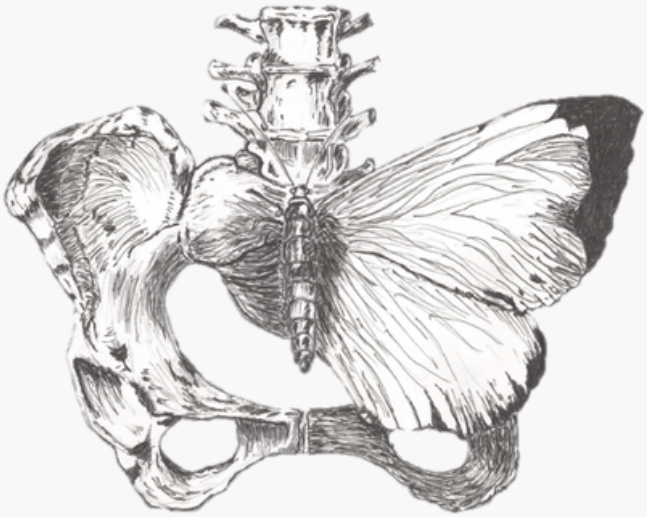

APLICACIONES CLÍNICAS DE LA DETERMINACIÓN DE LAS PROPIEDADES MECÁNICAS PARAESPINALES LUMBARES Y LA CINEMÁTICA LUMBOPÉLVICA EN SUJETOS CON LUMBALGIA MECÁNICA E INFLAMATORIA

CLINICAL APPLICATIONS OF LUMBAR PARASPINAL MECHANICAL PROPERTIES AND LUMBOPELVIC KINEMATICS IN SUBJECTS WITH MECHANICAL AND INFLAMMATORY LOW BACK PAIN

PROGRAMA DE DOCTORADO DE BIOMEDICINA

DOCTORANDA
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TITULO: *APLICACIONES CLÍNICAS DE LA DETERMINACIÓN DE LAS PROPIEDADES MECÁNICAS PARAESPINALES LUMBARES Y LA CINEMÁTICA LUMBOPELVICA EN SUJETOS CON LUMBALGIA MECÁNICA E INFLAMATORIA*

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Tesis doctoral presentada por Sandra Alcaraz Clariana, Graduada en Fisioterapia, para optar al Grado de Doctora

Tesis doctoral realizada bajo la dirección del Prof. Dr. D. Francisco Alburquerque Sendín

Programa de doctorado en Biomedicina

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TÍTULO DE LA TESIS: Aplicaciones clínicas de la determinación de las propiedades mecánicas paraespinales lumbares y la cinemática lumbopélvica en sujetos con lumbalgia mecánica e inflamatoria

DOCTORANDA: Sandra Alcaraz Clariana

INFORME RAZONADO DEL DIRECTOR DE LA TESIS

La alumna de Doctorado presenta la siguiente Tesis doctoral con los trabajos de investigación derivados de su actividad en el Programa de Doctorado. Como puede apreciarse, la evolución y el desarrollo de los trabajos es elevada y se ha acompañado de una intensa actividad investigadora desarrollada por la alumna en el equipo de trabajo, alcanzando los requerimientos necesarios de una Tesis doctoral.

De dichos trabajos se han derivado una serie de publicaciones de alta calidad, entre las que se encuentran dos artículos publicados en la revista Diagnostics, que se encuadra en el segundo cuartil (Q2) de la categoría Medicine, General & Internal (Posición en la categoría: 60/172; Factor de impacto: 3,992), dentro del índice Journal Citation Reports (JCR) 2021, publicado anualmente por la Web of Science:

Título: Paravertebral Muscle Mechanical Properties in Patients with Axial Spondyloarthritis or Low Back Pain: A Case-Control Study.

Autores: Sandra Alcaraz-Clariana. Lourdes García-Luque (equal contribution), Juan Luis Garrido-Castro, I. Concepción Aranda-Valera, Lourdes Ladehesa-Pineda, María Ángeles Puche-Larrubia, Cristina Carmona-Pérez, Daiana Priscila Rodrigues-de-Souza, Francisco Alburquerque-Sendín.

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Título: Influence of Spinal Movements Associated with Physical Evaluation on Muscle Mechanical Properties of the Lumbar Paraspinal in Subjects with Acute Low Back Pain

Autores: Sandra Alcaraz-Clariana. Lourdes García-Luque (equal contribution), Juan Luis Garrido-Castro, Cristina Carmona-Pérez, Daiana Priscila Rodrigues-de Souza, César Fernández-de-las-Peñas, Francisco Alburquerque-Sendín.

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Además, la alumna ha publicado dos artículos en revistas indexadas en JCR y nueve comunicaciones en Jornadas, Congresos nacionales e internacionales, fruto del trabajo de investigación desarrollado en el marco de la Tesis doctoral. Así como cuatro publicaciones en JCR y cuatro comunicaciones a Congresos Internacionales como otra producción científica durante el programa de doctorado.

Por todo ello, se autoriza la presentación de la tesis doctoral.

Córdoba, 30 de enero de 2023

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Fdo.:_____

A todos los que me acompañaron en tan largo proceso

“Me enseñaron que el camino del progreso no es ni rápido ni fácil”

Marie Curie

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A mi familia en Physiobalance, gracias por vuestra disponibilidad, generosidad y profesionalidad. Gracias a todos los que creéis que necesito desconexión y manipuláis mi agenda o directamente me lleváis engañada a un concierto para evitar la frase más nombrada…"no puedo, tengo que trabajar…" ¡GRACIAS!

A mi socio y AMIGO, Jesús Fernández, por ser alguien muy especial en mi vida. Una de esas decisiones de las que jamás me podré arrepentir. Gracias por tu apoyo incondicional, por tu preocupación por mi bienestar… ¡TE QUIERO!

A mi peluda, siempre a mi lado, por largo que se hiciese el día frente al ordenador.

A Miguel Ángel, porque ha sabido transmitirme la importancia de la palabra TRANQUILIDAD. Una persona a la que admiro por su nobleza y sensibilidad. Con un corazón tan grande como su despiste. GRACIAS también a mi profesión por ponerlo en mi camino.

A mi madre y mi padre q.e.p.d, por ser referentes en mi vida. Ejemplo de esfuerzo, sacrificio y generosidad. Si de algo estoy orgullosa es de tener la familia que tengo. Gracias por preocuparos por mí, por cuidarme y estar ahí siempre. Me siento muy afortunada por ello. ¡GRACIAS, SIEMPRE!

ÍNDICE

RESUMEN

El dolor lumbar (Low Back Pain, LBP) es uno de los trastornos musculoesqueléticos más comunes, que afecta al 80% de la población en algún momento de su vida. Atendiendo a su patrón clínico, suele clasificarse como mecánico o inflamatorio y se asocia con cambios en la actividad neuromuscular, disminución de la movilidad de la columna, flexibilidad muscular lumbar limitada o cinemática espinal alterada. La creciente prevalencia del LBP requiere una mejor comprensión de la etapa aguda/subaguda de la patología para optimizar el diagnóstico y el tratamiento y así minimizar su carga socio-económica.

El objetivo general fue profundizar en la descripción y la relevancia clínica de las Propiedades Mecánicas Musculares (*Muscle Mechanical Properties*, MMPs) de la musculatura espinal y la cinemática lumbopélvica en sujetos con espondiloartritis axial (axSpA), dolor lumbar agudo (acute LBP), subagudo (*Subacute LBP*, sLBP) y controles. Los objetivos específicos contemplaban identificar diferencias en las MMPs a nivel lumbar y cervical entre sujetos con axSpA, sLBP y controles. Identificar asociaciones entre MMPs y variables sociodemográficas y clínicas. Identificar los cambios de dichas propiedades tras realizar una secuencia estandarizada de movimientos y determinar la influencia del LBP y la edad en dichos cambios. Así como, identificar las diferencias en el ritmo lumbopélvico (*Lumbopelvic Rhythm*, LPR) entre sujetos con aLBP y controles.

La muestra fue reclutada desde el centro privado Physiobalance, el Departamento de Reumatología del Hospital Reina Sofía, y el Campus Biosanitario de la Universidad de Córdoba.

Los resultados indicaron que el tono y la rigidez paraespinal fue mayor en patología inflamatoria que en LBP mecánico o sanos ($p<0.05$), y que las MMPs fueron capaces de clasificar grupos patológicos, así como LBP inflamatorio y sanos (Área bajo la curva (Área Under the curve, AUC) operativa del receptor >0.8). Tras movimientos secuenciados, el tono y la rigidez aumentaron 0.37 Hz y 22.75 N/m, respectivamente, en los sujetos jóvenes independientemente de la presencia o ausencia de dolor. La relajación fue mayor en los sujetos jóvenes sanos, así como la fluencia lo fue en sujetos con LBP menores de 35 años. Por último, los sujetos con aLBP mostraron diferencias en el LPR respecto a sanos, presentando durante la flexión, un menor movimiento lumbar en el segundo cuartil (Q2) ($p=0.001$), y de pelvis y troco durante el tercer (Q3) ($p=<.001$; $p=.001$) y cuarto (Q4) cuartil ($p=.001$; $p=.045$). Durante la extensión, el tronco y el segmento lumbar en Q2 y Q3 se movieron menos en los sujetos con dolor ($p=.030$; $p=.046$ and $p=.013$; $p=.002$ respectivamente).

En conclusión, las MMPs lumbares y cervicales son diferentes según el tipo de LBP y, al menos en los pacientes con axSpa, se asocian un peor estado y progresión de la enfermedad a mayor tono y rigidez en las regiones lumbar y cervical. Asimismo, el movimiento espinal secuenciado puede modificar el tono

y la rigidez paraespinal lumbar según la edad del paciente, pero no según la presencia de LBP. El LPR es diferente entre sujetos con aLBP y sanos. Estos hallazgos permiten afirmar que las MMPs y el LPR son relevantes clínicamente y su evaluación debe realizarse durante el seguimiento del paciente.

ABSTRACT

Low back pain (LBP) is one of the most common musculoskeletal disorders, affecting 80% of the population at some point in their lives. Based on its clinical pattern, it is usually classified as mechanical or inflammatory. It is associated with changes in neuromuscular activity, decreased spinal mobility, limited lumbar muscle flexibility, or altered spinal kinematics. The increasing prevalence of LBP requires a better understanding of the acute/subacute stage of the pathology to optimize diagnosis and treatment and thus minimize its socio-economic burden.

The general objective was to deepen the description and clinical relevance of the Muscle Mechanical Properties (MMPs) of the spinal musculature and lumbopelvic kinematics in subjects with axial spondyloarthritis (axSpA), acute low back pain (aLBP), subacute (sLBP) and controls. The specific objectives were to identify differences in MMPs at the lumbar and cervical levels between subjects with axSpA, sLBP, and controls. To identify associations between MMPs and sociodemographic and clinical variables. To identify the changes in these properties after performing a standardized sequence of movements and to determine the influence of LBP and age on these changes. Also, to identify the differences in the Lumbopelvic Rhythm (LPR) between subjects with aLBP and controls.

The sample was recruited from the private Physiobalance center, the Rheumatology Department of the Reina Sofia Hospital, and the Biosanitary Campus of the University of Cordoba.

The results indicated that paraspinal tone and stiffness were higher in inflammatory pathology than in mechanical or healthy LBP ($p<0.05$) and that MMPs were able to classify pathological groups, as well as inflammatory and healthy LBP (Area Under the curve (AUC) receptor operative >0.8). After sequential movements, tone and stiffness increased by 0.37 Hz and 22.75 N/m, respectively, in young subjects irrespective of the presence or absence of pain. Relaxation was greater in young, healthy subjects, as was creep in LBP subjects younger than 35 years. Finally, subjects with aLBP showed differences in the LPR to healthy subjects, presenting during flexion, less lumbar movement in the second quartile (Q2) ($p=0.001$), and of pelvis and trochus during the third (Q3) ($p=<.001$; $p=.001$) and fourth (Q4) quartiles ($p=.001$; $p=.045$). During extension, the trunk and lumbar segment in Q2 and Q3 moved less in subjects with pain ($p=.030$; $p=.046$ and $p=.013$; $p=.0029$, respectively).

In conclusion, lumbar and cervical MMPs differ according to LBP type. At least in axSpa patients, worse disease status and progression are associated with greater tone and stiffness in the lumbar and cervical regions. Likewise, sequenced spinal motion can modify lumbar paraspinal tone and stiffness according to patient age but not according to the presence of LBP. The LPR is different between aLBP

and healthy subjects. These findings affirm that MMPs and LPR are clinically relevant and that their evaluation should be performed during patient follow-up.

CAPÍTULO I: Marco teórico

1.1 DEFINICIÓN DE DOLOR LUMBAR

El dolor lumbar (*Low Back Pain*, LBP) es definido por La Organización Mundial de la Salud, en su "Clasificación Internacional de Enfermedades CIE-11" de 2019, como "un dolor y malestar localizado por debajo del margen costal y por encima de los pliegues glúteos inferiores, con o sin dolor en las piernas". El código asignado al LBP es ME84.2 (1).

LBP es una afección asociada a cambios en la actividad neuromuscular (2,3), a una disminución de la movilidad de la columna vertebral, a la limitación de la flexibilidad de los músculos lumbares y a la alteración de la cinemática de la columna (4). Además, se ha descrito una modificación de las cargas mecánicas, relacionada con la redistribución de la actividad muscular dentro y entre los músculos, en sujetos con LBP (3,5). Estos cambios determinan una reducción de la función de la columna lumbar, una alteración de las Propiedades Mecánicas del Músculo (*Muscle Mechanical Properties*, MMPs) (4,6–8) y un control motor inadecuado (9,10).

1.2 INCIDENCIA Y PREVALENCIA DEL DOLOR LUMBAR

El LBP es un síntoma musculoesquelético común, que afecta a sujetos de todos los países, independientemente de su nivel de desarrollo, en todos los grupos de edad, y en casi todas las personas durante la vida, como episodio agudo o como afección crónica (11,12). A pesar de los numerosos estudios publicados sobre la prevalencia o incidencia del LBP, hay poco consenso con respecto a su epidemiología y sus factores de riesgo (13,14). En 2019, se registraron aproximadamente 568,4 millones de casos prevalentes, 223,5 millones de casos incidentes y 63,7 millones de años vividos con discapacidad (11) **(Figura 1)**, siendo el LBP, la principal causa de discapacidad a nivel mundial (15).

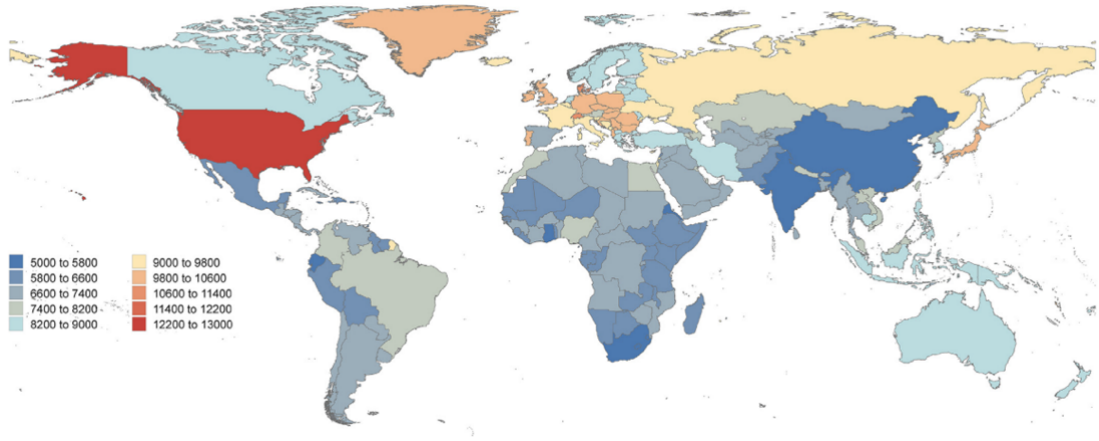


Figura 1. Estimaciones de prevalencia del dolor lumbar por cada 100.000 habitantes por país en 2019. Tomada de Chen et al. (11).

La prevalencia del LBP en Europa es del 25-45%, siendo sus causas más frecuentes las degenerativas y las traumáticas (16). El LBP es más prevalente en los países industrializados, y la tasa de prevalencia global es mayor en mujeres que en hombres. Además, se ha sugerido que la prevalencia o incidencia del LBP aumenta con la edad (13), alcanzando su punto máximo en el grupo de edad de 80 a 84 años en ambos sexos (11). Aunque un episodio de LBP agudo (*acute LBP*, aLBP) puede llegar a resolverse, hasta el 70% de los pacientes pueden sufrir un episodio recurrente de lumbalgia en el plazo de 1 año y el 54% de ellos en 6 meses (17).

Una prevalencia al alza, tal y como describen estudios recientes (12), alerta del incremento del coste sanitario y el impacto social que conlleva (18). La Organización Mundial de la Salud (OMS), señala la importancia de las consecuencias a nivel laboral, como la falta de productividad y las jubilaciones anticipadas, o los menores niveles de bienestar y la menor capacidad de participación social que genera. El coste de la atención al LBP en España representa el 0,68% del Producto Interior Bruto, y los costes indirectos (absentismo y presentismo) representan el 74,5% de los costes totales del LBP (19). Dichos

costes, aumentan más rápido que el gasto general en atención médica y no existe evidencia que demuestre que se pueden obtener mejores resultados en el manejo de la patología (20).

1.3 ETIOLOGÍA Y CLASIFICACIÓN DEL DOLOR LUMBAR

Partiendo del vigente modelo biopsicosocial en ciencias de la salud, debemos atender a factores de etiología multifactorial al hablar de LBP (21–23). Una mejor comprensión de los factores de riesgo de un episodio de LBP puede suponer un gran apoyo en la prevención y el tratamiento de esta afección (24,25). Entre ellos, se han identificado como factores de riesgo potenciales, la obesidad, las comorbilidades físicas y mentales, el tabaquismo, el nivel socioeconómico bajo (26), el embarazo, la enfermedad pulmonar obstructiva crónica o las enfermedades cardiovasculares entre otras (27). En la literatura, encontramos a los factores de riesgo clasificados en: factores biológicos o personales, como las alteraciones del sistema musculoesquelético y el estado de salud general; las condiciones laborales como factor social; los factores psicológicos como gestores de la percepción y el afrontamiento del dolor (13,22), que a su vez contribuyen a la cronicidad (28); o las posturas de trabajo no neutrales, y el trabajo físicamente exigente, como factores de riesgo ambientales (13,29,30).

Actualmente, no existe una clasificación única bien aceptada, ya que la taxonomía de LBP está poco desarrollada (31). Aun así, existen diferentes clasificaciones utilizadas, de acuerdo al tiempo de evolución, origen, signos y síntomas acompañantes o respuesta al tratamiento, entre otros (32,33).

Para clasificar la lumbalgia en función de la duración del dolor, independientemente de la etiología, hay una clara falta de consenso. Así, aLBP (<4 semanas), subagudo (*Subacute LBP*, sLBP) (4-12 semanas) y crónico (*chronic LBP*, cLBP) (>12 semanas), son los términos que se utilizan con mayor frecuencia (17,34,35), aunque recientemente, también se han utilizado términos como el del LBP persistente (36), lumbalgia recurrente si se presenta un nuevo episodio de lumbalgia tras seis meses asintomático, o exacerbación si ocurre antes de los seis meses (37). Trabajos previos sobre la prevalencia del cLBP han establecido criterios de duración del dolor significativamente variables (38). Episodios de más de seis semanas, más de siete semanas, más de tres meses, más de seis meses o el dolor continuo, se han tomado como referencia para determinar la presencia de dicho dolor crónico (38).

Knezevic et al. en 2021 (39) clasificaron el LBP por su naturaleza mecánica, radicular (neuropática) o principalmente nociplástica. En los estudios que han tratado de determinar el desglose del LBP la prevalencia del dolor neuropático ha oscilado entre el 16% y el 55% de los pacientes con lumbalgia crónica (39) y se ha clasificado además por su localización como central, foraminal o por su afectación a los recesos laterales (40). En cambio, la estenosis espinal es una afección anatómicamente progresiva y una consecuencia directa de los procesos degenerativos relacionados con la edad que no cursa necesariamente con la presencia de dolor radicular (39). El dolor nociplástico es la categoría más reciente de dolor, con sensibilización central como patología principal. Cuando se experimenta en la

zona lumbar, este dolor suele denominarse lumbalgia inespecífica, aunque este término suele aplicarse erróneamente a personas cuya causa es desconocida o ambigua. El dolor inespecífico también puede acompañar al dolor mecánico y neuropático (41).

Por otro lado, Barrey et al., en 2019, (42) propusieron clasificar el LBP en tres categorías: no degenerativo, degenerativo e indeterminado. El LBP no degenerativo hallaría su origen en un traumatismo, espondilólisis, un tumor, una infección o un proceso inflamatorio. El LBP degenerativo sería el causado por combinaciones variables de anomalías en uno o más discos intervertebrales, articulaciones facetarias y/o ligamentos, con o sin alteraciones regionales y/o globales en la alineación de la columna. Finalmente, el LBP indeterminado no se correlacionaría con ninguna anormalidad detectable utilizando los estudios de imágenes disponibles.

