambia de tumbado a sentado.
9. Se cambia de boca abajo a de lado.
10. Se cambia de un lado al otro.
11. Mantiene el equilibrio sentado con las piernas estiradas.

Aseo personal:

12. Se cepilla los dientes o la dentadura.
13. Peina/cepilla su pelo.

Baño:

14. Lava y seca su tronco.
15. Lava y seca su parte inferior.
16. Lava y seca sus pies.
17. Lava y seca su pelo.

Transferencias:

18. Se pasa de la cama a la silla.
19. Se pasa de la silla a la cama.
20. Se pasa de la silla al WC (o a la silla WC).
21. Se pasa del WC a la silla.
22. Se pasa de la silla al coche.
23. Se pasa del coche a la silla.
24. Se pasa de silla a la ducha/bañera.
25. Se pasa de la ducha/bañera a la silla.

Vestido:

26. Se pone en el tronco ropa de casa.
27. Se quita del tronco ropa de casa.
28. Se pone en su parte inferior del cuerpo ropa de casa.
29. Se quita de su parte inferior del cuerpo ropa de casa.
30. Se pone o se quita calcetines.
31. Se pone o se quita el calzado.
32. Usa cierres o cremalleras.

Movilidad en silla de ruedas:

33. Gira en una esquina con la silla.
34. Se mueve marcha atrás con la silla.
35. Bloquea los frenos de la silla.
36. Se mueve y acomoda en la silla.
37. Mantiene el equilibrio sentado en la silla.