UNIVERSIDAD DE EXTREMADURA

TESIS DOCTORAL

REINCORPORACIÓN LABORAL EN PACIENTES CON FRACTURAS VERTEBRALES TORACOLUMBARES Y SU RELACIÓN CON LOS PARÁMETROS RADIOGRÁFICOS

Alejandro Lorente Gómez

R007 - PROGRAMA DE DOCTORADO EN MODELIZACIÓN Y EXPERIMENTACIÓN EN CIENCIA Y TECNOLOGÍA POR LA UNIVERSIDAD DE EXTREMADURA

BADAJOZ, 2021

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THESIS

RETURN-TOWORK IN PATIENTS WITH THORACOLUMBAR VERTEBRAL FRACTURES ANF ITS RELATIONSHIP WITH RADIOLOGICAL PARAMETERS

Alejandro Lorente Gómez

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Conformidad del Director:

Fdo.: Rafael Lorente Moreno

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"Happiness should always remain a bit incomplete. After all, dreams are boundless."

Anatoly Karpov, chess world champion

A mi padre, mi maestro

A mi madre, por todo su cariño

To my father, my master

To my mother, for all your love

ÍNDICE

ABSTRACT

Lumbar and thoracic vertebral fractures and dislocations are very severe injuries that frequently occur in young people, generally caused by high-energy trauma such as traffic accidents and falls.

Neurological injuries can occur from 15% to 40% of these fractures and more than 30% of these patients may develop a chronic pain which entails limitations in daily activities and difficulty in returning to work, and therefore, the proper management of these fractures is essential.

Fractures of the thoracic and lumbar spine are nowadays a great challenge, since we have gone from a time in which orthopedic treatment was the rule to a more rational approach due to a better anatomical and biomechanical knowledge in relationship to the spine, which often implies the need for a surgical intervention. This has also been favored by the improvements in anesthetic techniques that allow more aggressive surgical approaches, as well as posterior, anterior and combined segmental vertebral instrumentation depending on the type of traumatic injury. In the same way, the rehabilitative management of the patient has improved and, therefore, the chances of socio-occupational recovery of vertebral injuries have increased as well.

To assess the stability of a vertebral fracture, two parameters have traditionally been used: the kyphotic deformity and the percentage of compression. These measurements were also carried out by hand, without any specific software.

The launch of a new software which allows digitizing and performing computerized measurements opens up a new range of possibilities in the field of vertebral fractures.

In this study, we intend to carry out an exhaustive radiological follow-up, analyzing the radiological evolution of unstable thoraco-lumbar fractures without neurological symptoms treated with posterior instrumentation and fusion using six measurement parameters. Our hypothesis is that there are parameters that have not been traditionally studied that may lose correction during the follow-up of these fractures, and that may be important when making clinical and surgical decisions. All measurements will be done using the RIC / PACS software.

The objectives that we have sought are:

- To analyze the epidemiological characteristics of unstable thoracolumbar fractures in our environment.

- To analyze the evolution of six radiological parameters over 3 years in patients with unstable thoracolumbar fractures.

- To analyze the short, medium and long term complications of unstable thoracolumbar fractures.

All parameters that have been used had never been analyzed all-together and in a shared way with such serious statistical studies, neither in so many vertebral fractures nor in such a long term follow up.

These studies have been possible thanks to the obtained knowledge after visiting several national and international universities and hospitals which have let us over time to accept and present our results in the form of oral or poster communications in regional, national and international meetings and which have been accepted in journals with JCR both in the first, second and third tercile as shown throughout the development of the thesis.

To conclude, we would briefly like to point out that the results of this thesis can be considered a contribution to the future diagnosis, treatment and control of patients who have suffered a spinal injury.

Key-words: Thoracolumbar spine. Radiology. Instrumentation. Open posterior fixation. Percutaneous fixation. Return to work.

RESUMEN

Las fracturas y luxaciones vertebrales torácicas y lumbares son lesiones muy serias que ocurren con frecuencia en gente joven, generalmente producidas por traumatismos de alta energía tales como accidentes de tráfico y precipitaciones.