Nuevas tendencias como la clasificación basada en el tratamiento, muestran un método para clasificar a las personas que pueden responder preferentemente a las siguientes intervenciones: (a) ejercicios de dirección específica, (b) manipulación, (c) estabilización, y (d) tracción (33). La literatura afirma que el 85% de las lumbalgias no tienen una causa específica. Lo que significa que no se puede encontrar ningún cambio estructural o enfermedad específica como causa (5). Un 10% serán de causa mecánico-degenerativa, y el 5% restante tendrán una causa infecciosa, tumoral, inflamatoria, traumática o metabólica (5,43,44). Como puede observarse, no existe un consenso respecto a la clasificación temporal o etiológica del LBP. En este sentido, estudios recientes hacen hincapié en la importancia de atender al patrón clínico y saber distinguir entre LBP mecánico y LBP inflamatorio para poder establecer un correcto manejo de la patología (45,46) **(Tabla 1).**

Tabla 1. Clasificación del dolor lumbar según el patrón clínico (46).

Mecánico	Inflamatorio
Inicio súbito	Progresivo
Empeora con el ejercicio	Mejora con el ejercicio
Mejora con el reposo	Empeora con el reposo
Diurno	Nocturno
No rigidez matutina	Rigidez matutina
Estado general normal	Afectación del estado general
Paciente inmóvil	Paciente inquieto
Antecedentes previos	No antecedentes previos

CAPÍTULO II: Aspectos generales de la investigación

2.1 JUSTIFICACIÓN

La presente investigación surge de una necesidad manifiesta de ampliar el conocimiento en una patología tan habitual en el ámbito clínico como el LBP, capaz de repercutir negativamente y a gran escala a nivel físico, psíquico y social.

Tal y como detalla la literatura reciente…

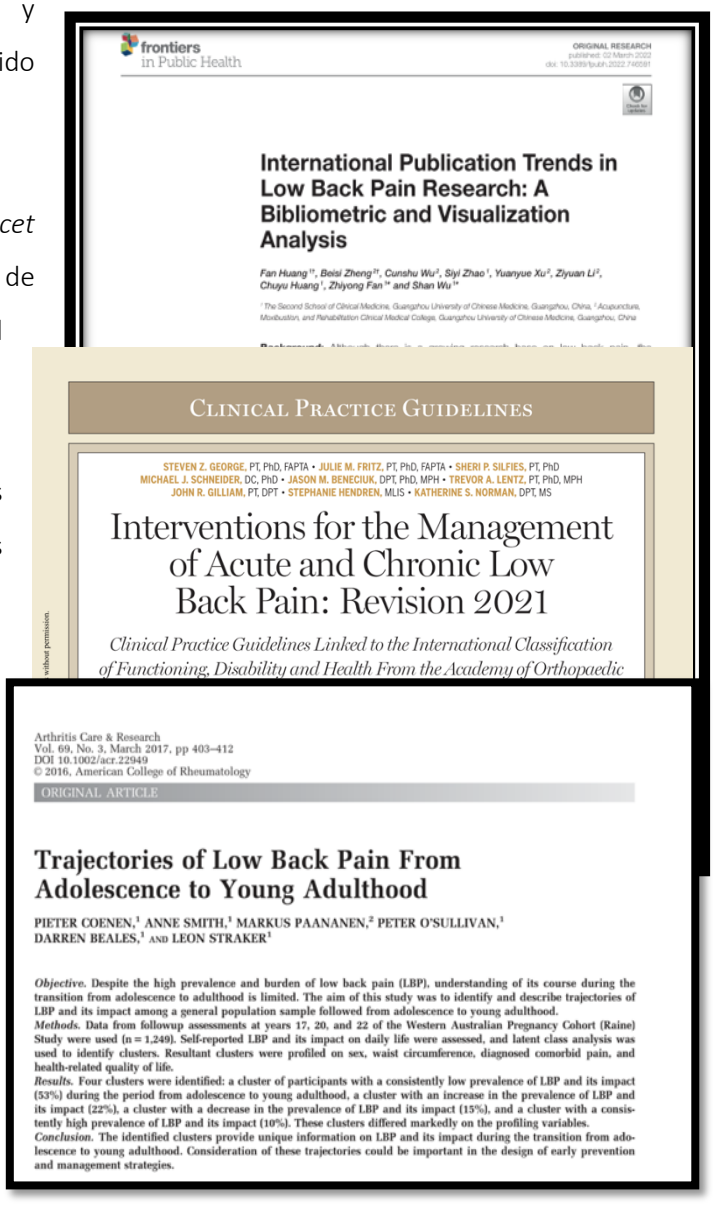
"los intentos actuales de prevención y manejo efectivos del dolor lumbar han tenido un éxito limitado" (47).

"En 2018, una serie de artículos en *The Lancet* llamaron la atención sobre la alta prioridad de mejorar la calidad de la atención en el manejo del dolor lumbar" (20).

"Es una de las entidades clínicas más estudiadas …con ausencia de exitosos resultados en el manejo" (48).

"El número anual de publicaciones sobre LBP ha aumentado considerablemente en las últimas dos décadas, lo que demuestra que LBP tiene el potencial de ser estudiado con precisión" (31).

"El terapeuta debe reconocer la patología, la exploración específica de dicha patología y los criterios de derivación" (48).



2.2 OBJETIVOS

Objetivo General

- Profundizar en la descripción y la relevancia clínica de las MMPs de la musculatura espinal y la cinemática lumbopélvica en sujetos con axSpA, sLBP y controles.

1º objetivo específico (vinculado al primer artículo)

Objetivo principal

- Identificar las diferencias en las MMPs a nivel de la columna lumbar y cervical entre sujetos con axSpA, sLBP y controles.

Objetivo secundario

- Identificar asociaciones entre MMPs y variables sociodemográficas y clínicas.

2º objetivo específico (vinculado al segundo artículo)

Objetivo principal

- Identificar los cambios en las MMPs paraespinales cuando se someten a una secuencia estandarizada de movimientos lumbares.

Objetivo secundario

- Determinar la influencia del aLBP y la edad en dichos cambios.

3º objetivo específico

- Identificar las diferencias en el Ritmo lumbopélvico (Lumbopelvic Rhythm, LPR) entre sujetos con dolor lumbar mecánico agudo inespecífico y sujetos sanos.

2.3 HIPÓTESIS

En función de los objetivos previstos, se plantean las siguientes hipótesis de estudio:

Primera: Los sujetos con sLBP y axSpa presentan características propias en relación a las MMPs de la columna cervical y lumbar.

Segunda: Los sujetos con patología lumbar presentan un comportamiento diferencial con respecto a los sujetos sanos en relación a las MMPs.

Tercera: Las MMPs lumbares se verán modificadas en función de la realización de movimientos espinales secuenciados y la edad, en sujetos con aLBP.

Cuarta: Los sujetos con aLBP presentan una cinemática lumbopélvica diferencial con respecto a los sujetos sanos.

2.4 MÉTODOS

1º OBJETIVO ESPECÍFICO (ARTÍCULO 1)		2º OBJETIVO ESPECÍFICO (ARTÍCULO 2)	
Propiedades mecánicas de los músculos paravertebrales en pacientes con espondiloartritis axial o lumbalgia		Influencia de los movimientos de la columna asociados con la evaluación física, sobre las propiedades mecánicas de la musculatura paraespinal lumbar en sujetos con dolor lumbar agudo	
DISEÑO	Estudio observacional transversal de casos y controles	DISEÑO	Estudio observacional, Test-Retest
MUESTRA	43 sujetos por grupo - sLBP - axSpA - Sanos	MUESTRA	33 sujetos por grupo - aLBP - Sanos
VARIABLES	Sociodemográficas Intensidad de dolor Daño estructural Actividad de la enfermedad Capacidad funcional Calidad de vida (QoL) MMPs Movilidad espinal Evolución de la enfermedad	VARIABLES	Sociodemográficas Intensidad de dolor Capacidad funcional MMPs
INSTRUMENTOS DE MEDIDA	Numerical pain rating scale (**NPRS**) Modified Stoke Ankylosing Spondylitis Spinal Score (**mSASSS**) Bath Ankylosing Spondylitis Disease Activity Index (**BASDAI**) (50) Bath Ankylosing Spondylitis Functional Index (**BASFI**) (49) Oswestry Disability Index (**ODI**) (51) 12- item short-form health survey (**SF-12**) (52) Miotonometría (**MyotonPro©**) Metrología convencional (**cinta métrica y goniómetro**) Bath Ankylosing Spondylitis Metrology Index (**BASMI**) **Tiempo de evolución**	INSTRUMENTOS DE MEDIDA	Visual analogue scale (**VAS**) **ODI** **MyotonPro©**

<table>
<tr><th colspan="4">3º OBJETIVO ESPECÍFICO</th></tr>
<tr><td colspan="4">Alteración del ritmo lumbopélvico según el origen del dolor lumbar</td></tr>
<tr><td>DISEÑO</td><td colspan="3">Estudio observacional transversal de casos y controles con muestreo no probabilístico de casos consecutivos</td></tr>
<tr><td>MUESTRA</td><td colspan="3">39 sujetos por grupo
- aLBP
- Sanos</td></tr>
<tr><td>VARIABLES</td><td>Sociodemográficas
Intensidad de dolor
Discapacidad
Ángulo de Lordosis
Ritmo Lumbopélvico</td><td>INSTRUMENTOS DE MEDIDA</td><td>VAS
Roland Morris Disability Questionnaire (RMDQ)
Sensores inerciales (IMUs)</td></tr>
</table>

2.5 CONCLUSIONES

De forma general podemos concluir que las MMPs y el LPR son relevantes clínicamente y su evaluación debe realizarse durante el seguimiento del paciente, atendiendo a la edad y el tipo de dolor como condicionantes de su comportamiento.

Conclusiones 1º objetivo específico (artículo 1)

- Las MMPs lumbares y cervicales son diferentes según el tipo de dolor de columna.

- Los pacientes con axSpA muestran un mayor tono y rigidez y una menor relajación y fluencia que aquellos con sLBP y controles sanos. Además, las MMPs espinales, salvo el decrement (inverso a la elasticidad), son capaces de clasificar a pacientes con axSpA y sujetos sanos, pero no a sujetos con LBP y sanos, lo que aumenta el interés en la valoración de las MMPs espinales como posible marcador del estado muscular y progresión en el contexto clínico del dolor espinal inflamatorio.

- Los pacientes con axSpA muestran un patrón específico de correlaciones entre MMPs y resto de variables clínicas y metrológicas que no aparece en sLBP y sujetos sanos. Este patrón asocia un peor estado y progresión de axSpA a mayor tono y rigidez en regiones lumbares y cervicales.

Conclusiones 2º objetivo específico (artículo 2)

- Un protocolo de movimiento espinal secuenciado puede modificar el tono y la rigidez paraespinal lumbar según la edad del paciente, independientemente de su estado clínico.

- Los cambios en las características viscoelásticas de los músculos lumbares dependen de la edad y de la presencia o ausencia de dolor, pero no de la realización de movimientos secuenciados.

- Los sujetos mayores mostraron menos elasticidad que los más jóvenes a nivel de la 5ª vértebra lumbar independientemente de su condición.

- Las MMPs deben evaluarse en un ámbito clínico, no sólo al inicio de la evaluación física en reposo, sino también durante el seguimiento del paciente, con especial atención a los sujetos de mayor edad y con dolor.

Conclusiones 3º objetivo específico

- El análisis por cuartiles de movimiento permite observar diferencias entre sujetos con aLBP y controles sanos, que no se encuentran en los movimientos totales.

- Los sujetos con aLBP mostraron durante la flexión, menos movimiento lumbar en el segundo cuartil y menos movimientos de pelvis y tronco en Q3 y Q4 que los individuos sanos.

- Durante la extensión, los sujetos con dolor mostraron menos movimientos del tronco y del segmento lumbar en Q2 y Q3.

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2.7 LISTA DE ABREVIATURAS

ABREVIATURAS	TÉRMINO
aLBP	Acute Low Back Pain/Dolor lumbar agudo
AUC	Area Under the Curve / Área bajo la curva
axSpA	Axial Spondyloarthritis / Espondiloartritis axial
BASFI	Bath Ankylosing Spondylitis Functional Index / Índice de Funcionalidad de la Espondilitis Anquilosante
BASMI	Bath Ankylosing Spondylitis Metrology Index / Índice de Metrología de la Espondilitis Anquilosante
BASDAI	Bath Ankylosing Spondylitis Disease Activity Index / Índice de Actividad de la Enfermedad de la Espondilitis Anquilosante
cLBP	Chronic Low Back Pain / Dolor lumbar crónico
CI	Confidence Interval / Intervalo de confianza
FABQ	Fear-Avoidance Beliefs Questionnaire / Cuestionario Creencia Miedo-Evitación
IMU	Inertial Motion Unit / Unidad de movimiento inercial
LBP	Low Back Pain / Dolor lumbar
LPR	Lumbopelvic rhythm / Ritmo lumbopélvico
mSASSS	Modified Stoke Ankylosing Spondylitis Spinal Score / Puntuación Modificada de la Espondilitis Anquilosante de Stoke
MMPs	Muscle Mechanical Properties / Propiedades Mecánicas Musculares
NPRS	Numerical Pain Rating Scale / Escala numérica de valoración del dolor
OMS	Organización Mundial de la Salud
ODI	Oswestry Disability Index / Cuestionario de Discapacidad de Oswestry
QoL	Quality of life / Calidad de vida
Q	Quartil / Cuartil
ROC	Receiver Operating Characteristics / Característica Operativa del Receptor
RMDQ	Roland Morris Disability Questionnaire / Cuestionario de discapacidad de Roland Morris
SF-12	12- item short-form health survey / Encuesta breve de Salud de 12 ítems
sLBP	Subacute Low Back Pain / Dolor lumbar subagudo
VAS	Visual Analogue Scale / Escala visual analógica

<u>CAPÍTULO III</u>: Propiedades mecánicas de los músculos paravertebrales en pacientes con espondiloartritis axial o dolor lumbar

diagnostics

MDPI

Article

Paravertebral Muscle Mechanical Properties in Patients with Axial Spondyloarthritis or Low Back Pain: A Case-Control Study

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Abstract: Different musculoskeletal disorders are a source of pain in the spinal region; most of them can be divided into mechanical, such as low back pain (LBP), or inflammatory origins, as is the case of axial spondyloarthritis (axSpA). Nevertheless, insufficient information is available about the muscle negative consequences of these conditions. Thus, the objective of this study was to identify whether mechanical muscle properties (MMPs) of cervical and lumbar muscles are different between patients with axSpA, subacute LBP (sLBP), and healthy controls. Furthermore, we aimed identify whether MMPs were related to sociodemographic and clinical variables in various study groups. The MMPs, sociodemographic, and clinical variables were obtained in 43 patients with axSpA, 43 subjects with sLBP, and 43 healthy controls. One-way ANOVAs and ROC curves were applied to identify whether the MMPs could differentiate between the study groups. Intra-group Pearson *r* coefficients to test the associations between MMPs and the rest of the variables were calculated. The results showed that axSpA subjects have a higher tone and stiffness and a lower relaxation and creep than sLBP and healthy ones ($p < 0.05$). All lumbar and cervical MMPs, except for decrement, could correctly classify axSpA and healthy subjects and axSpA and sLBP patients (in both cases, Area Under the Curve > 0.8). However, no MMP could differentiate between sLBP and healthy subjects. Each group had a different pattern of bivariate correlations between MMPs and sociodemographic and clinical data, with a worse state and progression of the axSpA group associated with a higher tone and stiffness in both spinal regions. This study supports that MMPs are different and show different patterns of correlations depending on the type of spinal pain.

Keywords: myotonometry; metrology; cervical spine; low back pain

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1. Introduction

Spinal disorders constitute a significant health problem with a high prevalence rate [1] that has increased in recent years [2]. The annual costs for the management of spinal pain costs 17 billion euros in Germany or 100 billion dollars in the United States [3,4]. Common symptoms and signs have been identified in subjects with spinal pain, such as a decreased range of motion (ROM), impaired spinal motor control disability, or decreased quality of life (QoL) [5-9].

Rheumatic pathologies, specifically axial spondyloarthritis (axSpA), are among the most relevant etiologies of spinal pain. This chronic inflammatory disease has an estimated prevalence of between 0.9 and 1.4% of the adult population in the United States [10] and 1.9% of the general Spanish population, and the delay of its diagnosis is more than six years [11]. In most cases, back pain is the initial manifestation of the disease, which is associated with stiffness and inflammation of the spinal and sacroiliac joints [12], with a clear evolution towards new bone formation in the sacroiliac joints and axial skeleton and decreased spinal mobility and functionality [10,13]. Furthermore, these subjects' skeletal muscles, especially the paravertebral muscles, are also affected [14-16], showing electromyographic alteration, fatty infiltration, fibrosis, and atrophy. Myofascial hypertonicity at the lumbar level, even in the early stage, stiffness and tightness can also be observed [17-20], but less information is available for cervical spinal muscles. Moreover, limited information is available on the relations between spinal mechanical muscle properties (MMPs) and clinical state in axSpA patients.

Low back pain (LBP) is the pathology that most contributes to the years lived with disability [21,22]. Its estimated prevalence in 2017 was about 577 million people [4,23], and more than 90% of the total LBP cases corresponds to unspecific mechanical LBP [24,25]. Important muscle morphological changes have been associated with the presence of LBP [26]. Among them, the presence of fat infiltration, reduction in muscle size, alteration in fiber distribution, and muscle recruitment strategies have been described [8,27-29], as well as their relationship with the evolution time [30]. Although these muscle alterations are well documented, mainly at the lumbar level, it remains unknown whether the muscle behavior is similar between different causes of spinal pain [31,32]; it could even depend on the acute or chronic stages [33,34]. For these purposes, more resources are necessary to assess MMPs in a clinical setting.

It has been described that muscle alterations may be an underestimated source of spinal pain [22] and that muscle physiology determines optimal spinal performance [30]. Indeed, excessive spinal muscle use or disuse is a well-known source of pain [35]. Although magnetic resonance imaging, computed tomography and ultrasound methods have allowed us to assess the soft tissues in spinal pain patients [36,37], more information and resources are necessary to describe other muscle features, such as MMPs. In recent years, the MyotonPro©, a manual device designed to assess MMPs, has provided

reliable data in clinical settings [38]. In fact, the determination of MMPs has been successfully applied in assessing healthy subjects and athletes, patients with stroke, scoliosis, Parkinson's, chronic low back pain (cLBP), and cervical dystonia, among others [32,39-42]. In spinal pain research, increases in tone and stiffness and decreases in the elasticity of the lumbar paraspinal muscles have been detected for axSpA and cLBP with the MyotonPro© [6,38,43,44]. However, no data are available in other regions, such as the cervical spine, which could be of interest in terms of disease state and evolution for axSpA [45] and due to possible compensatory mechanisms in LBP [6].

The MMP similarities or differences between axSpA and LBP patients along the spinal paraspinal muscles are still unknown. Their determination can be helpful to improve diagnosis and to control the evolution of patients in a clinical setting [6,46]. Therefore, the main objective of this study was to identify differences in the MMPs at lumbar and cervical spinal levels between subjects with axSpA, subacute LBP (sLBP), and controls. The secondary objective was to identify associations between MMPs and sociodemographic and clinical variables.

2. Methods

An observational, cross-sectional case-control study with consecutive sampling was conducted. Participants were recruited with a non-probabilistic sampling from three centers, Physiobalance (private physiotherapy center), Rheumatology Department of the Hospital Universitario Reina Sofía, Córdoba, and the Biosanitary campus of the University of Córdoba, in Spain, from November 2018 to January 2021.

The Research Ethics Committee of Córdoba approved this project (registration Number 0887, 2017). All participants signed the informed consent form.

2.1. Participants

Subjects of both sexes, over 18 years, participated in the study. Two groups of cases were defined. First, the axSpA group was composed of patients diagnosed according to the evaluation criteria of the SpondyloArthritis International Society (ASAS) [47]. Second, for the sLBP group, the subjects had less than 12 weeks of pain evolution time [48] and a value of ≥3 on the numerical pain rating scale (NPRS) [49]. The existence of any inflammatory pathology was a specific exclusion criterion for this group.

The control group included healthy subjects that did not have spinal pain in the last six months or any neurological or musculoskeletal disorder.

Exclusion criteria common to the three groups were history of vertebral fracture or spinal surgery; deformity due to scoliosis (Cobb angle higher than 20°); less than 20° of a total range of rotation in either hip; received physiotherapy treatment in the last six months; pregnancy.

To improve comparability between groups, for each subject with sLBP included in the study, one axSpA patient and one healthy subject were recruited, in both cases matched for age (±3 years), body mass index (BMI) (±3 Kg/m^2), and sex.

All measurements were performed by rheumatologists and physiotherapists trained in the Movement Analysis Laboratory of the Reina Sofía University Hospital in Córdoba (Spain).

2.2. Sample Size

Sample calculation was performed using the G*Power 3.1 software with the one-way ANOVA (F-test) as a statistical test. To achieve a moderate f effect size of 0.33 for MMPs, common in clinical practice for musculoskeletal outcomes [50], with an α coefficient of 0.05 and a power of 0.90, 40 subjects per group are necessary. Finally, 43 subjects per group were included due to possible missing data.

2.3. Assessments and Procedures

Sociodemographic aspects such as age, sex, weight, height, and BMI were collected. Commonly well-known questionnaires in clinical setting for axSpA and sLBP patients were applied to identify disability and QoL. Subsequently, an evaluation of the MMPs of the cervical and lumbar spine was carried out. After this, a record of spinal mobility was made using conventional metrology. Approximately 45 min were necessary for the complete evaluation of each subject.

2.4. Myotonometric Measurements

A manual myotonometer (MyotonPro® Myoton AS, Tallinn, Estonia) was used to record the MMPs of the lumbar and cervical regions with the patient lying in the prone position with the arms along the body. The probe of the device was positioned perpendicular to the erector spinae, 2.5 cm from the spinous process of L5 in both sides [46] **(Figure 1a)** and in the semispinalis capitis of both sides at the C4 level [51,52] **(Figure 1b)**. The mechanical impulses exerted by the probe, with a pulse of 15 ms and 0.40 N of mechanical force, allowed us to record the tissue response. The MMPs are expressed as follows: muscle tension or tone in resting state (Hz), defined by frequency; stiffness (N/m), which reflects the ability of the muscle to resist contraction or external force that deforms its initial shape; logarithmic decrement in the amplitude of oscillation, which has no unit (Ø), and describes the ability of the tissue to restore its shape after deformation, characterizing the inverse of the elasticity (the lower the decrement value, the greater elasticity [53,54]); the relaxation time of stress (ms), which is the recovery time for the muscle to return to its normal state after deformation; and the Creep (Deborah Number), which is the property of progressive deformation while applying constant stress, which reflects the viscosity of the tissue [43].

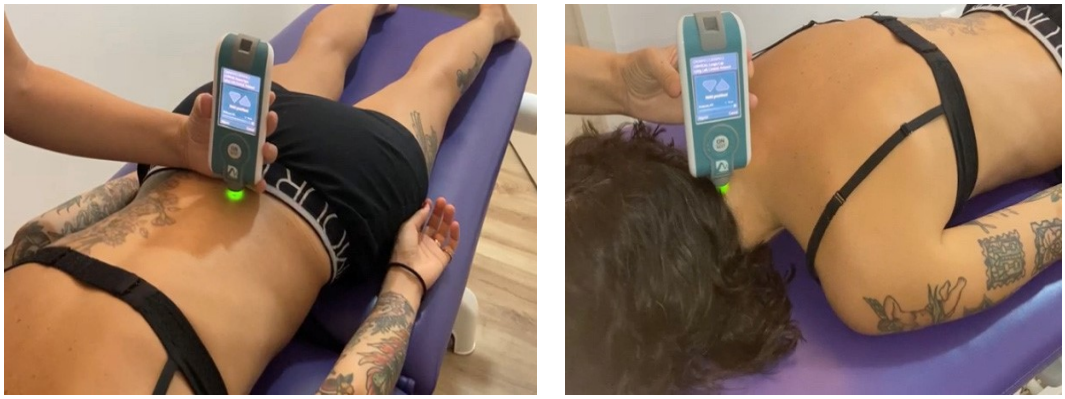

Figure 1. Measurement of the Mechanical Properties of Muscles (MMPs). (**a**) Lumbar evaluation. Position of the subject at rest and location of the myotonometer. (**b**) Cervical evaluation. Position of the subject at rest and location of the myotonometer.

The recording was performed during five seconds of apnea after exhalation [45] to reduce the abdominal influence on the test. The test had to be repeated if the coefficient of variation among the mechanical impulses was higher than 3% [44].

A randomization plan generator (www.randomization.com, accessed on 5 November 2018) was used to establish the order of the evaluations (right/left). The first ten subjects in each group were reassessed after one week, and intraclass correlation coefficients (ICC) > 0.8 was obtained for all evaluations and MMPs to assess intra-rater reliability between days. The absence of differences between sides allowed the utilization of the mean of both sides for the analyses.

2.5. Clinical Variables

After the myotonometric measurement, a metrological assessment was performed that consisted of: (1) cervical rotation; (2) tragus-wall distance; (3) lateral spinal flexion; (4) modified Schöber test; (5) intermalleolar distance [13]. Additionally, the Bath Ankylosing Spondylitis Metrology Index (BASMI) was added. The axSpA patients also completed the Bath Ankylosing Spondylitis Functional Index (BASFI) and the Bath Ankylosing Spondylitis Disease Activity Index (BASDAI) for the function and disease activity evaluation, respectively. BASMI, BASFI, and BASDAI ranged from zero to ten, with the higher values identifying the worse condition. The radiographic structural damage of these patients was determined according to the modified Stoke Ankylosing Spondylitis Spinal Score (mSASSS) index, which ranges from 0 to 72 [13], where the higher values also Score (mSASSS) index, which ranges from 0 to 72 [13], where the higher values also demonstrated a worse condition. The Oswestry Disability Index (ODI), which scores from zero (no disability) to five (highest disability) and has demonstrated high internal consistency (Cronbach's $\alpha = 0.92$) and construct validity [55], was applied to sLBP patients.

The 12-item short-form health survey (SF-12) was used to assess health-related QoL. It contains 12 questions that can be answered in less than two minutes. Each of the questions has a possibility of three to five responses; such a survey reflects the general state of health with two different scores: a physical component (PCS-12) and a mental component (MCS-12) [56,57]. Scores are calibrated so that 50 is the average or the norm, and lower scores represent poorer health-related QoL [58]. The SF-12 has shown good internal consistency (Cronbach's α from 0.72 to 0.89) and test–retest reliability (ICC from 0.73 to 0.86) [59]. High correlations (ICC = 0.94) were also found between the SF-12 and the SF-36 in Spain [57].

The intensity of the patients' pain was recorded with an NPRS, whose reliability and validity are widely demonstrated [48,49,60].

2.6. Statistical Analysis

For descriptive purposes, frequencies and percentages of categorical variables were presented, while mean and standard deviation with a 95% confidence interval (95%CI) were used for continuous data. The Kolmogorov–Smirnov test showed their normal distribution (all variables: $p > 0.05$).

As the study's main aim was to identify differences in MMPs and sociodemographic and clinical variables between groups, one-way ANOVAs were conducted, with Tukey's test for post-hoc analyses. To compare pain data between the axSpA and sLBP groups, the unpaired Student-*t* test was applied.

To determine if the MMPs can classify subjects between the three groups, Receiver Operating Characteristics (ROC) curves were developed, with the Area Under the Curve (AUC) interpreted as follows: fail to discriminate (0.5 to 0.6), poor (0.6 to 0.7), acceptable (0.7 to 0.8), excellent (0.8 to 0.9), and outstanding (more than 0.9) [61].

Finally, Pearson *r* coefficients were calculated to identify intra-group associations between the MMPs and sociodemographic and clinical data. Correlations were considered to be negligible (0.0 to 0.19), fair (0.20 to 0.39), moderate (0.40 to 0.69), strong (0.70 to 0.89) or almost perfect (0.0 to 1.00) [62].

The level of significance was set at 0.05. The IBM-SPSS® software, version 25 (SPSS Inc., Chicago, IL, USA), was used for the analyses.

3. Results

3.1. Differences in MMPs, Sociodemographic, and Clinical Variables between Groups

Table 1 shows the scores in all outcomes of the three groups. Age, sex, BMI, and MCS-12 were not different between the three groups. The PCS-12 was more than 11 points higher for healthy controls

than for both spinal pain groups with statistical differences. Additionally, pain intensity, assessed with NPRS, did not show statistical differences between the subjects with spinal pain. For the metrological variables, the cervical rotation showed the differences between the three groups, with at least 9° of difference and the axSpA group having less mobility. The lateral spinal flexion and intermalleolar distance showed lower values for the axSpA group compared with the other groups, as with BASMI. No differences were identified for the tragus to the wall distance and the modified Schöber test.

Table 1. Sociodemographic, clinical characteristics, and MMPs of patients with subacute low back pain, axSpA, and healthy controls.

	axSpA Group (n = 43)	sLBP Group (n = 43)	Control Group (n = 43)	p-Value
Age (years)	41.9 ± 9.5	40.2 ± 12.3	39.2 ± 11.3	0.581
Sex (female/male)	15/28	15/28	15/28	1.000
BMI (Kg/m^2)	24.6 ± 3.4	24.7 ± 3.0	23.9 ± 3.4	0.440
PCS-12	42.5 ± 9.8	41.0 ± 8.3	53.9 ± 4.3	<0.001 ‡
MCS-12	50.4 ± 9.1	51.0 ± 9.0	53.2 ± 6.6	0.483
NPRS	4.4 ± 2.6	4.9 ± 1.8		0.341
Lateral spinal flexion (cm)	13.8 ± 8.4	18.5 ± 5.2	21.7 ± 11.5	<0.001 †
Tragus to wall distance (cm)	12.5 ± 4.0	11.9 ± 1.6	11.5 ± 1.4	0.197
Modified Schöber test (cm)	5.1 ± 1.5	4.8 ± 1.4	5.1 ± 1.2	0.562
Intermalleolar distance (cm)	98.0 ± 16.6	114.3 ± 20.0	116.3 ± 14.1	<0.001 †
Cervical rotation (°)	61.2 ± 17.3	70.3 ± 13.3	79.3 ± 7.5	<0.001 §
Evolution time (years)	17.6 ± 12.0			
BASMI	3.0 ± 1.6	1.9 ± 0.6	1.5 ± 0.6	<0.001 †
BASFI	2.8 ± 2.6			
BASDAI	3.8 ± 2.5			
mSASSS	15.3 ± 14.7			
ODI		18.0 ± 12.6		
Muscle Mechanical Properties (MMPs)				
Lumbar tone (Hz)	18.23 ± 1.67	16.01 ± 2.34	15.28 ± 2.21	<0.001 †
Lumbar stiffness (N/m)	383.13 ± 53.22	303.81 ± 64.79	284.23 ± 82.61	<0.001 †
Lumbar decrement	1.45 ± 0.29	1.38 ± 0.28	1.25 ± 0.31	0.009 *
Lumbar relaxation (ms)	14.03 ± 1.64	17.88 ± 3.70	18.99 ± 4.54	<0.001 †
Lumbar creep (Deborah number)	0.88 ± 0.09	1.09 ± 0.18	1.13 ± 0.25	<0.001 †
Cervical tone (Hz)	16.56 ± 1.70	14.76 ± 1.85	14.71 ± 1.99	<0.001 †
Cervical stiffness (N/m)	314.71 ± 43.87	250.60 ± 54.76	247.40 ± 61.21	<0.001 †
Cervical decrement	1.25 ± 0.20	1.35 ± 0.36	1.25 ± 0.25	0.134
Cervical relaxation (ms)	16.53 ± 20.13	20.69 ± 3.49	16.53 ± 2.22	<0.001 †
Cervical creep (Deborah number)	1.01 ± 0.12	1.23 ± 0.18	1.19 ± 0.20	<0.001 †

§: Statistical differences between the three groups. ‡: Statistical differences between both LBP and axSpA groups against the control group. †: Statistical differences between axSpA group and both LBP and control groups. *: Statistical differences between axSpA and control groups. Abbreviations: BMI: body mass index; PCS-12: Physical Component Summary of 12-item Short-Form Health Survey; MCS-12: Mental Component Summary of 12-item Short-Form Health Survey; NPRS: Numerical Pain Rating Scale; BASMI: Bath Ankylosing Spondylitis Metrology Index; BASFI: Bath Ankylosing Spondylitis Functional Index; BASDAI: Bath Ankylosing Spondylitis Disease Activity Index; mSASSS: modified Stoke Ankylosing Spondylitis Spinal Score; ODI: Oswestry Disability Index.

For the MMPs of the lumbar region, the one-way ANOVA showed significant differences between the axSpA group and the others ($p < 0.001$), except for decrement, which was different only between axSpA and healthy groups. The axSpA patients showed a higher tone and stiffness, with more than 2 Hz and 80 N/m in mean, respectively. On the contrary, lower relaxation and creep was found for the axSpA group. The lumbar decrement was significantly higher ($p = 0.007$) in the axSpA group than in the control group (2.01, 95%CI 0.35–0.05), but was not significantly different compared with the sLBP group (0.12, 95%CI −0.27–0.03). No differences were detected between the sLBP and the healthy groups, although, as occurred with the axSpA group, the sLBP patients showed a higher tone, stiffness and decrement, and a lower relaxation and creep, on average, than the healthy ones.

When the cervical region was analyzed, a similar pattern of differences between the axSpA group and the other two groups was detected ($p < 0.001$), except for decrement, which showed no statistical significance. Thus, tone and stiffness were higher, and the relaxation and creep were lower in the axSpA group ($p < 0.001$), with similar values for sLBP and healthy groups ($p > 0.05$ for all MMPs).

The cervical tone, stiffness, and decrement were higher in all groups, and the relaxation and creep were lower for the lumbar region compared with the cervical region. Furthermore, the size of the differences and the variability of the results were, in general, slightly lower for the cervical MMPs than for those found in the lumbar region (Table 1).

3.2. ROC Curves Based on MMPs

To classify subjects with axSpA and healthy controls, the ROC curves of all lumbar MMPs demonstrated statistical significance ($p \leq 0.003$). The high AUC values were for tone, stiffness, relaxation, and creep (0.832< AUC < 0.855), while the lowest ones were for the decrement (AUC = 0.687, 95%CI 0.572–0.801) (Figure 2a). The same pattern of ROC curves was found for the cervical MMPs ($p < 0.001$), except for decrement ($p = 0.904$). The AUCs were between 0.757 (95%CI 0.653-0.861) for the tone and 0.815 (95%CI 0.721-0.909) for the stiffness (Figure 2b).

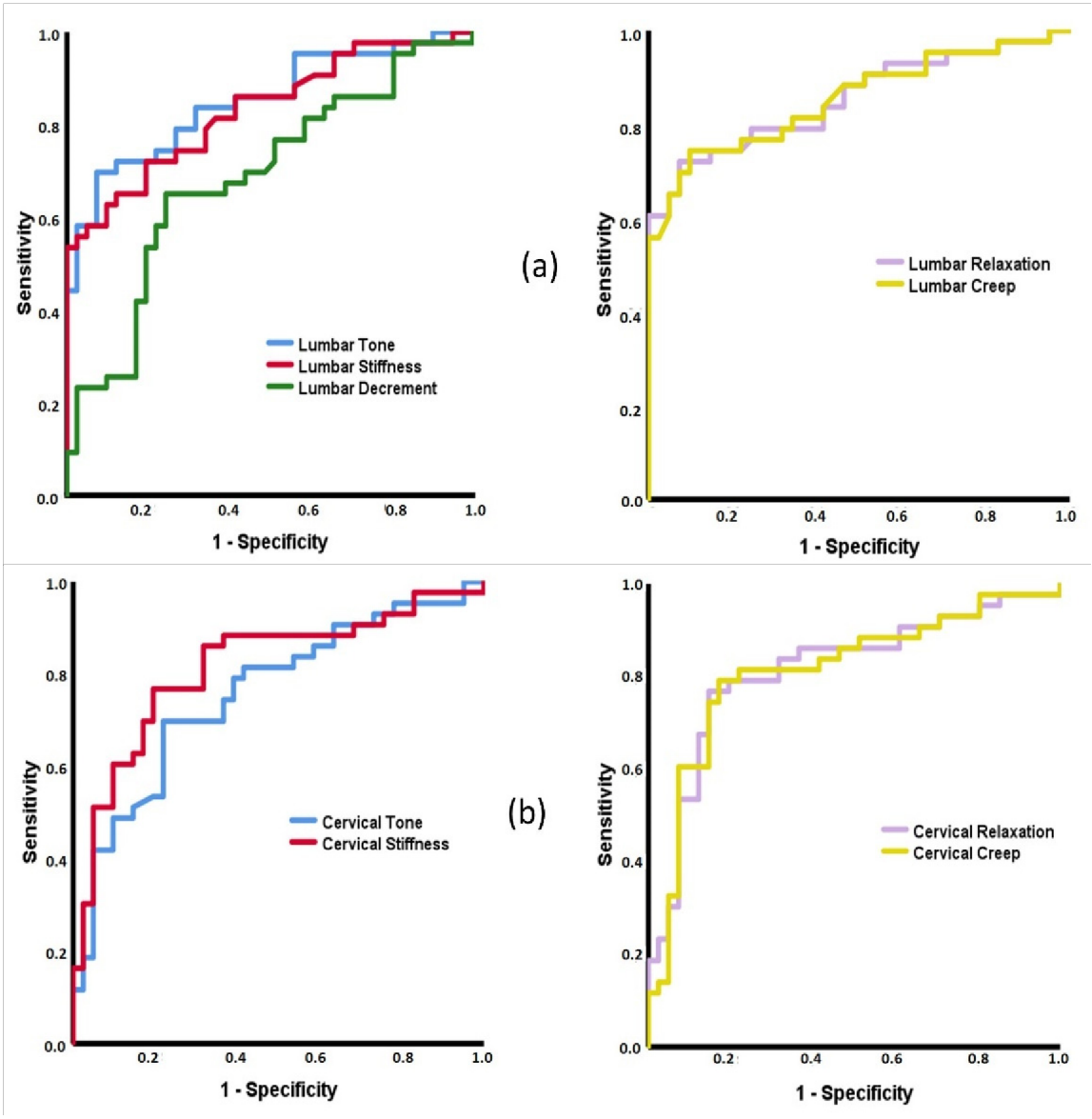

Figure 2. Receiver Operating Characteristic (ROC) curves of the MMPs to discriminate between axSpA and healthy subjects. (**a**, left) Area Under the Curve (AUC) for: Lumbar Tone = 0.851 (95%CI = 0.770–0.933); Lumbar Stiffness = 0.832 (95%CI = 0.745–0.918); Lumbar Decrement = 0.687 (95%CI = 0.572–0.801). (**a**, right) AUC: Lumbar Relaxation = 0.855 (95%CI = 0.772–0.937); Lumbar Creep = 0.854 (95%CI = 0.771–0.936). (**b**, left) AUC for: Cervical Tone = 0.757 (95%CI = 0.653–0.861); Cervical Stiffness = 0.815 (95%CI = 0.721–0.909). (**b**, right) AUC: Cervical Relaxation = 0.813 (95%CI = 0.718–0.909); Cervical Creep = 0.812 (95%CI = 0.715–0.909).

The ROC curves to classify patients with axSpA and sLBP were similar to those obtained for axSpA and healthy controls. Thus, with the only exception of the decrement, all lumbar and cervical MMPs showed AUCs with values higher than 0.8 ($p < 0.001$) **(Figure 3)**. On the contrary, no ROC curve achieved statistical significance ($p > 0.05$) when sLBP and healthy groups were analyzed.

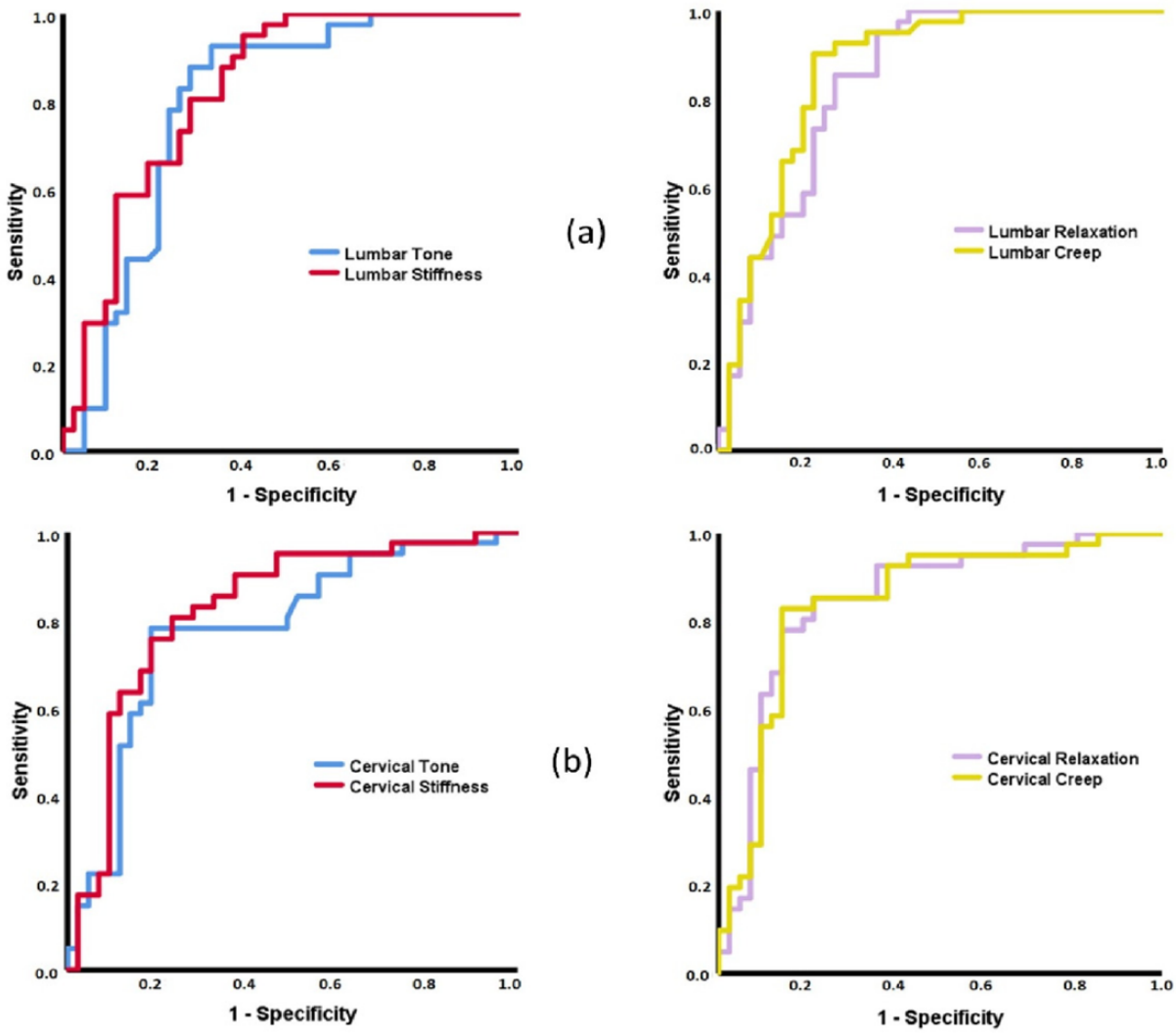

Figure 3. Receiver Operating Characteristic (ROC) curves of the MMPs to discriminate between axSpA and sLBP subjects. (a, left) Area Under the Curve (AUC) for: Lumbar Tone = 0.797 (95%CI = 0.695–0.898); Lumbar Stiffness = 0.828 (95%CI = 0.738–0.917). (a, right) AUC: Lumbar Relaxation = 0.841 (95%CI = 0.755–0.928); Lumbar Creep = 0.868 (95%CI = 0.788–0.948). (b, left) AUC for: Cervical Tone = 0.779 (95%CI = 0.676–0.881); Cervical Stiffness = 0.825 (95%CI = 0.732–0.918). (b, right) AUC: Cervical Relaxation = 0.848 (95%CI = 0.761–0.936); Cervical Creep = 0.846 (95%CI = 0.758–0.935).