Las lesiones neurológicas pueden ocurrir en un 15% a 40% de estas fracturas y más de un 30% de los pacientes pueden desarrollar dolor crónico que conlleva limitaciones en las actividades de la vida diaria y dificultad en la reincorporación laboral, por lo que, el manejo adecuado de dichas fracturas es fundamental.

Las fracturas del raquis torácico y lumbar constituyen hoy en día un gran reto, pues se ha pasado de una época en la que el tratamiento ortopédico era la regla a un planteamiento, en la actualidad, más racional debido al mejor conocimiento desde el punto de vista anatómico y biomecánico de la columna vertebral, que implica muchas de las veces la necesidad de una actuación quirúrgica. Lo que ha venido también favorecido por la mejoras de las técnicas anestésicas que permiten abordajes quirúrgicos más agresivos, así como, de las instrumentaciones vertebrales segmentarias posteriores, anteriores y combinas dependiendo del tipo de lesión traumática. Del mismo modo, el manejo rehabilitador del paciente ha mejorado y, por tanto, han aumentado las posibilidades de recuperación socio-laboral de los lesionados vertebrales.

Para la valoración de la estabilidad de una fractura vertebral, clásicamente se han utilizado dos parámetros: la deformidad cifótica y el porcentaje de compresión. Estas mediciones además se realizaban a mano, sin ningún software específico.

La aparición de nuevos software que permiten digitalizar y realizar mediciones computerizadas abren un nuevo abanico de posibilidades en el campo de las fracturas vertebrales.

En este estudio, pretendemos realizar un seguimiento evolutivo radiológico exhaustivo, analizando la evolución radiológica de las fracturas inestables toraco-lumbares sin clínica neurológica tratadas con instrumentación posterior y artrodesis mediante seis mediciones. Nuestra hipótesis es que existen parámetros que no han sido estudiados tradicionalmente que pueden perder corrección a lo largo del seguimiento de estas fracturas, y que pueden ser importantes a la hora de la toma de decisiones clínicas y quirúrgicas. Todas las mediciones las haremos un el software RIC/PACS.

Los objetivos que hemos pretendido son:

- Analizar las características epidemiológicas de las fracturas inestables toracolumbares en nuestro medio.

- Analizar la evolución de seis parámetros radiológicos a lo largo de 3 años en pacientes con fracturas inestables toracolumbares.

- Analizar las complicaciones a corto, medio y largo plazo de las fracturas inestables toracolumbares.

Todos parámetros que nunca se habían analizado en conjunto y de forma compartiva con estudios estadísticos tan serios, ni en tantas fracturas vertebrales ni a tan largo plazo.

Dichos estudios han sido posibles gracias a la ayuda y aprendizaje tras visitar distintas universidades y hospitales tanto nacionales como internacionales que nos han ido permitiendo a lo largo del tiempo que nos acepten presentar nuestros resultados en forma de comunicaciones orales o de poster en congresos regionales, nacionales e internacionales y que hayan sido aceptados en revistas con JCR tanto de primer como de segundo y tercer tercil como se muestran a lo largo del desarrollo de la tesis

Para concluir, brevemente nos gustaría señalar que los resultados de esta tesis pueden considerarse una contribución para el futuro diagnostico, tratamiento y control de pacientes que han sufrido una fractura en la columna vertebral

Palabras clave: Columna torácica y lumbar. Radiología. Instrumentación. Fijación posterior abierta. Fijación percutánea. Vuelta al trabajo

1. INTRODUCCIÓN GENERAL

1.1 Introducción

Las fracturas del raquis torácico y lumbar son hoy en día un reto para el cirujano ortopédico, pues se ha pasado de una época en la que el tratamiento ortopédico era la regla a un planteamiento, en la actualidad, más racional debido al mejor conocimiento desde el punto de vista anatómico [1,2] y biomecánico[3,4] de la columna vertebral, que implica muchas de las veces la necesidad de una actuación quirúrgica. Lo que ha venido también favorecido por la mejoras de las técnicas anestésicas que permiten abordajes quirúrgicos más agresivos, así como, de las instrumentaciones vertebrales segmentarias posteriores, anteriores y combinas dependiendo del tipo de lesión traumática. Del mismo modo, el manejo rehabilitador del paciente ha mejorado y, por tanto, han aumentado las posibilidades de recuperación socio-laboral de los lesionados vertebrales.