3.3. Intra-Group Associations among MMPs, Sociodemographic, and Clinical Variables

The axSpA group showed multiple associations between MMPs and clinical variables, with a higher intensity for the lumbar region. Specifically, age was positively related to lumbar tone, stiffness, and decrement and negatively to cervical tone and decrement ($0.323 < r < 0.696$). Moreover, the evolution time was related to all lumbar MMPs and cervical tone, stiffness, and relaxation in moderate to strong fashion ($|0.743 < r < 0.405|$). Similarly, total pain, PCS-12, and MCS-12 were fair to moderately related

to almost all the MMPs (|0.315 < r < 0.618|). BASMI, BASDAI, and BASFI showed fair to moderate relations with the MMPs, mainly for the lumbar region. In all cases, the higher tone, stiffness and decrement, and the lower relaxation and creep, the higher evolution time, pain, BASMI, BASDAI, and BASFI, and the lower PCS-12 and MCS-12.

Some metrology variables showed fair and moderate correlations (|0.342 < r < 0.560|) with the lumbar MMPs, except for the decrement. Finally, only the lateral spinal flexion showed significant relations with cervical MMPs (|0.384 < r < 0.456|). In all cases, the lower the metrology values, the higher the tone, stiffness and decrement, and the lower the relaxation and creep (Table 2).

Table 2. Correlations between sociodemographic and clinical characteristics within the axSpA group.

	Lumbar Tone	Lumbar Stiffness	Lumbar Decrement	Lumbar Relaxation	Lumbar Creep	Cervical Tone	Cervical Stiffness	Cervical Decrement	Cervical Relaxation	Cervical Creep
Age	0.520**	0.326*	0.696**	NS	NS	0.323*	NS	0.573**	NS	NS
Height	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weight	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BMI	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Evolution time	0.622**	0.513**	0.743**	−0.473**	−0.405**	0.627**	0.505**	NS	−0.407*	NS
Total pain	0.370*	0.412**	0.504**	−0.336 *	NS	0.478**	NS	NS	−0.316*	−0.315*
PCS-12	−0.617**	−0.551**	−0.369*	0.494**	0.476**	−0.610**	−0.462*	NS	0.417*	NS
MCS-12	−0.546**	−0.497**	NS	0.538**	0.540**	−0.592**	−0.467**	NS	0.481**	0.444*
BASMI	0.449**	0.419**	0.385*	−0.330*	NS	NS	NS	NS	NS	NS
BASDAI	0.416**	0.437**	0.445**	−0.352*	NS	0.389*	NS	NS	NS	NS
BASFI	0.500**	0.513**	0.533**	−0.423**	−0.362*	0.356*	NS	NS	NS	NS
mSASSS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Lateral spinal flexion	−0.407**	−0.388*	NS	0.370*	0.342*	−0.456**	−0.456**	NS	0.384*	NS
Tragus to wall distance	0.491**	0.560**	NS	−0.469**	−0.441**	NS	NS	NS	NS	NS
Modified Schöber test	−0.402*	−0.469**	NS	0.455**	0.453**	NS	NS	NS	NS	NS
Intermalleolar distance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cervical rotation	−0.346*	−0.373*	NS	NS	NS	NS	NS	NS	NS	NS

Abbreviations: BMI: body mass index; PCS-12: Physical Component Summary of 12-item Short-Form Health Survey; MCS-12: Mental Component Summary of 12-item Short-Form Health Survey; BASMI: Bath Ankylosing Spondylitis Metrology Index; BASDAI: Bath Ankylosing Spondylitis Disease Activity Index; BASFI: Bath Ankylosing Spondylitis Functional Index; mSASSS: modified Stoke Ankylosing Spondylitis Spinal Score; NS: Not significant (*p*-value > 0.05); * expresses significance at 0.05 level; ** expresses significance at 0.01 level.

In the sLBP group, few significant correlations were detected. In fact, only age showed a consistent trend of fair to strong relations with both lumbar and cervical MMPs (|0.360 < r < 0.767|), except for creep. The higher the age, the higher the tone, stiffness, and decrement, and the lower the relaxation and creep. BMI was negatively related to the cervical decrement (r = −0.342, p = 0.025), and was positively related to cervical relaxation (r = 0.381, p = 0.013) and creep (r = −0.327, p = 0.032). Only fair

correlations were found between the ODI and tone and stiffness at the lumbar level; no other clinical variable was related to the MMPs.

Some metrology variables showed significant correlations with MMPs to a fair intensity, mainly at the lumbar region. This pattern was identified for lateral spinal flexion, intermalleolar distance, and cervical rotation (|0.309 < r < 0.398|). In all cases, the higher tone, stiffness, and decrement, and the lower relaxation and creep, the lower the metrology values. Only the intermalleolar distance showed correlations with two cervical MMPs (stiffness: r = −0.342, p = 0.025; decrement: r = −0.475, p = 0.001) (Table 3).

Table 3. Correlations between sociodemographic and clinical characteristics within the sLBP group.

	Lumbar Tone	Lumbar Stiffness	Lumbar Decrement	Lumbar Relax	Lumbar Creep	Cervical Tone	Cervical Stiffness	Cervical Decrement	Cervical Relax	Cervical Creep
Age	0.470**	0.579**	0.605**	−0.394**	NS	0.464**	0.523**	0.767**	−0.360*	NS
Height	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.339*
Weight	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.379*
BMI	NS	NS	NS	NS	NS	NS	NS	−0.342*	0.381*	0.327*
Total pain	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PCS-12	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MCS-12	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ODI	0.366*	0.322*	NS	NS	NS	NS	NS	NS	NS	NS
Lateral spinal flexion	−0.348*	−0.333*	NS	−0.311*	NS	NS	NS	NS	NS	NS
Tragus to wall distance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Modified Schöber test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Intermalleolar distance	NS.	−0.349*	−0.309*	NS	NS	NS	−0.342*	−0.475**	NS	NS
Cervical rotation	−0.384*	−0.332*	NS	0.398**	0.393**	NS	NS	NS	NS	NS

Abbreviations: BMI: body mass index; PCS-12: Physical Component Summary of 12-item Short-Form Health Survey; MCS-12: Mental Component Summary of 12-item Short-Form Health Survey; ODI: Oswestry Disability Index; NS: Not significant (p-value > 0.05). * expresses significance at 0.05 level; ** expresses significance at 0.01 level.

For the control group, again the age was the variable that showed more quantity and more intensity correlations with MMPs. Specifically, the age was positively correlated with lumbar tone (r = 0.685, $p \leq$ 0.001), stiffness (r = 0.670, $p \leq$ 0.001), decrement (r = 0.570, $p \leq$ 0.001), cervical tone (r = 0.312, p = 0.042) and decrement (r = 0.475, p = 0.01), and negatively with lumbar relaxation (r = −0.604, $p \leq$ 0.001) and creep (r = −0.513, $p \leq$ 0.001). Furthermore, the anthropometrical variables showed a fair to strong relationship with the cervical MMPs, as occurred between cervical decrement (r = −0.463, p = 0.002) and relaxation (r = 0.420, p = 0.005), and height, and between all cervical MMPs and the weight (|0.401 < r < 0.665|) and BMI (|0.306 < r < 0.702|). With the exception of the negative relation between MCS-12 and cervical decrement (r = −0.448, p = 0.042), no other clinical variable was correlated with any MMP.

Finally, some metrological variables were related to both lumbar and cervical MMPs, in all cases in a fair to moderate intensity. This was the case with the tragus to wall distance with lumbar and cervical decrement (r = −0.315, p = 0.040 and r = −0.428, p = 0.004, respectively) and cervical relaxation (r = 0.372, p = 0.014), and the cervical rotation with lumbar tone (r = −0.335, p = 0.028), lumbar and cervical stiffness (r = −0.340, p = 0.026, r = −0.311, p = 0.043, respectively), and lumbar and cervical decrement (r = −0.521, $p \leq 0.001$, r = −0.382, p = 0.011, respectively). In all cases, the higher tone, stiffness, and decrement and the lower relaxation and creep were linked to the lower metrological variable values (Table 4).

Table 4. Correlations between sociodemographic and clinical characteristics within the healthy control group.

	Lumbar Tone	Lumbar Stiffness	Lumbar Decrement	Lumbar Relax	Lumbar Creep	Cervical Tone	Cervical Stiffness	Cervical Decrement	Cervical Relax	Cervical Creep
Age	0.685**	0.670**	0.570**	−0.604**	−0.513**	0.312*	NS	0.475**	NS	NS
Height	NS	NS	NS	NS	NS	NS	NS	−0.463**	0.420**	NS.
Weight	NS	NS	NS	NS	NS	−0.401**	−0.413**	−0.442**	0.665**	0.603**
BMI	NS	NS	NS	NS	NS	−0.408**	−0.445**	−0.306*	0.642**	0.702**
PCS-12	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MCS-12	NS	NS	NS	NS	NS	NS	NS	−0.448*	NS	NS
Lateral spinal flexion	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tragus to wall distance	NS	NS	−0.315*	NS	NS	NS	NS	−0.428**	0.372*	NS
Modified Schöber test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Intermalleolar distance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cervical rotation	−0.335*	−0.340*	−0.521**	NS	NS	NS	−0.311*	−0.382*	NS	NS

Abbreviations: BMI: body mass index; PCS-12: Physical Component Summary of 12-item Short-Form Health Survey; MCS-12: Mental Component Summary of 12-item Short-Form Health Survey; NS: Not significant (p-value > 0.05). * expresses significance at 0.05 level; ** expresses significance at 0.01 level

4. Discussion

This study showed that cervical and lumbar MMPs are different depending on the type of spinal pain. In fact, except for the decrement, the spinal MMPs of axSpA patients showed a higher tone and stiffness and a lower relaxation and creep than those with sLBP and healthy controls. Furthermore, all lumbar and cervical MMPs, except decrement, correctly classified patients with axSpA and healthy subjects, as well as subjects with axSpA and sLBP, but not with sLBP and those who were healthy, according to ROC curves.

Each one of the groups showed a different pattern of correlations between MMPs and sociodemographic and clinical variables, age being the variable most correlated with the MMPs of both regions for the three groups. Moreover, the lumbar MMPs of the axSpA patients were correlated with clinical and metrological variables in a moderate to strong intensity, while a scant number of correlations with moderate intensity were found for sLBP patients. Furthermore, the healthy group showed a similar

trend to the sLBP one, but more correlations between cervical MMPs and weight and BMI inside this group were identified.

4.1. Differences in MMPs, Spinal Mobility, Pain, and Quality of Life between Groups

Higher lumbar tone or stiffness values were found in patients with axSpa compared to sLBP and healthy ones. Our results for the axSpA group are consistent with recent research that found that higher lumbar and cervical tone, stiffness and decrement, and lower relaxation and creep for axSpA patients compared to healthy controls [45] is possibly due to increased spinal stiffness associated with axSpA [17,19,43]. Furthermore, the lumbar tone, stiffness, and decrement of the current sLBP and healthy groups were similar to those reported in subjects with chronic LBP and healthy subjects, respectively [54]. On the contrary, our results showed higher tone and stiffness and lower relaxation and creep than those reported in other younger axSpA and healthy samples [17,53], probably due to the changes of the MMPs associated with age [44].

Surprisingly, the sLBP and healthy groups did not show statistical differences in the MMPs, although the tone, stiffness, and decrement for the sLBP group were slightly higher than for the healthy one in both spinal regions, in line with results previously reported in sLBP [6], and were slightly lower than those previously reported for cLBP [44]. Such findings could be explained by the association between the behavior of MMPs and the evolution of the LBP from acute to chronic, where higher tone, stiffness, and lower elasticity have been described [30,40]. Furthermore, this different behavior between the types of spinal pain, and even between spinal regions, could be explained by the spinal biomechanics or the different molecular compositions of the muscle tissues responsible, among other aspects, of the development of passive tension, related to the collagen content [63].

Related to lumbar decrement, which is the inverse of the tissue elasticity, we found differences only between axSpA and healthy ones. Our decrement values at the lumbar level were similar to those detailed in previous studies [38,43,44], although these researchers found differences between groups. Moreover, the cervical decrement did not show differences between the three groups in the current research. These results are consistent with those reported for axSpA patients by Garrido-Castro et al. [45] However, other recent research in sLBP patients has shown that the spinal decrement is important to distinguish between subjects with acute spinal mechanical pain and healthy ones [6], which could mean that the elasticity is affected to different intensities depending on the type of spinal pain, the chronicity of the disease or even other unknown factors.

Independent of the statistical significance, the differences in the MMPs found between axSpA, sLBP, and healthy groups exceeded in all cases the Minimum Detectable Change in both regions (MDC: lumbar

< 2%, cervical > 7%) [45]. Furthermore, the differences obtained for tone and stiffness between axSpA and sLBP in the present study and between axSpA and healthy groups were greater than those reported in previous LBP studies (0.7 Hz and 26.6 N/m) [40,64] and even in healthy subjects (1.22 Hz and 45.40 N/m) [65], which reflects the clinical significance of the current results.

Concerning metrology, several outcomes also showed differences between the three groups. Specifically, the lowest cervical rotation was found in the axSpA group, followed by the sLBP group. This pattern of mobility restriction can be caused by the pathological status at the spinal level, with compensatory movements in other structures, such as the ribcage. In addition, lateral flexion and intermalleolar distance differentiated the axSpA group from the other two groups, but not the sLBP and healthy subjects. The mean values of both variables were similar to those reported by other studies with patients with spinal inflammatory pathology [66].

Finally, the PCS-12 was higher in healthy subjects with respect to spinal pain patients, as has been previously reported in acute spinal pain [6], but there was no difference between patients with sLBP and with axSpA, which reflects the negative consequences of the spinal pain disorders in the patients' QoL. The mean values of the PCS-12 in our sample were similar to others reported in sLBP [6] and cLBP [67] researches. However, the data related to the MCS-12 in our study are higher and are similar between groups. The causes of this behavior could be complex in chronic diseases [68], which exceeds the objectives of the current research, but it could be related to the recent improvements of the healthcare received for the chronic inflammatory patients [69].

4.2. Capacity of MMPs to Discriminate between Patients with Inflammatory and Mechanical Low Back Pain and Healthy Subjects

The ROC curves of all lumbar and cervical MMPs, except for decrement, demonstrated an excellent capacity for classifying subjects with axSpA and healthy controls. A similar pattern yields the ROC curves for patients with axSpA and sLBP. No previous research studied the discriminant capacity of MMPs to identify axSpA patients, which prevents possible direct comparisons with the current data. However, it has been suggested that MMPs can become a specific marker of the axSpA status and progression [18,45,64], increasing interest in their determination in spinal pain syndromes in both lumbar and cervical regions.

With respect to sLBP and healthy groups, no other MMP could discriminate the subjects. In a previous study, the cervical decrement consistently classified subjects with acute LBP and healthy subjects [6]. The elasticity may be a specific characteristic in LBP at the early stages, but the current study cannot confirm this.

4.3. Associations between MMPs with Sociodemographic and Clinical Data

In general, there were different patterns of correlations depending on the study group. Therefore, different origins of spinal pain can determine specific associations between MMPs and other clinical and sociodemographic variables. The age was the variable correlated with a greater number of MMPs, which is directly related to tone, stiffness, and decrement, and inversely related to relaxation and creep, independent of the study group. These results agree with previous research at the spinal level, both in axSpA [45,46] and cLBP patients [44] and in other regions, such as neck and upper and lower limb muscles [43,51,70], which demonstrate that the advance of age is related to MMPs changes (i.e., increase in tone and stiffness, decrease in elasticity, relaxation time and viscosity), independent of the clinical state. Moreover, as proposed by White et al., the longer duration of the disease may be related to the lumbar myofascial changes [43], as occurred in the current study, where higher tone and stiffness at lumbar and cervical levels, and lower relaxation, are related to a higher evaluation time of the axSpA.

Regarding the metrological data, a negative relationship between the cervical rotation and lumbar tone and stiffness was observed in all groups. This relationship has already been reported for acute LBP patients [6] and could be based on the regional interdependence concept [71], which establishes the possible consequences of specific disorders (i.e., lumbar pain) at distant levels (i.e., at cervical region). The lumbar lateral flexion showed negative relations with lumbar tone and stiffness and positivity with relaxation and creep in both spinal pain groups, as previous research stated for axSpA [46]. Nevertheless, only the axSpA patients showed a relationship with cervical MMPs, probably due to the most intense cervical involvement in patients with axSpA.

The clinical variables of the axSpA group, such as evolution time, BASMI, BASDAI, and BASFI, correlated with most of the lumbar MMPs and with cervical tone. This outcome is relevant since possible interactions between the muscle alterations and the clinical state could explain some pathological mechanism. In fact, it is known that mechanical stress is a relevant factor in the pathophysiology of the disease when an advanced structural damage is found [72]. Furthermore, the pain was related to different MMPs of both spinal regions only in axSpA patients. Therefore, these results reinforce that muscle tone could be a contributor to the bidirectional pain-spasm model [40] as well as being the cause of a circulatory deficit in the musculature that generates an increase in stiffness [73], at least in chronic states. Moreover, the associations found between MMPs and QoL, detected mainly in the axSpA group, confirm the impact of the physical symptoms, including rigidity, linked to the axSpA progression in the physical and mental state, as established by other authors [16,20].

The low number of correlations between MMPs and sociodemographic variables identified in the sLBP group, which agrees with previous patterns in acute LBP [6], differs from the pathological changes described in chronic stages and is related to the viscoelastic characteristics of the musculature [74].

Moreover, the disability was only associated with the lumbar tone and stiffness, with fair intensity. In other words, the pathological mechanisms underlying the deterioration associated with cLBP have not occurred in subacute stages. The similarities identified in the correlation pattern between MMPs and metrological and QoL data, when the sLBP and the healthy groups were compared, could be in line with this approach. Finally, the stable pattern of correlations between cervical MMPs and weight and BMI found in the healthy group has not been previously reported. Nonetheless, the positive relationship between anthropometric variables, such as weight and BMI, the cervical relaxation time and the tissue viscosity, was reported in a similar sample [6]. This association could be originated by the increment of lipid content in skeletal muscles when weight and BMI increase [75].

4.4. Strengths and Limitations

One of the strengths of this study was the evaluation of cervical MMPs in patients with a main alteration at the lumbar level, as previously suggested [54]. On the other hand, it is necessary to emphasize the clinical applicability of this research. Indeed, the determination of the MMPs is fast and painless and does not need to use expensive imaging systems. Finally, the study results could help in decision making, facilitating the adequate selection of treatment approaches or the identification of clinical effects for spinal pain patients [76-78].

Likewise, it is necessary to recognize some limitations of the study. First, the assessor was not blinded to the group assignment, as the subjects with spinal pain were in an active phase of disease. Second, the depth reached by the MyotonPRO device does not exceed 2 cm [17], which prevented the recording of the MMPs in deep musculature. Third, our study did not differentiate the sample by sex, which could be interesting since differences between both sexes have been described in the muscle structure. Finally, the differentiation of the subjects with spinal pain according to the time suffering from pain (i.e., acute, subacute, or chronic stages) is of interest since a delay of only six months in diagnosis can lead to structural damage and worse treatment results [11], but this was not performed in this study.

5. Conclusions

The lumbar and cervical MMPs are different depending on the type of spinal pain. The patients with axSpA show a higher tone and stiffness and lower relaxation and creep than those with sLBP and healthy controls. Furthermore, the spinal MMPs, except for decrement, are able to classify patients with axSpA and healthy subjects, but not subjects with sLBP and healthy ones, which increases the interest regarding the assessment of the spinal MMPs as a possible marker of the muscle state and progression in the clinical context of inflammatory spinal pain.

The patients with axSpA show a specific pattern of correlations between MMPs and clinical and metrological variables that do not appear in sLBP and healthy subjects. This pattern associates a worse state and progression of axSpA to higher tone and stiffness in lumbar and cervical regions.

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Abbreviation

ASAS	SpondyloArthritis International Society
axSpA	Axial spondyloarthritis
AUC	Area Under the Curve
BASDAI	Bath Ankylosing Spondylitis Disease Activity Index
BASFI	Bath Ankylosing Spondylitis Function Index
BASMI	Bath Ankylosing Spondylitis Metrology Index
BMI	Body Mass Index
cLBP	Chronic low back pain
ICC	Intraclass Correlation Coefficient
LBP	Low Back Pain
MCS-12	Mental Component Summary of 12-item Short-FormHealth Survey
MMP	Muscle Mechanical Property
mSASSS	Modified Stoke Ankylosing Spondylitis Spinal Score
NPRS	Numerical Pain Rating Scale
NS	Not Significant
NWC	Number of Words Chosen
PCS-12	Physical Component Summary of 12-item Short-Form Health Survey
QoL	Quality of life
ROC	Receiver Operating Characteristic
ROM	Range Of Motion
SF-12	12-item Short-Form Health Survey
sLBP	Subacute LBP
95%CI	95% Confidence Interval

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CAPÍTULO IV: Influencia de los movimientos de la columna asociados con la evaluación física, sobre las propiedades mecánicas de la musculatura paraespinal lumbar en sujetos con dolor lumbar

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Article

Influence of Spinal Movements Associated with Physical Evaluation on Muscle Mechanical Properties of the Lumbar Paraspinal in Subjects with Acute Low Back Pain

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Abstract: This research aimed to identify changes in muscle mechanical properties (MMPs) when a standardized sequence of movements is performed and to determine the influence of acute low back pain (LBP) and age on the MMPs. Socio-demographic, clinical variables and MMPs were collected in 33 patients with LBP and 33 healthy controls. A 2 × 2 × 2 (group × age × time) analysis of variance (ANOVA) mixed model was used to determine the effect of the study factors on the different MMPs. There were no significant triple interactions. After the movements, tone and stiffness increased 0.37 Hz and 22.75 N/m, respectively, in subjects <35 years, independent of their clinical status. Relaxation showed differences by age in healthy subjects and creep in LBP subjects. Furthermore, elasticity was higher in <35 years ($p < 0.001$) without the influence of any other factor. In conclusion, sequenced movements can modify tone and stiffness as a function of age, while age-associated changes in viscoelastic characteristics depends on pain but not on movements. The MMPs should be assessed, not only at the beginning of the physical examination at rest, but also along the patient's follow-up, depending on their pain and age, in a clinical setting.

Keywords: myotonometry; thixotropy; viscoelasticity; spinal pain

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1.Introduction

Back pain is one of the most common musculoskeletal pain disorders, affecting 80% of the population at some point in their lives [1]. The increasing prevalence of low back pain (LBP) is extensively detailed in the literature [2,3], which shows the necessity of a better understanding of the acute stage of the pathology to improve diagnosis and treatment, as well as to minimize the socio-economic burden [4]. Researchers categorize about 85% of LBP as non-specific, without structural changes, inflammation, or specific underlying disease [5,6]. Nevertheless, LBP has been associated with changes in neuromuscular activity [7,8], decreased spinal mobility, limited lumbar muscle flexibility, and altered spinal kinematics [9]. Furthermore, a modification of the mechanical changes associated to within and between muscle activity redistribution in subjects with LBP has been described [6,7].
These changes determine a reduction in lumbar spine function and alteration of the muscle mechanical properties (MMPs) [9-12], as well as inadequate motor control [13].

The MMPs play a central role in several physiological and pathophysiological processes, suggesting a relationship between pain and muscle stiffness in different spinal pain disorders, including LBP [14,15]. However, previous studies have not described predictive models of the anisotropic viscoelastic responses of relaxed muscles under physiological conditions. The changes in muscle tissues that determine spinal stiffness are not fully understood, requiring further research [15,16]. One of the characteristics of muscle tissue that could modify its mechanical properties is thixotropy [17]. Thixotropy refers to the property of a tissue to become fluid under certain conditions, such as voluntary movement or passive muscle stretch, and to return to its primary characteristic at rest [18]. Thixotropic substances are, therefore, history-dependent and have a “memory time” [19,20]. Some researchers described this thixotropic behaviour as a “short-range stiffness”, which tends to reduce or disappear after a few repetitions of movement and reappear after resting in healthy subjects [21]. The influence of such viscoelastic properties on the determination of MMPs in acute LBP and their modifications associated with the spinal movements performed on the physical evaluation, age or sex are relevant from a clinical point of view.

New technologies, such as elastography, help to study the passive mechanical behaviour of skeletal muscles [22]. However, their high cost makes them inaccessible to a clinical setting, challenging the determination of the MMPs. Since a decade ago, the device MyotonPRO© emerged as a non-invasive and reliable alternative to assess and monitor MMPs with clinical applications Several studies have shown sufficient accuracy and precision to determine MMPs in spinal muscles [23-26] and other tissues and regions [23,27-29], although efforts to better determine the concurrent validity need further research [30]. Previous research has associated MMPs alterations, specifically an increase in stiffness and tone or a decrease in elasticity, and axial spondyloarthritis [24]. Moreover, aging is associated with

structural tissue remodelling, which contributes to increased stiffness and tone, and decreased elasticity at the cervical spine, and also the extremities [31,32]. Age and gender can also influence measures of muscle tone in the orofacial musculature [33]. Likewise, changes in cervical and lumbar MMPs concerning position or movement have been identified [31,33-36]. However, the behaviour of these patterns in the central stabilizer system, such as the paraspinal muscles [12], remains unknown when the subjects develop a standardized sequence of spinal movements, as is performed during physical examination, which could improve the diagnosis and treatment processes.

Therefore, this study aimed to identify changes in paraspinal MMPs when submitted to a standardized sequence of lumbar movements and to determine the influence of lumbar pain and age in those changes.

2. Methods

An observational, test-retest study including subjects with LBP and healthy controls was performed. Participants were recruited with a non-probabilistic sampling of two centres, Physiobalance (private physiotherapy centre) and the Biosanitary campus of the University of Córdoba, Spain, from November 2018 to January 2021. Assessments were conducted between April 2019 and March 2021. The Córdoba Research Ethics Committee approved this project (reference number 4016/2018). All participants signed written informed consent.

2.1. Participants

Sixty-six subjects of both sexes participated in this study. Thirty-three of them presented acute LBP with less than four weeks of evolution [37] and a pain score of ≥3 on the visual analogue scale (VAS) [38]. The control group consisted of 33 healthy subjects, matched by sex, age (±3 years), and body mass index (BMI) (±3 kg/m^2), without spinal pain in the last six months or any neurological or musculoskeletal pain disorder.

The exclusion criteria for both groups were history of traumatic lesions at the spine, scoliosis, spinal surgery, congenital deformity, inflammatory disease, pregnancy, and receiving spinal physiotherapy treatment in the last six months.

2.2. Sample Size

A moderate difference size (Cohen d = 0.7) [39], considered clinically relevant in musculoskeletal pathology and physiotherapy field [40], was estimated for between-group comparisons of MMPs. With an alpha level of 0.05 and power of 0.8, 33 subjects per group were needed (GPower 3.1 software, Düsseldorf, Germany).

2.3. Assessments and Procedures

After signing the informed consent form, researchers collected socio-demographic (age, sex, weight, height, and BMI) and clinical (severity of back pain and disability using a VAS scale and the Oswestry Disability Questionnaire (ODI) data, respectively [41]). Subsequently, the MMPs, using a MyotonPRO® (Myoton AS, Tallinn, Estonia) device, were assessed before and after a standardized sequence of movements. The MyotonPRO© provides measurements of five MMPs: tone or state of tension, determined by the frequency (Hz); biomechanical properties such as dynamic stiffness (N/m) and decrement, that characterizes elasticity; and viscoelastic properties such as relaxation or mechanical stress relaxation time (ms) and creep (Deborah number), which corresponds to the gradual elongation in the tissue when subjected to constant tension [42]. The device induces a natural damped oscillation of the tissue following the application of a controlled load through a cannula. To the initial 0.18 N of compression of the subcutaneous tissue, the MyotonPRO® added a pulse of 15 ms and 0.40 N of mechanical force. The accelerometer at the sensor's tip provides the data that characterizes the tissue [43].A clinician with more than fifteen years of clinical experience, identified the spinous process of L5 by palpatory testing and performed the tonometric test on the erector spinae, located 2.5 cm to the right and left of the spinous process. The assessment was performed with the patient in a prone position with both arms alongside the body. Muscle measurements were taken first on the left side, then on the right side, and the process was repeated. The measurement was taken during a five-second apnea after the normal expiratory phase [24,44] (Figure 1).

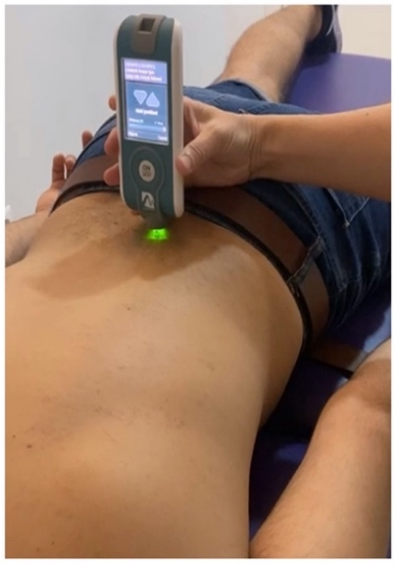

Figure 1. Procedure for measuring MMPs at lumbar level with MyotonPRO.

The standardized sequence of movements involved the maximum range of motion in frontal flexion, extension, lateral flexion, and rotation of the spine in a standing position, all routinely used in the

conventional evaluation of the amount of movement of patients in a clinical setting [45]. Each movement lasted four seconds, with two seconds to achieve the maximum range of motion and two seconds to return to the neutral position, controlled with a metronome (view Supplementary Material, Figures S1–S6). A total of three repetitions per movement were performed, supervised by a second clinician with more than ten years of clinical experience. The whole procedure did not take more than ten minutes.

2.4. Statistical Analysis

Descriptive results for qualitative variables were expressed as frequencies and percentages. Quantitative variables were expressed as means, standard deviations, and 95% confidence interval (CI). The Kolmogorov–Smirnov test was used to assess the normality of the data distribution, with $p > 0.05$ in all case. In a preliminary analysis of the data, no side-to-side differences were identified when applying Student's t-test between measurements on each group ($p > 0.05$). Consequently, pooled (mean) data from both sides were used in the main analysis.

A 2 × 2 × 2 mixed model (group × age × time) of analysis of variance (ANOVA) was used to determine the effect of the study factors on the different MMPs. The first factor was clinical status (LBP patients vs. healthy subjects). The second factor was the age, with two levels (subjects <35 vs. >35 years) as previous studies with similar objectives has defined [1,46-48]. Finally, the third factor analysed was time of assessment, with before and after movement measure as the levels of this repeated measures factor. The first hypothesis of interest was the triple interaction. In the absence of triple interaction, double interactions (group-by-time, group-by-age, time-by-age) were those of interest. If no interactions were observed, the main effect of each factor was finally studied. Pairwise comparisons were conducted by post hoc Bonferroni tests when necessary.

In all cases, the confidence level was established at 95%, and the statistical significance level for the tests was $p < 0.05$. The analyses were carried out by IBM SPSS® Statistics version 25 (SPSS Inc., Chicago, IL, USA).

3. Results

A total of 66 subjects were analysed, 33 with acute LBP (<35 years $n = 19$, >35 years $n = 14$) and 33 healthy controls (<35 years $n = 18$, >35 years $n = 15$), with a mean age of 33.3 ± 11.8 years and a BMI of 23.9 ± 2.6 kg/m^2 (Table 1).

Table 1. Demographic characteristics of the sample.

	LBP Group (N = 33)	Healthy Group (N = 33)	*p*-Value
Age (years)	33.05 ± 11.8	33.6 ± 12.0	NS
Sex (female/male)	14/19	14/19	NS
BMI (kg/m²)	24.2 ± 2.45	23.6 ± 2.8	NS
Pain intensity (VAS)	4.7 ± 1.7	-	-
ODI	7.8 ± 5.4	-	-

Results are expressed as: mean ± standard deviation, frequencies. Abbreviations: BMI: Body mass index, VAS: Visual analogic scale, ODI: Oswestry disability questionnaire, NS: not significant differences.

There was no triple interaction when analysing the pooled effect of movement, clinical status, and age on the behaviour of the MMPs (frequency: F = 0.169, p = 0.682; stiffness: F = 0.623, p = 0.433; decrement: F = 0.947, p = 0.334; relaxation: F = 0.003, p = 0.982; creep: F = 0.632, p = 0.430).

With borderline statistical significance found in the double interactions, frequency (F = 3.342, p = 0.045) and stiffness (F = 3.145, p = 0.048) increased 0.37 Hz (95% CI 0.06–0.70) and 22.75 N/m (95% CI 5.83–39.67), respectively, in the younger subjects after the movements, independent of their clinical status. Only the baseline measure showed significant differences ($p < 0.05$) between both age groups in both MMPs. No other time-by-age interaction was identified neither for decrement (F = 0.060, p = 0.808), relaxation (F = 1.599, p = 0.211), and creep (F = 0.007, p = 0.934) outcomes.

Likewise, the relaxation and creep showed interactions between age and clinical status of the subjects (F = 3.202, p = 0.047; F = 3.345, p = 0.045, respectively), with relaxation being 2.98 ms (95% CI 0.36–6.01) higher in young healthy subjects. In contrast, creep was 0.10 (95% CI 0.06–0.15) greater in subjects with LBP over 35 years. Differences between patients and controls in those over 35 were also found (mean difference 0.12, 95% CI 0.01–0.27, p = 0.04). Frequency (F = 1.391, p = 0.243), stiffness (F = 0.675, p = 0.414), and decrement (F = 0.013, p = 0.908) did not show group-by-age interaction.

The group-by-time interaction did not reveal any statistical significance (frequency: F = 0.244, p = 0.623; stiffness: F = 0.028, p = 0.868; decrement: F = 0.212, p = 0.647; relaxation: F = 0.135, p = 0.714; creep: F = 0.111, p = 0.740).

Finally, the evaluation of the main factors showed that the decrement was different depending on age. Thus, older subjects presented higher decrement than the younger ones (mean difference 0.337, 95% CI 0.21–0.46, F = 29.176, $p < 0.001$) (Table 2).

Table 2. Results of MMPs according to the clinical status (LBP group, N = 33; healthy group, N = 33), age, (under 35 years, n = 37; over 35 years, n = 29), and time of assessment.

	Group	Age	Baseline evaluation	After movement evaluation	Between evaluation differences
Frequency (Hz)	**LBP**	**<35**	14.26±1.50	14.64±2.07	-0.38(-0.83,0.06)
	Healthy		13.94±1.40	14.30±1.87	-0.36(-0.82,0.09)
	Between clinical status differences		0.31(-0.98,1.61)	0.33(-1.09,1.77)	
	LBP	**>35**	14.91±2.51	14.98±2.50	-0.07(-0.59,0.44)
	Healthy		15 87±2,46	15.73±2.33	0.14(-0.35,0.64)
	Between clinical status differences		-0.96(-2.43,0.50)	0.74(-2.36,0.87)	
Stiffness (N/M)	**LBP**	**<35**	250.26±59.63	269.03±89.23	-18.77(-42.37,4.82)
	Healthy		235.23±55.73	261.95±110.83	-26.72(-50.97,-2.47)
	Between clinical status differences		15.02(-30.99,61.05)	7.08(-53.09,67.26)	
	LBP	**>35**	283.36±80.95	295.48±76.09	-12.12(-39.61,15.37)
	Healthy		309.95±85.27	309.85±81.04	0.10(-26.46,26.66)
	Between clinical status differences		-26.58(-78.58,25.41)	14.36(-82.35,53.62)	
Decrement	**LBP**	**<35**	1.05±0.23	1.08±0.31	-0.02(-0.10,0.05)
	Healthy		1.08±0.22	1.04±0.17	0.03(-0.04,0.11)
	Between clinical status differences		-0.02(-0.19,0.15)	0.04(-0.13,0.21)	
	LBP	**>35**	1.41±0.24	1.41±0.21	0.00(-0.09,0.09)
	Healthy		1.38±0.34	1.40±0.33	-0.01(-0.10,0.07)
	Between clinical status differences		0.03(-0.16,0.22)	0.01(-0.18,0.21)	
Relaxation (Ms)	**LBP**	**<35**	19.35±5.89	19.05±5.96	0.29(-0.38,0.98)
	Healthy		20.79±4.05	20.35±4.61	0.44(-0.28,1.17)
	Between clinical status differences		-1.44(-4.56,1.66)	-1.30(-4.54,1.94)	
	LBP	**>35**	19.26±4.20	19.43±4.54	0.16(-0.96,0.63)
	Healthy		17.58±3.86	17.61±3.70	-0.03(-0.80,0.73)
	Between clinical status differences		1.68(-1.77,5.15)	1.81(-1.79,5.43)	
Creep (Deborah Number)	**LBP**	**<35**	1.15±0.14	1.13±0.19	0.02(-0.05,0.09)
	Healthy		1.20±0.22	1.16±0.28	0.04(-0.035,0.11)
	Between clinical status differences		-0.04(-0.19,0.09)	0.03 (-0.19,0.12)	
	LBP	**>35**	1.27±0.28	1.22±0.28	0.05(-0.02,0.14)
	Healthy		1.14±0.21	1.12±0.18	0.01(-0.07,0.09)
	Between clinical status differences		0.13(-0.25,0.30)	0.09(-0.08,0.27)	

Results are expressed as mean ± standard deviation, mean difference (95% confidence interval).

4. Discussion

The results showed that paraspinal lumbar MMPs have different behaviour under specific conditions of lumbar movements, clinical status or age. Thus, the sequenced lumbar movements protocol

influenced tone and stiffness depending on age, with lower values for the MMPs in younger subjects, which were more susceptible to be influenced by movement. However, the presence of LBP did not influence MMPs. On the other hand, although with almost statistical significance, the viscoelastic state of paraspinal muscles, expressed as relaxation and creep, depends on the combination of pain and age. While healthy subjects showed a reduction in relaxation with age, these differences did not occur in individuals with LBP. The presence of pain determined the differences in creep concerning age. In this case, the performance of sequenced lumbar movements did not influence the MMPs. Furthermore, the elasticity, as the inverse of the decrement, was higher in younger subjects, without the influence of any other factor.

Curiously, when the presence or absence of LBP was analysed separately, no significant differences were detected, despite the higher values of tone, stiffness, and lower values of decrement, relaxation, and creep found in LBP subjects. This was an unexpected result, since acute LBP is commonly associated to muscle spasm throughout the paraspinal muscles [13,49,50]. However, it could be explained by the mild disability that showed the current sample. Finally, it is relevant to note that there was no interdependence among the execution of the movements, the age, and the clinical condition of the subjects, showing that the three factors were independent. In summary, the influence of movements, pain, and age is different depending on each specific MMP, which means that MMPs should be assessed, not only at the beginning of the physical examination, but also along the follow-up of the patient, with emphasis on elder subjects and those with pain.

This study determined the interaction between the effect of sequenced movements and the advancing of age on tone and stiffness at the lumbar level, where the first measure reports a difference between age groups of 1.29 Hz that decreases to 0.88 Hz after movement. This difference indicates that younger subjects experienced a change in their muscle tone that did not occur in older subjects. Regarding stiffness, from a difference between age groups of more than 50 N/m, younger subjects increased their stiffness more than 8% after the movements, while older subjects showed a rise of only 2%. Apparently, our results would contradict the behaviour of thixotropic properties of specific tissues, which establishes the reduction of viscosity and, therefore, of muscle stiffness, during and, for some time, after movement [19,21,51]. However, the procedures to perform the movements associated to physical evaluation may explain the results. In fact, Altman et al. [18] reported that the frequencies of movements that allow observing both thixotropic and rheopectic reactions, this one being opposite phenomenon to thixotropy, in muscle fibres are in the range of 1 to 20 Hz [20]. Specifically, in those movements below 1 Hz, a rheopectic behaviour is observed in activated fibres in rabbits [18]. Likewise, although some authors report thixotropic behaviours, even in short-range movements or with just two repetitions [21,51], the recovery of rigidity could occur after only 15 s of rest [21]. This could explain our

observations, because the lumbar movements associated with physical evaluation have a low frequency and are followed by rest periods.