1.2 Recuerdo embrionario-anatómico

Sería inútil repetir en este estudio la anatomía detallada de los huesos, músculos, ligamentos y demás estructuras que forman la columna vertebral, por lo que nos limitaremos a hacer un pequeño recuerdo embriológico, anatómico descriptivo y biomecánico del raquis.

La columna vertebral, llamada también columna raquídea o más abreviadamente raquis, es un largo tallo óseo, situado en la línea media y parte posterior del tronco[5], formando el esqueleto de una amplia región que se denomina retrosoma[1], cuyas funciones fundamentales son las de servir de sostén al cuerpo, proteger la médula espinal y la de ser palanca ósea para realizar los movimientos del tronco[6].

Siguiendo las observaciones de diversos autores[7,8,9] podemos decir que a los dos meses y medio de la vida embrionaria se han diferenciado los cuerpos vertebrales y los arcos neurales que ocupan su posición dorsal, todo ello de predominio netamente cartilaginoso. A esta edad los arcos neurales son todavía incompletos, estando unidas ambas porciones por una débil membrana.

El significado de la notocorda en el desarrollo de la columna vertebral es fundamental [10,11].

Tanto en el cuello como en el cuerpo del embrión, cada somita se diferencia en tres porciones:

- Una placa lateral y superficial, el dermatoma.
- Una masa lateral pero más profunda, el miotoma.
- Una masa media y ventral, el esclerotoma

Las células esclerotómicas[3,10] de cada par de somitas migran hacia la línea media hasta que se encuentran alrededor del notocordio, separándolo del tubo neural y del intestino. Cada masa de este material esclerotómico axial, marcada por esta segmentación, tiene una porción caudal condensada y una porción craneal un poco más laxa. En la parte segmentaria central la porción condensada se diferencia en disco intervertebral. La porción caudal de cada esclerotoma se une con la porción cefálica menos celular del esclerotoma que le sigue inmediatamente para formar el cuerpo vertebral membranoso o precartilaginoso. De modo similar, más dorsal y lateralmente, las porciones menos condensadas forman los arcos neurales precartilaginosos y los procesos transversos, mientras que la porción más densa originan los ligamentos intervertebrales.

Se formarán sucesivamente varios centros de condrificación en cuerpo y arco neural, igualmente en las áreas membranosas costales , que se condrificarán para formar las costillas. Poco después, se originarán centros primarios de osificación, del mismo modo que los centros cartilaginosos primitivos que después del nacimiento completarán las vertebras[10].

Una vez desarrollada, la columna vertebral, formada por la superposición de muchas vértebras, se extiende desde el atlas a la punta del coxis dividiéndose en cuatro porciones, que son, de arriba hacia abajo en:

1ª.- La porción cervical (columna cervical) formada por siete vertebras.

2ª.- La porción torácica (columna torácica o dorsal) formada por doce vértebras.

3ª.- La porción lumbar (columna lumbar) formada por cinco vértebras.

4ª.- La porción pelviana (columna sacro-coccígea), que comprende el sacro y el coxis.

Nos encontramos finalmente que de las 32 a 35 vértebras que se esbozan en el embrión, solamente 24 guardan su individualidad durante la vida adulta, mientras que las cinco más caudales se sueldan para formar el sacro y las dos o tres últimas formarán el coxis.

La vértebra típica[12], está constituida por varias partes fusionadas entre sí que forman un solo hueso. Encontramos un cuerpo, relativamente voluminoso y de situación anterior, y un arco vertebral posterior que rodea la médula espinal. Cada arco está formado por dos pedículos, que se originan en las superficies postero-externas del cuerpo vertebral, y de dos láminas, que nacen de los pedículos y se unen por detrás en la línea media. En el punto de unión entre los pedículos y las láminas se desprenden las apófisis transversas, y donde se juntan las láminas tiene su origen la apófisis espinosa. También en la unión entre el pedículo y la lámina se encuentran dos pequeñas apófisis articulares, superior e inferior.