On the other hand, the fact that only subjects under 35 years presented a significant change in muscle tone and stiffness after movement supports the relationship between age and MMPs changes [14,31,32,44]. Supporting this approach, Ayapong-Badu et al. [32] identified an 30% decrease in elasticity between age groups for biceps brachialis and between 20% and 30% for rectus femoris, as was detected in our sample in the lumbar muscles, and changes in tone of 10%. With similar aims, Kocur et al. [31] showed that aging provokes an increase in the tone and stiffness of 11–17% for sternocleidomastoid and trapezius muscles in healthy subjects. These changes in MMPs could be due to the muscle composition and architecture alterations that occur with advancing age [31,32,53] and begin in the young adulthood [53,54]. For example, some authors have suggested that increased intramuscular adipose tissue in older adults is the cause of increased muscle stiffness [52,55], as well as the qualitative change in muscle fibres, with an increase in the proportion of type I muscle fibres, characterized by greater stiffness than type II ones [31]. Curiously, the tendon tissue shows a decrease in tone and stiffness in elderly subjects [56,57], which means that different tissues show specific physiological adaptations to age. In summary, for evaluation purposes, the significant changes in tone and post-movement stiffness in subjects under 35 years suggest that the baseline measure represents the best approach to characterize the MMPs in this population.

Our study also reported the relationship between LBP and age with relaxation, and creep, as viscoelastic characteristics, of paraspinal muscles. Relaxation was different in healthy subjects depending on age. In fact, advanced age established differences in creep between healthy subjects and patients. However, the presence of LBP inhibited this behaviour in the creep. Although there is no previous research on viscoelastic properties in acute LPB, previous studies have determined changes in MMPs in subjects with chronic mechanical and inflammatory LBP and neck pain [24,36,43,58]. In these studies, the differences for MMPs between subjects with spinal pain and healthy subjects were explained by the response of muscle spasm to pain, which decreases circulation and increases stiffness [50], disuse as a cause of muscle atrophy, that also increases stiffness [33], or disease of long duration, that alters elasticity and stiffness [43]. It is possible that the acute LBP and, consequently, the short period of evolution of our sample, prevented the changes in the MMPs. Future studies are required to confirm these findings as well as determine these effects on a longer follow-up.

4.1 Strengths and Limitations

To date, no previous study has attempted to establish the adequate moment to evaluate MMPs in clinical practice based on the physical evaluation, clinical status and age. Consequently, these results will allow us to determine the effect of the therapy on the MMPs with greater precision.

However, several limitations must be recognized. First, the raters were not blinded, although the assessment of the MMPs has shown high reliability and low rater dependence, which limits a negative influence on the results [25,59]. Second, the evaluation of the MMPs was only determined in paraspinal muscles at the L5 level, making it impossible to know if other muscles and tissues exhibit similar behaviour. Third, although 35 years has been used to distinguish younger than older adults [32,46,47], other age classifications could provide different results and interpretations. Additionally, the study of other factors, such as the level of physical activity, work or leisure-time activity [60-62], among others, could have afforded other relationship patterns to the results. Furthermore, adding other techniques to analyse muscle characteristics, such as surface electromyography, could provide information on normal or unusual activity, such as muscle spasm during the evaluation. Finally, our sample showed mild disability according to ODI, which could limit the external validity of the results for higher levels of disability.

5. Conclusions

A sequenced spinal movement protocol can modify lumbar paraspinal tone and stiffness according to the patient's age but not according to the presence of LBP. The changes in viscoelastic characteristics of lumbar muscles depend on age and the presence or absence of pain, but not on the performance of the sequenced movements. Older subjects showed less elasticity than younger ones at the L5 spinal level, independent of their condition.

The MMPs should be assessed in a clinical setting, not only at the beginning of the physical evaluation during rest, but also during the patient's follow-up, with special attention to elder subjects and those with pain.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/diagnostics12020302/s1, Figure S1: Flexion, Figure S2: Extension, Figure S3: Right lateral flexion, Figure S4: Left lateral flexion, Figure S5: Right rotation, Figure S6. Left rotation.

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Supplementary Materials

Figure S1: Flexion, Figure S2: Extension, Figure S3: Right lateral flexion, Figure S4: Left lateral flexion, Figure S5: Right rotation, Figure S6. Left rotation.

Figure S1. Flexion

Figure S2. Extension

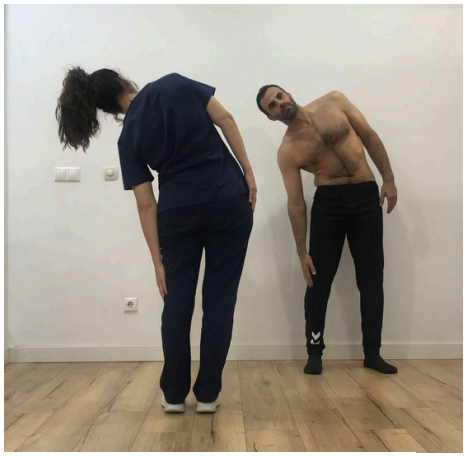

Figure S3. Right lateral flexion

Figure S4. Left lateral flexion

Figure S5. Right rotation

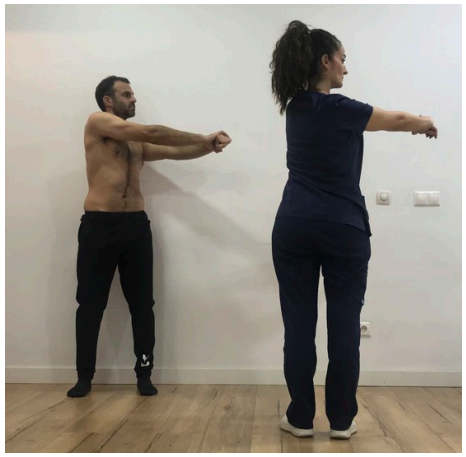

Figure S6. Left rotation

CAPÍTULO V: Alteración del ritmo lumbopélvico en sujetos con dolor lumbar agudo: estudio de casos y controles

RESUMEN

Introducción: El dolor lumbar (LBP) es una de las principales causas de la presencia de alteraciones cinemáticas. Específicamente, el ritmo lumbopélvico (LPR), que se ha mostrado clínicamente relevante, no ha suficientemente descrito en estados agudos de LBP, por lo que requiere una mejor comprensión.
Objetivos: Identificar las diferencias en el LPR entre sujetos con lumbalgia aguda (aLBP) y sujetos sanos.
Métodos: Participaron 39 sujetos diagnosticados de aLBP y 39 sujetos sanos, de ambos sexos. Se evaluaron el LPR, total y por cuartiles durante los movimientos de flexión y de extensión, y los datos metrológicos y clínicos. Se analizaron las diferencias entre los grupos, tanto del LPR, como de las variables sociodemográficas y clínicas.
Resultados: En cuanto al movimiento de flexión, el grupo con dolor lumbar agudo (aLBP), mostró menor movimiento lumbar ($p<.001$) en el segundo cuartil (Q2), además de ser significativamente diferente a los sujetos sanos en la ratio Lumbar/Pelvis (L/P) ($p=.014$) y la Contribución Lumbar (LC) ($p=.029$) de Q2 y Q4. El movimiento de pelvis y tronco de Q3 ($p=<.001$; $p=.001$, respectivamente) y Q4 ($p=.001$; $p=.045$, respectivamente) fue igualmente de menor rango en los sujetos con aLBP. Para el movimiento de extensión, el movimiento del tronco y lumbar de Q2 ($p=.030$; $p=.046$, respectivamente) y Q3 ($p=.013$; $p=.0029$ respectivamente) fue menor para el grupo con patología.
Conclusión: Los sujetos con aLBP mostraron, durante la flexión, menos movimiento lumbar en el segundo y tercer cuartil, y menos movimiento de pelvis y tronco que los individuos sanos en Q3 y Q4. Durante la extensión, los sujetos con dolor mostraron menos movimiento del tronco y del segmento lumbar en Q2 y Q3.

Palabras clave: extensión lumbar, flexión lumbar, ángulos lumbopélvicos, cinemática lumbopélvica, trastornos de la columna vertebral.

1.Introducción

El dolor lumbar (LBP) es una de las patologías musculoesqueléticas más frecuentes en todo el mundo (1), altamente costosa (2) y una de las principales causas de discapacidad (3), lo que requiere una mayor investigación en este campo (4). A pesar de que sabemos que los sujetos con LBP presentan una reducción del rango de movimiento (ROM) lumbar (5), una alteración de la propiocepción, de la actividad neuromuscular y una pérdida del control motor (4,6), otras especificidades no están completamente descritas. El 90% de los casos de LBP se clasifican como inespecíficos mecánicos, mientras que en otros pacientes se diagnostican afecciones específicas, como radiculopatías, tumores, fracturas o enfermedades reumatológicas crónicas (7).

La evaluación de la postura y el movimiento debe formar parte de la evaluación clínica (8), tanto en la fase inicial (5) como en el seguimiento (9), en los pacientes con LBP. Las medidas metrológicas estandarizadas se han utilizado ampliamente para identificar cambios en la movilidad (10,11), pero en los últimos años, las unidades de movimiento inercial (IMUs) (12,13), han aumentado la precisión de la evaluación de las alteraciones del movimiento en un entorno clínico (14). En el plano sagital, la sincronización y la magnitud de las contribuciones lumbar y pélvica a la flexión anterior del tronco, denominada ritmo lumbopélvico (LPR), se ha investigado para comprender el patrón de movimiento en los síndromes lumbares (15,16), tras la cirugía de la columna (17), o en la investigación deportiva (18).

En relación con el LBP, se ha descrito en los sujetos que la padecen, un menor rango de flexión lumbar (19,20) y una menor contribución lumbar en comparación con la pelvis en la fase inicial de flexión del tronco (21), aumentando las cargas espinales que perpetúan el dolor y la discapacidad (22,23). No obstante, sigue sin estar descrito si los cambios en el movimiento y los cambios en el dolor o las limitaciones en la actividad se relacionan de forma consistente (24).

La escasa literatura en relación a la fase aguda de la patología, nos insta a realizar este trabajo que permita comprender la evolución hacia las fases subaguda y crónica más comúnmente estudiadas. El objetivo de este estudio fue identificar diferencias en el LPR entre sujetos con dolor lumbar mecánico agudo inespecífico (aLBP) y sujetos sanos.

2. Métodos

2.1 Diseño de estudio

Se diseñó un estudio observacional transversal de casos y controles con muestreo no probabilístico de casos consecutivos.

Fueron reclutados sujetos con aLBP y controles sanos, en un centro privado de fisioterapia y en el campus Biosanitario de la Universidad de Córdoba, en España, desde marzo de 2019 hasta enero de 2022. Se utilizaron las normas STrengthening the Reporting of OBservational studies in Epidemiology

(STROBE). El Comité de Ética de la Investigación de Córdoba aprobó este proyecto (número de registro 4016, 2019). Todos los participantes firmaron el consentimiento informado.

2.2 Participantes

Se incluyeron un grupo de casos y un grupo control, cada uno formado por 39 sujetos de ambos sexos con edades comprendidas entre 18 y 68 años, apareados por sexo y edad (±6 años). El grupo aLBP incluyó pacientes con dolor lumbar (<4 semanas de evolución) (25) sin ninguna enfermedad inflamatoria y puntuación de dolor ≥3 evaluada con escala visual analógica (visual analogue scale, VAS). El grupo control incluyó sujetos sin síntomas de dolor vertebral en los últimos 6 meses. Los criterios de exclusión para ambos grupos fueron: deformidad congénita, antecedentes traumáticos, cirugía de columna, embarazo y haber recibido tratamiento de fisioterapia de columna en los últimos 6 meses.

2.3 Tamaño muestral

Se realizó un cálculo de la muestra para alcanzar un tamaño de efecto d de Cohen moderado (diferencia entre dos medias independientes, prueba t) de 0,5, comúnmente utilizado para los resultados musculoesqueléticos en el ámbito clínico, (13,26) para la relación L/P de cualquier cuartil y el ROM total como resultado, con un nivel alfa de 0,05 y una potencia de 0,80. Se necesitan treinta y dos individuos por grupo, pero se incluyeron 39 individuos por grupo debido a la posible falta de datos (software G*Power 3.1.9.7).

2.4 Evaluaciones y procedimientos

Tras recibir el consentimiento informado del paciente, los investigadores recogieron datos sociodemográficos (edad, sexo e IMC) y clínicos. Los sujetos completaron la escala VAS para evaluar la intensidad del dolor y el Cuestionario de Discapacidad de Roland Morris (RMDQ). El LPR se evaluó de forma fiable (27) con dos IMUs (28) (Dosarvi ViMoveTM®). El primer sensor se ubicó en las espinas ilíacas posterosuperiores (Pelvis) y para ubicar el segundo sensor (Tronco) se utilizó una plantilla estándar acorde con la altura del paciente, facilitada por el propio fabricante (13) (Figura 1).

Figura 1. Colocación de los IMUs (Dosarvi ViMoveTM®).

Estos dispositivos registraron el ROM en el plano sagital, que se calculó como la diferencia con la posición inicial del paciente (calibración) con el sujeto en posición erguida de pie. En la fase de calibración, el ángulo de lordosis se calculó como la diferencia de la orientación inicial del tronco y la pelvis. Tras la fase de calibración, el operador del sistema pedía al sujeto que iniciara un movimiento de flexión lumbar anterior completa (sin rebote y sin dolor) (29) y un movimiento de extensión hasta la posición inicial. En cada posición, se pidió al sujeto que mantuviera la postura 5 segundos **(Figura 2)**.

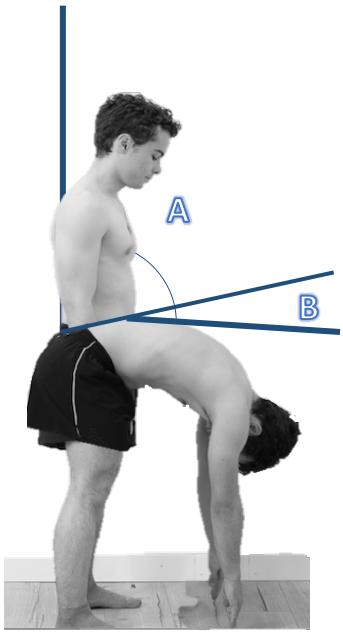

Figura 2. Ángulos de movimiento de pelvis y segmento lumbar. (A) Ángulo de la pelvis. (B) Ángulo lumbar.

La secuencia se repitió 3 veces y se calcularon los valores medios del ROM de cada sensor para su análisis. Un algoritmo automatizado detectó el punto inicial y final de cada ciclo de movimiento analizando un valor de corte del 5% del ROM máximo del Tronco.

El ROM del movimiento lumbar se determinó como la diferencia entre los valores de Tronco y Pelvis **(Figura 3)**.

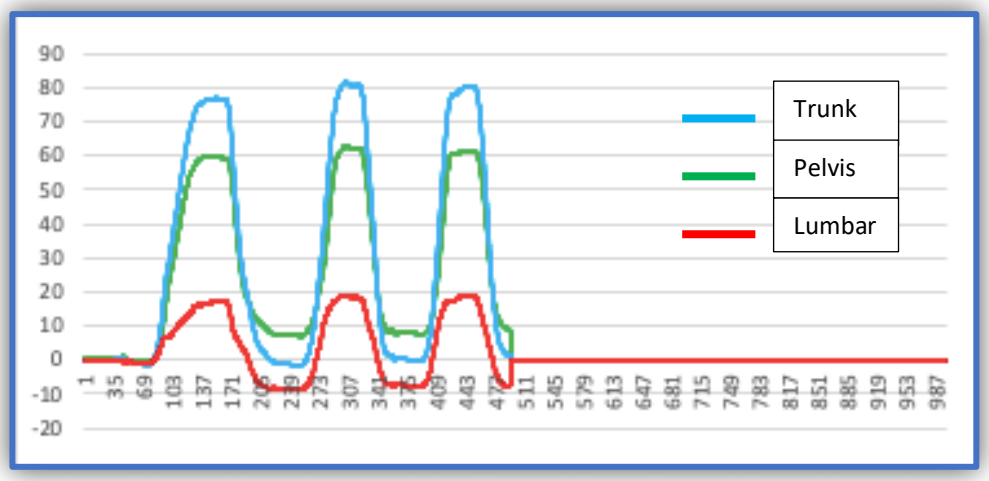

Figura 3. Ilustración del momento y la magnitud de las contribuciones del tronco, lumbar y pelvis a la flexión anterior del tronco.

El ROM total de flexión y extensión se dividió en cuatro cuartiles (Q) cada uno: Q1 (0-25% del movimiento total), Q2 (25-50% del movimiento total), Q3 (50-75% del movimiento total) y Q4 (75-100% del movimiento total). El ROM de cada cuartil se obtuvo restando los grados al final del cuartil de los grados al principio del Q.

La suma de ángulos en cada cuartil es algunos grados inferior al ROM total debido al algoritmo automático, que detecta el momento de inicio y fin del movimiento, utilizando un valor de corte (5% del ROM máximo del tronco) como incremento de la posición inicial para declarar el inicio del movimiento y la misma cantidad sobre el ROM máximo para declarar el fin del movimiento **(Figura 4)**.

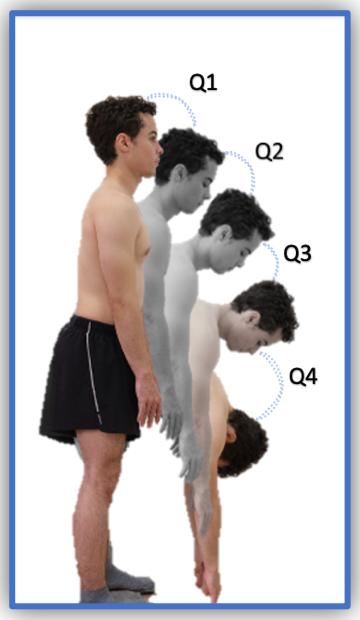

Figura 4. ROM total de flexión dividido por cuartiles de movimiento.

La contribución del movimiento lumbar (lumbar contribution, LC) al movimiento global se calcula dividiendo el rango de movimiento lumbar entre el rango de movimiento del tronco expresado en porcentaje. La relación lumbar-pelvis (L/P) se calcula como el coeficiente de estas dos medidas (30).

2.5 Análisis estadístico

Con fines descriptivos, se utilizaron las frecuencias y los porcentajes de las variables categóricas, mientras que para los datos continuos se hizo uso de la media y la desviación estándar y el intervalo de confianza del 95% (IC 95%). En caso de no normalidad, se reportó la mediana y el rango intercuartílico. El análisis de normalidad se realizó mediante la prueba de Kolmogorov-Smirnov.

Para comparar el LPR y las variables sociodemográficas y clínicas entre grupos, se aplicó como prueba paramétrica la prueba t de Student para muestras independientes y para aquellas variables que no cumplían esta condición, se aplicó la prueba U de Mann-Whitney.

Para todas las pruebas, el nivel de significación se fijó en 0,05. Para el análisis estadístico se utilizó el programa IBM-SPSS® 25 (Armonk, NY, EE.UU.).

3. Resultados

Se analizó a un total de 78 adultos jóvenes (edad media 37,91±13,27años). Cada grupo estaba compuesto por 16 mujeres y 23 hombres sin diferencias estadísticamente significativas de edad e IMC. El grupo con aLBP presentaba sobrepeso (>25Kg/m^2), dolor moderado (31) y baja discapacidad (32) **(Tabla 1).**

Tabla 1. Características sociodemográficas y clínicas de los grupos de estudio.

	aLBP (n = 39)	Sanos (n = 39)	p-valor
Edad (años)	37.85±13.77	37.97±12.92	NS
Sexo (mujer/hombre)	16/23	16/23	NS
IMC (Kg/m^2)	25.39±3.75	23.93±3.14	NS
VAS	4.59±1.53	-	-
RMDQ	5(5)	-	-

Abreviaturas: IMC: índice de masa corporal; VAS: escala visual analógica; RMDQ: Roland Morris Questionaire. Los valores son media ± desviación estándar; mediana (rango intercuartílico).

3.1 Diferencia en el LPR entre grupos

No se hallaron diferencias significativas en la lordosis ni en los ángulos de flexión total del tronco, lumbar y pélvico entre los grupos. En consecuencia, no se encontraron diferencias ni en el L/P ni en el LC. Tampoco se encontraron diferencias entre los grupos durante el Q1. Sin embargo, la cantidad de movimiento lumbar en el Q2 mostró diferencias (p<.001) entre aLBP y el grupo control (-4.88°, 95%CI: -7.39,-2.38), siendo significativamente mayor en el grupo control. Asimismo, los valores de L/P (p=.014) y LC (p=.029) en este cuartil fueron significativamente diferentes entre los grupos.

El movimiento pélvico de los sujetos con aLBP fue significativamente menor durante el Q3 y Q4 que en el grupo control (-4.46°, IC 95%: -6.56,-2.37; -3.20°, IC 95%: -5.07,-1,33, respectivamente). El movimiento del tronco durante el Q3 y el Q4 volvió a detectar diferencias entre los grupos (-5.42°, IC95%: -8.41,-2.42; -2.54°, IC95%: -5.08,0.00, respectivamente).Por último, los valores de L/P y LC en Q4 fueron significativamente superiores en el grupo con aLBP en comparación con el grupo control (0.44°, IC 95%: 0.62,0.82; 0,23°, IC 95%: 0.12,0.35, respectivamente). No hubo diferencias para otros movimientos de flexión.

Durante la extensión, el movimiento del tronco y de la zona lumbar en Q2 (-4.85°, IC95%: -7.97, -1.73; -2.42°, IC95%: -4.80,-,0.04, respectivamente) y Q3 (-3.85°, IC95%: -7.14,-0.56; -2.57°, IC95%: -4.88,-0.27, respectivamente) fueron significativamente inferiores en los sujetos con aLBP en comparación con los sanos. No hubo diferencias para otros movimientos de extensión **(Tabla 2)**.

Tabla 2. LPR total y por cuartiles de la flexión y la extensión, de los grupos de estudio.

Ritmo Lumbopélvico de la flexión espinal				
		aLBP (n = 39)	**Sanos (n = 39)**	**p-valor**
LORDOSIS INICIAL (°)		-25.77±12.78	-25.36±11.99	NS
PELVIS (°)		52.48±17.71	56.68±13.43	NS
TRONCO (°)		101.70±21.27	109.51±13.26	NS
LUMBAR (°)		49.89±13.53	53.50±10.81	NS
L/P		1.12±0.78	1.02±0.40	NS
LC(%)		49±11	49±9	NS
Ritmo Lumbopélvico de la flexión espinal por cuartiles				
Q1	PELVIS (°)	12.91±7.56	11.10±5.44	NS
	TRONCO (°)	31.07±12.11	27.60±8.25	NS
	LUMBAR (°)	18.15±8.18	16.49±5.13	NS
	L/P	1.40±3.12	0.40±8.68	NS
	LC (%)	59±16	60±13	NS
Q2	PELVIS (°)	17.33±8.79	15.98±6.55	NS
	TRONCO (°)	31.76±9.35	35.30±7.63	NS
	LUMBAR (°)	14.43±5.47	19.32±5.64	<.001
	L/P	0.83±3.53	1.20±0.91	.014
	LC (%)	46±18	54±13	.029
Q3	PELVIS (°)	9.87±5.04	14.34±4.19	<.001
	TRONCO (°)	17.90±7.63	23.32±5.46	.001
	LUMBAR (°)	8.03±5.06	8.98±4.14	NS
	L/P	0.81±1.47	0.62±0.44	NS
	LC (%)	44±18	37±13	NS
Q4	PELVIS (°)	5.52±4.45	8.74±3.81	.001
	TRONCO (°)	8.85±5.93	11.39±5.32	.045
	LUMBAR (°)	3.32±2.78	2.64±3.03	NS
	L/P	0.60±1.11	0.30±0.45	<.001
	LC (%)	42±24	18±25	<.001
Ritmo Lumbopélvico de la extensión espinal por cuartiles				
Q1	**PELVIS (°)**	10.54±5.64	12.62±4.34	NS
	TRUNK (°)	16.93±7.48	19.16±5.70	NS
	LUMBAR (°)	6.39±4.46	6.53±3.23	NS
	L/P	0.60±0.73	0.51±0.41	NS
	LC%)	37±18	33±14	NS
Q2	**PELVIS (°)**	13.85±6.36	16.28±5.06	NS
	TRUNK (°)	26.04±6.84	30.90±6.98	.003
	LUMBAR (°)	12.19±4.56	14.61±5.90	.046
	L/P	0.88±0.98	0.89±0.58	NS
	LC(%)	47±15	46±14	NS
Q3	**PELVIS (°)**	10.60±5.25	11.88±6.34	NS
	TRUNK (°)	23.99±7.72	27.84±6.84	.013
	LUMBAR (°)	13.38±5.26	15.96±4.96	.029
	L/P	1.26±3.73	1.34±5.15	NS
	LC (%)	56±15	58±16	NS
Q4	**PELVIS (°)**	6.21±3.73	7.15±3.89	NS
	TRUNK (°)	18.06±7	18.56±5.60	NS
	LUMBAR (°)	11.84±5.45	11.40±3.84	NS
	L/P	1.90±12.48	1.59±26.81	NS
	LC (%)	64±16	62±15	NS

Abreviaturas: Q, Cuartil; L/P, Relación de movimiento Lumbar/Pelvis; LC, Contribución Lumbar al movimiento global en porcentaje; NS, no significativo. Los valores son la media ± desviación estándar.

4. Discusión

Los resultados mostraron que, aunque el LPR del movimiento total no fue diferente entre los grupos, la distribución del movimiento por cuartiles, tanto durante la flexión, como durante la extensión, es diferente cuando los individuos tienen aLBP. Así, los sujetos con aLBP mostraron durante la flexión menor movimiento lumbar en Q2 y menor movilidad de pelvis y tronco en Q3 y Q4 que los individuos sanos. Durante la extensión, se encontraron las mismas diferencias en el movimiento del tronco y del segmento lumbar en Q2 y Q3. En relación con el ángulo de lordosis lumbar, en línea con lo que ya indicó un metaanálisis en 2014 (33), no se observaron diferencias significativas entre los sujetos asintomáticos y los que padecían LBP.

Estudios anteriores han documentado una reducción de los movimientos lumbares totales en sujetos con dolor lumbar en comparación con sujetos sanos (14,34). En concreto, Shojaei et al. (20) y Wong and Lee (19), reportaron diferencias mayores a 10° y 20°, respectivamente. En nuestro trabajo, también encontramos un ROM de flexión lumbar inferior en el grupo con aLBP en comparación con los individuos sanos, pero sin diferencias estadísticas, como ocurrió con la lordosis. La importancia clínica del ROM lumbar total (35) y de la lordosis (9,34) ha sido cuestionada, lo que ha originado nuevas propuestas de estudio, como la determinación del LPR por cuartiles.

Atendiendo al Q1 de flexión, se observó mayor movilidad lumbar en los sujetos con aLBP (18,15°) que en sujetos sanos, aunque dicha diferencia no llegó a ser significativa estadísticamente. Un patrón similar fue descrito por Marich et al. (36), que sugirieron que, a mayor movimiento lumbar al inicio, mayor limitación funcional. Durante el avance del movimiento se encontró un menor rango de movimiento de la pelvis en Q3 y Q4 de flexión y del segmento lumbar en Q2 de extensión entre los sujetos con aLBP, en comparación con los sanos. Estas diferencias coinciden con investigaciones anteriores (37), que podrían encontrar justificación en la búsqueda de estrategias de prevención del dolor en el evento doloroso mediante la reducción de la tensión mecánica espinal en tareas dinámicas (20,30).

Por otro lado, en nuestro trabajo, el L/P presentó diferencias significativas en Q2 y Q4 de flexión entre sujetos con aLBP y sujetos controles. Diferencias éstas, en la segunda fase del movimiento, que también se encontraron en un trabajo comparativo entre sujetos asintomáticos con antecedentes de lumbalgia recurrente e individuos sanos realizado por Esola et al. (1996) (38). En este sentido, es reseñable que la aproximación del Q2 al rango medio de movimiento o zona neutra precisa de una mayor activación de la musculatura extensora y alto control neuromuscular (39,30). Un posible patrón desadaptativo e inestabilidad en dicha zona puedan hacer aumentar el ROM de la pelvis para prevenir los efectos de un movimiento excesivo lumbar ante la presencia de inestabilidad (30). Kim et al. (2013), sin embargo, describieron diferencias en el L/P de los cuatro cuartiles de flexión y extensión, entre dos

subtipos de LBP y sujetos sanos (37). La falta de información en relación al tiempo de evolución de la lumbalgia de la muestra, imposibilita comparar los resultados y justificar las diferencias respecto a los presentes resultados.

En resumen, es clínicamente importante conocer las estrategias de adaptación y compensatorias a nivel lumbopélvico, que generan y perpetúan el dolor (16,30), aplicar tratamientos específicos, como ejercicios de movilidad o estabilización, según el caso, y vigilar los cambios en el LPR (33), tanto al inicio de los síntomas, como durante la evolución de la patología.

4.1 Fortalezas y Limitaciones

Uno de los puntos fuertes del estudio es el uso de una metodología de evaluación sencilla, indolora y clínicamente aplicable. Los resultados podrían ayudar en la toma de decisiones de los pacientes con dolor de columna.

Asimismo, es necesario reconocer algunas limitaciones del estudio. En primer lugar, el evaluador no estaba cegado respecto al grupo de pertenencia de los sujetos de estudio, aunque los procedimientos han mostrado una baja dependencia del evaluador. En segundo lugar, la aplicabilidad de estos resultados se limita a características similares de la población, en términos de características clínicas, edad o IMC. Por último, sólo se investigaron los movimientos del tronco en el plano sagital, lo que impide extraer conclusiones sobre otro tipo de exigencias mecánicas. Futuras investigaciones deberían considerar la evaluación de otras tareas y factores funcionales.

5. Conclusión

El análisis por cuartiles de movimiento permite observar diferencias que no se encuentran en los movimientos totales. Los sujetos con aLBP mostraron durante la flexión, menos movimiento lumbar en el segundo cuartil y menos movimientos de pelvis y tronco en Q3 y Q4 que los individuos sanos. Durante la extensión, los sujetos con dolor mostraron menos movimientos del tronco y del segmento lumbar en Q2 y Q3.

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PRODUCCIÓN CIENTÍFICA DERIVADA DEL DESARROLLO DE LA TESIS DOCTORAL

PUBLICACIONES DERIVADAS DEL DESARROLLO DE LA TESIS DOCTORAL

En cumplimiento con lo establecido por el programa de Doctorado en Biomedicina de la Universidad de Córdoba para la presentación de Tesis Doctorales. El presente trabajo incluye la autoría principal de dos publicaciones en una revista de segundo cuartil (Q2), indexada en la última relación publicada del Journal Citation Reports (JCR-2021) de la Web Of Science (WOS).

Título: **Paravertebral Muscle Mechanical Properties in Patients with Axial Spondyloarthritis or Low Back Pain: A Case-Control Study.**

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Título: **Influence of Spinal Movements Associated with Physical Evaluation on Muscle Mechanical Properties of the Lumbar Paraspinal in Subjects with Acute Low Back Pain**

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*: Equal Contribution

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PRODUCCIÓN CIENTÍFICA RELACIONADA CON EL DESARROLLO DE LA TESIS DOCTORAL

REVISTAS INDEXADAS EN EL JOURNAL CITATION REPORTS

- Título: Paravertebral Muscle Mechanical Properties and Spinal Range of Motion in Patients with Acute Neck or Low Back Pain: A Case-Control Study.

  Autores: Sandra Alcaraz-Clariana [*], Lourdes García-Luque [*], Juan Luis Garrido-Castro, César Fernández-de-Las-Peñas, Cristina Carmona-Pérez, Daiana Priscila Rodrigues-de-Souza, Francisco Alburquerque-Sendín.

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- Título: Mechanical Properties of Lumbar and Cervical Paravertebral Muscles in Patients with Axial Spondyloarthritis: A Case-Control Study

  Juan L Garrido-Castro, I Concepción Aranda-Valera, José Peña-Amaro, Alfonso Martínez-Galisteo, Cristina González-Navas, Daiana P Rodrigues-de-Souza, Sandra Alcaraz-Clariana, Lourdes García-Luque, Iago R Martínez Sánchez, Clementina López-Medina, Eduardo Collantes-Estévez, Francisco Alburquerque-Sendín.

  Revista, año, volumen, número, páginas: Diagnostics, 2021, 11(9):1662

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COMUNICACIONES EN JORNADAS, CONGRESOS NACIONALES E INTERNACIONALES

- Plan de investigación: Identificación y análisis del fenómeno flexión-relajación en sujetos con lumbalgia mecánica aguda.

  Autores: S. Alcaraz; L. García; C. Carmona ; J.L. Garrido ; F. Alburquerque; E. Collantes.

  Presentado en el VI Congreso de Investigadores en formación de la Universidad de Córdoba en 2018.

- Lumbar muscles stiffness in patients with axial spondyloarthritis is altered in comparison with healthy subjects.

  Autores: Aranda-Valera, I.C; Alcaraz-Clariana, S; García-Luque, L; Garrido Castro, J.L; Martínez-Sánchez, I; González-Navas, C; Gardiner, P; Machado, P.M; Collantes-Estévez,E.

  Presentado en el XLIV Annual European Congress of Rheumatology EULAR- 2018.

- Relación entre movilidad, metrología, discapacidad, calidad de vida, kinesiofobia y dolor en cervicálgicos y lumbálgicos en fase aguda.

  Autores: S. Alcaraz-Clariana, F. Alburquerque-Sendín, J.L. Garrido-Castro, E. Collantes-Estévez.

  Presentado en el VII Congreso de Investigadores en formación de la Universidad de Córdoba en 2019.

- Lumbopelvic rhythm in patients with axial spondyloarthritis compared with low back pain and healthy subjects.

  Autores: Garrido-Castro, J.L; Aranda-Valera, I. C; Alcaraz-Clariana, S; Garcia-Luque; L; Rodriguez De Souza, D.P; González-Navas, C; Gardiner, P; Collantes-Estévez, E.

  Presentado en el XLV Annual European Congress of Rheumatology EULAR. 2019.

- Relación entre movilidad y miotonometría en cervicálgicos y lumbálgicos en fase aguda.

  Autores: García-Luque, L, Alcaraz-Clariana, S.

  Presentado en el 10º Congreso Virtual Internacional de Enfermería y Fisioterapia Ciudad de Granada. Innovación y mejoras en los cuidados. Avances y Tecnologías en Salud. 2019.

- Relación entre rigidez, movilidad, metrología, discapacidad, calidad de vida, kinesiofobia y dolor en lumbálgicos en fase aguda.

  Autores: S. Alcaraz-Clariana, F. Alburquerque-Sendín, E. Collantes-Estévez.

  Presentado en el VIII Congreso de Investigadores en Formación de la Universidad de Córdoba en 2020.

- POS1272 Differences in range of motion and mechanical muscle characteristics among inflammatory and mechanical spinal pain: a case-control study.

  Autores: Alcaraz-Clariana, S; García-Luque, L; Aranda-Valera, I.C; Ladehesa-Pineda, M.L; López-Medina, C; C; Alburquerque-Sendín, F; Rodrigues-de Souza, D.P; Garrido-González, C; Garrido Castro, J.L; Collantes-Estévez, E.

  Presentado en el XLVII Annual European Congress of Rheumatology EULAR. 2021

- Influence of low back pain, sequenced movement, short term rest, and age on lumbar muscle mechanical properties

  Autores: Sandra Alcaraz-Clariana, Lourdes García-Luque, Juan Luis Garrido-Castro, Cristina Carmona-Pérez, Daiana Priscila Rodrigues-de-Souza, Francisco Alburquerque-Sendín.

  Presentado en el 12th IMIBIC Young Investigators Meeting en 2021.

- Lumbopelvic rhythm in patients with acute low back pain compared with axial spondyloarthritis and healthy subjects

  Autores: Sandra Alcaraz-Clariana, Lourdes García-Luque, Cristina Carmona-Pérez, Francisco Alburquerque-Sendín.

  Presentado en el 13th IMIBIC Young Investigators Meeting en 2022.

OTRA PRODUCCIÓN CIENTÍFICA DURANTE EL PROGRAMA DE DOCTORADO

ARTÍCULOS EN REVISTAS INDEXADAS EN EL JOURNAL CITATION REPORT

- Concurrent Validity and Reliability of an Inertial Measurement Unit for the Assessment of Craniocervical Range of Motion in Subjects with Cerebral Palsy.

  Autores: Cristina Carmona-Pérez, Juan Luis Garrido-Castro, Francisco Torres Vidal, Sandra Alcaraz-Clariana, Lourdes García-Luque, Francisco Alburquerque-Sendín, Daiana Priscila Rodrigues-de-Souza.

  Revista año, volumen, número, páginas: Diagnostics, 2020, 10(2):80

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- Design, Validity, and Reliability of a New Test, Based on an Inertial Measurement Unit System, for Measuring Cervical Posture and Motor Control in Children with Cerebral Palsy.

  Autores: Cristina Carmona-Pérez, Alberto Pérez-Ruiz, Juan L Garrido-Castro, Francisco Torres Vidal, Sandra Alcaraz-Clariana, Lourdes García-Luque, Daiana Priscila Rodrigues-de-Souza, Francisco Alburquerque-Sendín.

  Revista, año, volumen, número, páginas: Diagnostics, 2020, 10(9):1-17

  Factor de impacto según JCR 2020, 3. 706

  Lugar que ocupa/nº de revista en el área temática 39/165 (Q2)

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- Absolute and Relative Reliability of the Assessment of the Muscle Mechanical Properties of Pelvic Floor Muscles in Women with and without Urinary Incontinence.

  Autores: Daiana Priscila Rodrigues-de-Souza, Sandra Alcaraz-Clariana, Lourdes García-Luque, Cristina Carmona-Pérez, Juan Luis Garrido-Castro, Inés Cruz Medel, Paula R. Camargo, Francisco Alburquerque-Sendín.

  Revista, año, volumen, número, páginas: Diagnostics , 2021, 11(12):2315

  Factor de impacto según JCR 2021: 3.992

  Lugar que ocupa/nº de revista en el área temática: 60/172 (Q2)

  DOI: 10.3390/diagnostics11122315

  ISSN: 2075-4418

- Asymmetries of the Muscle Mechanical Properties of the Pelvic Floor in Nulliparous and Multiparous Women, and Men: A Cross-Sectional Study.

  Autores: Daiana Priscila Rodrigues-de-Souza, Ana Carolina Satorato Beleza, Lourdes García-Luque, Sandra Alcaraz-Clariana, Cristina Carmona-Pérez, Amaranta de Miguel-Rubio, María Teresa Garzón Alfaro, Inés Cruz Medel, Juan Luis Garrido-Castro, Francisco Alburquerque-Sendín.

  Revista, año, volumen, número, páginas: Symmetry, 2022, 14(10):2124

  Factor de impacto según JCR 2021: 2.940

  Lugar que ocupa/nº de revista en el área temática: 34/73 (Q2)

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  ISSN: 2073-8994

COMUNICACIONES EN CONGRESOS INTERNACIONALES

- Advanced metrology in patiens with axial spondyloarthritis: lumbar or thoracic lumbar measurements for spinal mobility assessment?

  Autores: Aranda-Valera, I.C; García-Luque, L; Alcaraz-Clariana, S; Garrido-Castro, J.L; Martínez-Sánchez, I; González-NavasC; Gardiner, P; Machado, P.M; Collantes-Estévez, E.

  Presentado en el XLIV Annual European Congress of Rheumatology EULAR. 2018

- Identificación de patrones de dolor y abordaje desde la fisioterapia neuromusculoesquelética

  Autores: María Cristina Carmona-Pérez; Lourdes Garcia-Luque; Sandra Alcaraz-Clariana.

  Presentado en IV Congreso Internacional en contextos clínicos y de la salud. 2018

- Aplicación Android para el uso de sensores inerciales en la evaluación de la movilidad espinal de pacientes reumáticos.

  Autores: Torres-Vidal, F, Martinez-Sánchez, I, Rodrigues-de-Souza, D.P; Alburquerque-Sendín, F, García-Luque, L. Alcaraz-Clariana, Sandra. Aranda-Valera, I.C, Collantes-Estévez, E, Garrido-Castro, J.L.

  Presentado en la XLI Edición del Congreso de la Sociedad Ibérica de Biomecánica y Biomateriales. 2018

- Control motor y equilibrio evaluado con sensores inerciales en parálisis cerebral: proyecto de investigación.

  Autores: García-Luque, L; Carmona-Pérez, C; Alcaraz-Clariana, S; Rodrigues-de-Souza, D.P; Torres-Vidal, F; Martínez-Sánchez, I; Alburquerque-Sendín, F; Garrido-Castro, J.L.

  Presentado en la XLI Edición del Congreso de la Sociedad Ibérica de Biomecánica y Biomateriales. 2018

ANEXOS

ANEXO 1: DATOS SOCIODEMOGRÁFICOS Y CLÍNICOS

NOMBRE	**APELLIDOS**	**CÓDIGO**
FECHA ENSAYO	**SESIÓN Nº**	**PROFESIONAL SANITARIO**
EDAD	**SEXO**	**TELÉFONO**
	Mujer	
	Hombre	
PESO	**TALLA**	**AFECTACIÓN ESPINAL**
		Cervical
		Lumbar
RAZA	**ESTADO CIVIL**	**S. LABORAL**
Caucásica	Soltero	Hogar
Negra		Activo
Gitana		De baja
Árabe	Casado	Jubilado
Otras		Desempleo
TABACO	**ALCOHOL**	**LESIONES PREVIAS**
Si	Si	
No	No	
CRITERIOS EXCLUSIÓN		
Antecedentes traumáticos		
Cirugía columna vertebral		
Deformidad congénita		
Enfermedad inflamatoria		
Embarazo		
Tratamiento previo de Fisioterapia		

BATH ANKYLOSING SPONDYLITIS METROLOGY INDEX (BASMI)

Medidas metrológicas		Total
Rotación cervical (°)	Derecha: Izquierda:	
Distancia Trago-pared (cm)		
Flexión lateral lumbar (cm)	Derecha: Izquierda:	
Test de Schöber modificado (cm)		
Distancia intermaleolar (cm)		
BASMI		

ANEXO 2: TEST Y CUESTIONARIOS

BATH ANKYLOSING SPONDYLITIS DISEASE ACTIVITY INDEX (BASDAI)

Versión en español validada por Ariza-Ariza et al., 2004 (50).

Las siguientes preguntas se refieren a cómo se ha sentido usted en la ÚLTIMA SEMANA. Por favor, conteste haciendo una marca vertical en las líneas que aparecen debajo de las preguntas. Tenga en cuenta que mientras más a la izquierda quiere decir que se ha encontrado MEJOR y mientras más a la derecha significa que se ha encontrado PEOR

1. ¿Cuánta fatiga o cansancio ha sentido usted?

   NINGUNA _____ MUCHISIMA

2. ¿Cuánto dolor ha sentido usted en cuello, espalda o caderas debido a la espondilitis anquilosante?

   NINGUNO _____ MUCHISIMA

3. ¿Cuánto dolor o inflamación ha tenido usted en las otras articulaciones (sin contar cuello, espalda y caderas)?

   NINGUNO _____ MUCHISIMA

4. ¿Cuánto malestar ha tenido usted en las partes de su cuerpo que le duelen al tocarlas o presionarlas?

   NINGUNO _____ MUCHÍSIMA

5. ¿Cuánta rigidez matutina ha tenido usted al despertarse?

   NINGUNA_____ MUCHÍSIMA

6. ¿Cuánto tiempo le dura la rigidez matutina desde que se levanta?

   HORAS _____ HORAS
   0 ½ 1 1½ 2

BATH ANKYLOSING SPONDYLITIS FUNCTIONAL INDEX (BASFI)

Versión española validada por Ariza-Ariza et al., 2003 (49).

A continuación, se le indican una serie de actividades. Por favor, marque una raya vertical en la línea situada debajo de cada actividad, de acuerdo con su situación EN LA ÚLTIMA SEMANA. Tenga en cuenta que mientras más a la izquierda significa que se ha sentido MEJOR y que le ha sido más FÁCIL realizar esa actividad, mientras más a la derecha quiere decir que se ha encontrado PEOR y que le ha resultado más DIFÍCIL o, incluso, IMPOSIBLE realizar dicha actividad.

1. Ponerse los calcetines (o medias) sin la ayuda de otros medios externos.

FÁCIL _____ IMPOSIBLE

2. Recoger un bolígrafo del suelo sin ayuda inclinándose hacia adelante (doblando la cintura).

FÁCIL _____ IMPOSIBLE

3. Coger de una estantería un objeto situado por encima de su cabeza sin ayuda.

FÁCIL _____ IMPOSIBLE

4. Levantarse de una silla sin apoyar las manos ni utilizar ninguna otra ayuda?

FÁCIL _____ IMPOSIBLE

5. Estar acostado sobre la espalda y levantarse del suelo sin ayuda

FÁCIL _____ IMPOSIBLE

6. Estar a pie firme sin apoyarse en nada durante 10 minutos y no tener molestias.

FÁCIL _____ IMPOSIBLE

7 Subir 12 ó 15 escalones sin agarrarse al pasamanos ni usar bastón o muletas (poniendo un pie en cada escalón)

FÁCIL _____ IMPOSIBLE

8. Mirarse un hombro girando sólo el cuello (sin girar el cuerpo).

FÁCIL _____ IMPOSIBLE

9. Realizar actividades que supongan un esfuerzo físico como ejercicios de rehabilitación, trabajos de jardinería o deportes

FÁCIL _____ IMPOSIBLE

10. Realizar actividades que requieran dedicación plena durante todo el día (en casa o en el trabajo)

FÁCIL _____ IMPOSIBLE

OSWESTRY DISABILITY INDEX (ODI)

Adaptación de Flórez et al, 1995 a la población española. Versión 1.0 validada por Alcantara-Bumbiedro et al., 2006 (51).

Sección I: Intensidad del Dolor

1. Puedo tolerar el dolor sin necesidad de usar medios para disminuirlo.
2. El dolor es moderado, pero puedo manejarlo sin necesidad de medidas terapéuticas.
3. La terapia antiálgica proporciona alivio completo del dolor.
4. La terapia antiálgica proporciona alivio moderado del dolor.
5. La terapia antiálgica proporciona muy poco alivio del dolor.
6. La terapia antiálgica no tiene efecto sobre el dolor porque no la usó.

Sección II: Cuidado personal (lavarse, vestirse, etc)

1. Puedo cuidarme normalmente sin causar dolor añadido.
2. Puedo cuidarme pero me produce dolor añadido.
3. Me resulta dolorosa la realización de mis cuidados personales por lo que los hago lenta y cuidadosamente.
4. Necesito alguna ayuda, pero realizo parte de mis cuidados.
5. Necesito ayuda todos los días en la mayoría de mis cuidados personales.
6. No puedo vestirme, me lavo con dificultad y permanezco en la cama.

Sección III: Levantamiento de objetos

1. Puedo levantar pesos pesados sin dolor añadido.
2. Puedo levantar pesos pesados pero me produce dolor añadido.
3. El dolor me impide levantar pesos pesados desde el suelo pero puedo hacerlo si están convenientemente colocados, como por ejemplo en una mesa.
4. El dolor me impide levantar pesos pesados pero puedo levantar pesos ligeros y medios si están convenientemente situados.
5. Solo puedo levantar pesos ligeros.
6. No puedo levantar ni transportar ningún peso.

Sección IV: Caminar

1. El dolor no me impide caminar.
2. El dolor me impide caminar más de 1 kilómetro.
3. El dolor me impide caminar más de 5 kilómetro.
4. El dolor me impide caminar más de 10 kilómetros.
5. Sólo puedo caminar usando un bastón o muletas.
6. Estoy en la cama la mayor parte del tiempo y tengo que gatear para llegar al baño.

Sección V: Sentarse

1. Puedo sentarme en una silla todo el tiempo que quiero.
2. Solo puedo sentarme todo el tiempo que quiero en un tipo de silla determinada.
3. El dolor me impide sentarme más de una hora.
4. El dolor me impide sentarme más de media hora.
5. El dolor me impide sentarme más de 10 minutos.
6. El dolor me impide sentarme.

Sección VI: Permanecer de pie
1. Puedo permaneces de pie todo el tiempo que quiero sin dolor añadido.
2. Puedo permaneces de pie todo el tiempo que quiero, pero me produce dolor añadido.
3. El dolor me impide estar de pie más de una hora.
4. El dolor me impide estar de pie más de media hora.
5. El dolor me impide estar de pie más de 10 minutos.
6. El dolor me impide estar de pie.

Sección VII: Dormir
1. El dolor no me impide dormir bien
2. Solo puedo dormir bien si tomo fármacos.
3. Aun cuando uso fármacos, duermo menos de 6 horas.
4. Aun cuando uso fármacos, duermo menos de 4 horas.
5. Aun cuando uso fármacos, duermo menos de 2 horas.
6. El dolor me impide dormir.

Sección VIII: Vida sexual
1. Mi vida sexual es normal y no me causa dolor añadido.
2. Mi vida sexual es normal pero me causa algún dolor añadido.
3. Mi vida sexual es casi normal pero es muy dolorosa.
4. Mi vida sexual está severamente limitada por el dolor.
5. Mi vida sexual es casi inexistente por el dolor.
6. El dolor me impide tener vida sexual.

Sección IV: Vida social
1. Mi vida social es normal y no me causa ningún dolor añadido.
2. Mi vida social es normal, pero incrementa el nivel de dolor.
3. El dolor no tiene un efecto significativo sobre mi vida social excepto la limitación para realizar las actividades que requieran energía extra como la danza.
4. El dolor ha restringido mi vida social y no puedo salir con frecuencia.
5. El dolor ha restringido mi vida social a la que pueda venir a casa.
6. No tengo vida social debido al dolor.

Sección X: Viajar
1. Puedo viajar a cualquier parte sin dolor añadido.
2. Puedo viajar a cualquier parte, pero me produce dolor añadido.
3. El dolor es intenso pero soporte jornadas de viaje por encima de 2 horas.
4. El dolor restringe mis jornadas de viaje a menos de 1 hora.
5. El dolor restringe mis jornadas de viaje a menos de 30 minutos.
6. El dolor me impide viajar excepto al médico o al hospital

12-ITEM SHORT-FORM HEALTH SURVEY (SF-12)

Adaptación realizada para España por Alonso et al., 1998 (52).

Las preguntas que siguen se refieren a lo que usted piensa sobre su salud. Sus respuestas permitirán saber cómo se encuentra usted y hasta qué punto es capaz de hacer sus actividades habituales. Por favor, conteste cada pregunta marcando una casilla. Si no está seguro/a de cómo responder a una pregunta, por favor, conteste lo que le parezca más cierto.

1. **En general, usted diría que su salud es:**
    - Excelente
    - Muy buena
    - Buena
    - Regular
    - Mala
2. **Su salud actual, ¿le limita para hacer esfuerzos moderados, como mover una mesa, pasar la aspiradora, jugar a los bolos o caminar más de una hora?**
    - Sí, me limita mucho
    - Sí, me limita un poco
    - No, no me limita nada
3. **Su salud actual, ¿le limita para subir varios pisos por la escalera?**
    - Sí, me limita mucho
    - Sí, me limita un poco
    - No, no me limita nada
4. **Durante las 4 últimas semanas, ¿hizo menos de lo que hubiera querido hacer, a causa de su salud física?**
    - Sí
    - No
5. **Durante las 4 últimas semanas, ¿tuvo que dejar de hacer algunas tareas en su trabajo o en sus actividades cotidianas, a causa de su salud física?**
    - Sí
    - No

6. **Durante las 4 últimas semanas, ¿hizo menos de lo que hubiera querido hacer, a causa de algún problema emocional (como estar triste, deprimido, o nervioso)?**
    - Sí
    - No
7. **Durante las 4 últimas semanas, ¿no hizo su trabajo o sus actividades cotidianas tan cuidadosamente como de costumbre, a causa de algún problema emocional (como estar triste, deprimido, o nervioso)?**
    - Sí
    - No
8. **Durante las 4 últimas semanas, ¿hasta qué punto el dolor le ha dificultado su trabajo habitual (incluido el trabajo fuera de casa y las tareas domésticas)?**
    - Nada
    - Un poco
    - Regular
    - Bastante
    - Mucho
9. **Durante las 4 últimas semanas, ¿cuánto tiempo se sintió calmado y tranquilo?**
    - Siempre
    - Casi siempre
    - Algunas veces
    - Muchas veces
    - Sólo alguna vez
    - Nunca
10. **Durante las 4 últimas semanas, ¿cuánto tiempo tuvo mucha energía?**
    - Siempre
    - Casi siempre
    - Algunas veces
    - Muchas veces
    - Sólo alguna vez
    - Nunca

11. **Durante las 4 últimas semanas, ¿cuánto tiempo se sintió desanimado y triste? Siempre**

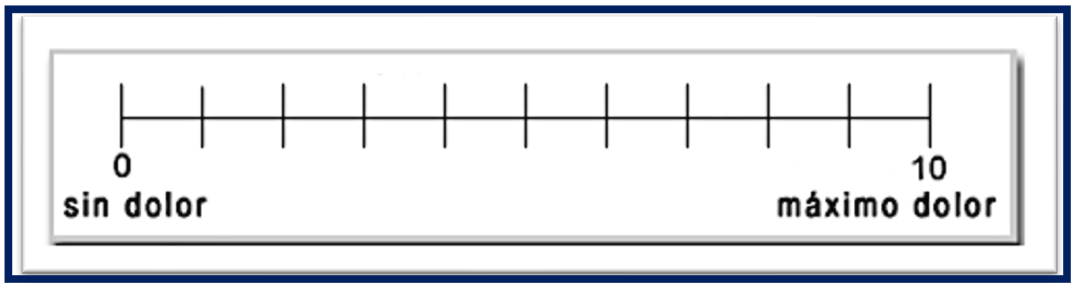
    - Casi siempre
    - Algunas veces
    - Muchas veces
    - Sólo alguna vez
    - Nunca

12. **Durante las 4 últimas semanas, ¿con qué frecuencia la salud física o los problemas emocionales le han dificultado sus actividades sociales (como visitar a los amigos o familiares)?**

    - Siempre
    - Casi siempre
    - Algunas veces
    - Muchas veces
    - Sólo alguna vez
    - Nunca

NUMERICAL PAIN RATING SCALE (NPRS)

Seleccione el valor más acorde con la intensidad de dolor experimentada en las últimas 24 horas.



VISUAL ANALOGUE SCALE (VAS)

Marque en la línea el punto que indique la intensidad de su dolor.

FEAR AVOIDANCE BELIEFS QUESTIONNAIRE (FABQ)

Versión en español validada por Kovacs et al., 2006 (53).

Aquí están algunas cosas que otros pacientes nos han dicho sobre su dolor. Por favor, para cada afirmación haga un círculo en un número del 0 al 6 para indicar hasta qué punto las actividades físicas tales como inclinarse, levantar peso, caminar o conducir afectan o afectarían a *su* dolor de espalda.

	En total desacuerdo			Ni de acuerdo ni en desacuerdo			Completamente de acuerdo
1. Mi dolor fue causado por la actividad física	0	1	2	3	4	5	6
2. La actividad física hace que mi dolor empeore	0	1	2	3	4	5	6
3. La actividad física podría dañar mi espalda	0	1	2	3	4	5	6
4. No debería hacer las actividades físicas que empeoran mi dolor, ni las que podrían empeorarlo	0	1	2	3	4	5	6
5. No puedo realizar las actividades físicas que empeoran mi dolor, ni las que podrían empeorarlo.	0	1	2	3	4	5	6

Las siguientes afirmaciones se refieren a cómo su trabajo normal afecta o afectaría a su dolor de espalda.

	En total desacuerdo			Ni de acuerdo ni en desacuerdo			Completamente de acuerdo
6. Mi dolor se debe a mi trabajo, o a un accidente en el trabajo	0	1	2	3	4	5	6
7. Mi trabajo agravó mi dolor	0	1	2	3	4	5	6
8. Estoy recibiendo o tramitando algún tipo de compensación por mi dolor de espalda, como una baja laboral, una pensión o una indemnización de cualquier tipo	0	1	2	3	4	5	6
9. Mi trabajo es demasiado pesado para mí	0	1	2	3	4	5	6
10. Mi trabajo empeora mi dolor, o podría empeorarlo	0	1	2	3	4	5	6
11. Mi trabajo puede dañar mi espalda	0	1	2	3	4	5	6
12. Con mi dolor actual, no debería hacer mi trabajo normal	0	1	2	3	4	5	6
13. Con mi dolor actual, no puedo hacer mi trabajo normal	0	1	2	3	4	5	6
14. No podré hacer mi trabajo normal hasta que mi dolor haya sido tratado	0	1	2	3	4	5	6
15. No creo que pueda regresar a mi trabajo habitual en los próximos 3 meses	0	1	2	3	4	5	6
16. No creo que sea capaz de volver nunca a mi trabajo habitual.	0	1	2	3	4	5	6

ROLAND MORRIS DISABILITY QUESTIONNAIRE (RMDQ)

Versión validada al español por Kovacs et al., 2002 (54).

Cuando le duele la espalda, puede que le sea difícil hacer algunas de las cosas que habitualmente hace. Esta lista contiene algunas de las frases que la gente usa para explicar cómo se encuentra cuando le duele la espalda (o los riñones). Cuando las lea, puede que encuentre algunas que describan su estado de *hoy*. Cuando lea la lista, piense en cómo se encuentra usted *hoy*. Cuando lea usted una frase que describa como se siente hoy, póngale una señal. Si la frase no describe su estado de hoy, pase a la siguiente frase. Recuerde, tan solo señale la frase si está seguro de que describe cómo se encuentra usted hoy.

1.- □ Me quedo en casa la mayor parte del tiempo por mi dolor de espalda.

2.- □ Cambio de postura con frecuencia para intentar aliviar la espalda.

3.- □ Debido a mi espalda, camino más lentamente de lo normal.

4.- □ Debido a mi espalda, no puedo hacer ninguna de las faenas que habitualmente hago en casa.

5.- □ Por mi espalda, uso el pasamanos para subir escaleras.

6.- □ A causa de mi espalda, debo acostarme más a menudo para descansar.

7.- □ Debido a mi espalda, necesito agarrarme a algo para levantarme de los sillones o sofás.

8.- □ Por culpa de mi espalda, pido a los demás que me hagan las cosas.

9.- □ Me visto más lentamente de lo normal a causa de mi espalda.

10.- □ A causa de mi espalda, sólo me quedo de pie durante cortos períodos de tiempo.

11.- □ A causa de mi espalda, procuro evitar inclinarme o arrodillarme.

12.- □ Me cuesta levantarme de una silla por culpa de mi espalda.

13.- □ Me duele la espalda casi siempre.

14.- □ Me cuesta darme la vuelta en la cama por culpa de mi espalda.

15.- □ Debido a mi dolor de espalda, no tengo mucho apetito.

16.- □ Me cuesta ponerme los calcetines - o medias - por mi dolor de espalda.

17.- □ Debido a mi dolor de espalda, tan solo ando distancias cortas.

18.- □ Duermo peor debido a mi espalda.

19.- □ Por mi dolor de espalda, deben ayudarme a vestirme.

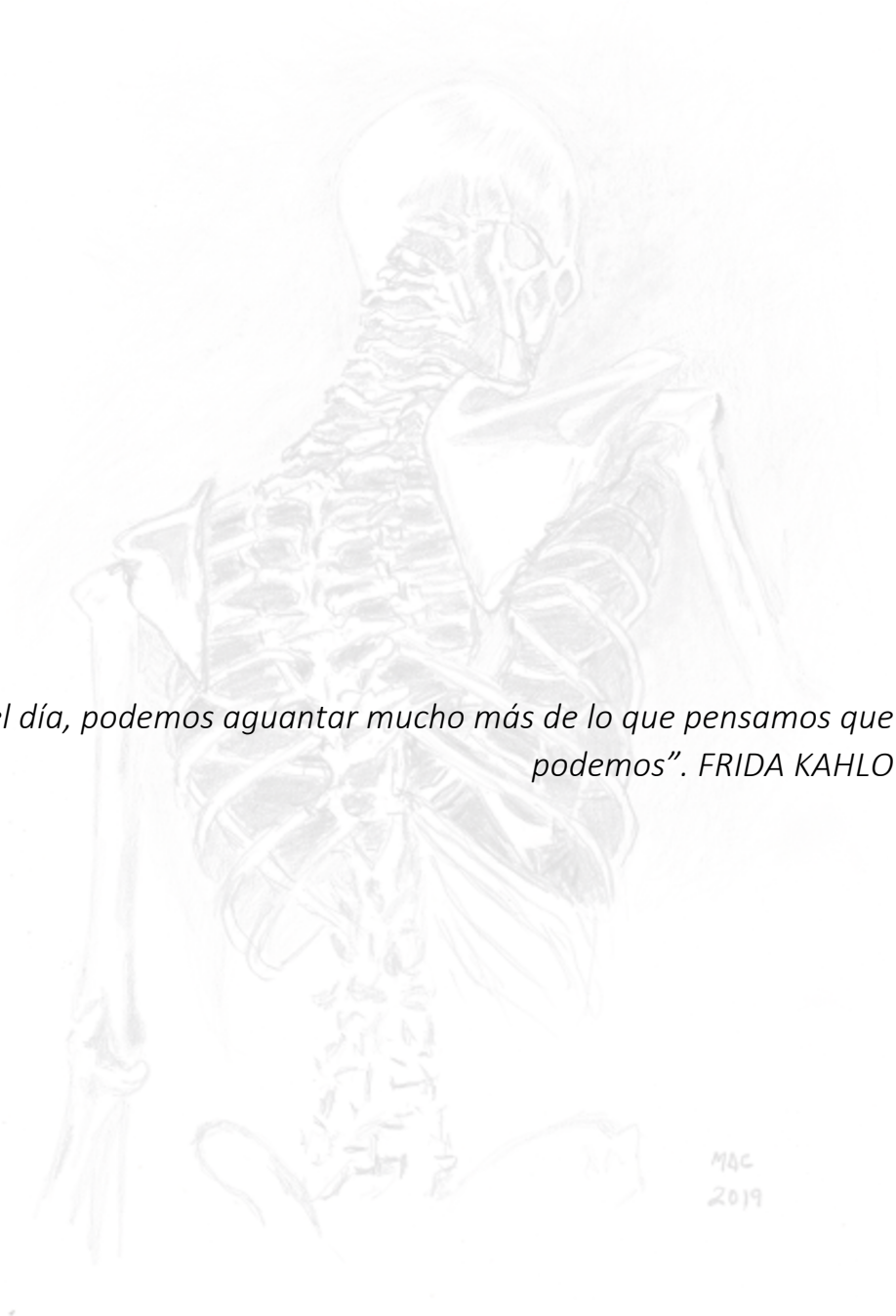
20.- □ Estoy casi todo el día sentado a causa de mi espalda.

21.- □ Evito hacer trabajos pesados en casa, por culpa de mi espalda.

22.- □ Por mi dolor de espalda, estoy más irritable y de peor humor de lo normal.

23.- □ A causa de mi espalda, subo las escaleras más lentamente de lo normal.

24.- □ Me quedo casi constantemente en la cama por mi espalda.



Al final del día, podemos aguantar mucho más de lo que pensamos que podemos". FRIDA KAHLO

Las Ilustraciones de la portada y de las páginas 7 y 137, fueron elaboradas a partir del original, por Manuel Alcaraz Cejas en 2019.