La unión de todas estas vértebras da lugar a una estructura que no es totalmente recta sino que dispone de una serie de curvas fisiológicas antero-posteriores y laterales, que tienen como significado una adaptación necesaria del raquis a las nuevas exigencias mecánicas creadas por la adquisición de la postura bípeda[10].

Estas curvaturas antero-posteriores son cuatro: la primera corresponde a la región cervical y es convexa hacia delante; la segunda corresponde a la región torácica y su convexidad mira hacia atrás; la tercera convexa hacia delante y corresponde a la región lumbar, y la cuarta corresponde a la región sacro-coccígea con disposición similar a la dorsal.

Con respecto a las curvas en el plano frontal o curvas laterales, aunque menos pronunciadas y menos constantes que las antero-posteriores, existen también de una manera normal en la mayoría de los casos como señalan Testut[5] y Marañón[13].

1.3 Biomecánica de la columna vertebral

La biomecánica está ganando terreno en todos los campos de la ortopedia y, debido a la notable complejidad que constituyen las distintas estructuras de la columna vertebral humana, aquí alcanza cotas muy altas.

Ya en el renacimiento contamos con algunos trabajos acerca de biomecánica, como son los dibujos anatómicos de Leonardo da Vinci, que a principios del siglo XVI dibujó croquis de disección de los articulaciones en sus diferentes posiciones, realizando, así mismo, maquetas que permitían una mejor comprensión de los músculos peri-articulares.

Sin embargo, a grandes rasgos, podemos considerar como padre de la biomecánica en general y, en particular, de la biomecánica de la columna vertebral, a Giovanni Alfonso Borelli (Nápoles 1608-1679), que podemos considerarlo como un genio que a lo largo de su vida se dedicó a la física, la astronomía e incluso llegó a convertirse en médico personal de la reina de Suecia. Borelli no solamente describió la anatomía de la columna con precisión, sino que ayudado de Marcelo Malpighi, de la Universidad de Pisa, también calculó las fuerzas que actúan sobre la musculatura y los discos intervertebrales, aproximándose a la distribución de cargas del cuerpo humano. Su obra culmen en este aspecto es la publicación De Motu Animalium, que podríamos traducir como “Sobre el movimiento de los animales”. Se trata de un texto que establece con profundidad y gran precisión, las bases o principios de la biomecánica del cuerpo humano.

Dicha obra fue desarrollándose a lo largo del siglo XVII, quedando un poco olvidado este campo hasta la retoma de los múltiples estudios, en el siglo XIX, realizados por autores como Culmann y Wolf en mecánica articular. Posteriormente tras la Segunda Guerra Mundial, destacan múltiples trabajos como los del alemán Pauwels, de los norteamericanos Steindler y Williams, de los italianos Cappozzo, Lorini y De Giorgi, del belga Maquet y de los franceses Rabischong, Kapandji y Frain, permitiendo la aplicación de las teoría mecánicas y el análisis de tensiones moderno al sistema músculo-esquelético, dando lugar a la biomecánica tal y como la conocemos hoy en día[14,15,16] tanto a nivel anatómico como con los implantes[17].

Para la evolución animal, la posibilidad de asociar resistencia y movilidad representa un logro importante. En los animales vertebrados esto se consigue merced a la existencia de la columna vertebral, cuyas funciones son proteger la médula espina, transferir solicitaciones mecánicas desde la cabeza, tronco y brazos a la pelvis y, permitir la movilidad del tronco.

La Unidad Funcional Básica de la columna vertebral es el segmento de movimiento, también denominado por Frankel[18] módulo vertebral de movimiento. A su vez, este módulo de movimiento puede considerarse integrado[4] por dos porciones como podeos ver en la clasificación de Hodsworth[19]:

a.- Una porción anterior, constituida por dos cuerpos vertebrales, un disco intervertebral y los ligamentos longitudinales anterior y posterior.

b.- Una porción posterior, formada por los arcos vertebrales, las articulaciones interapofisarias junto con los ligamentos asociados y, las apófisis transversas y espinosas.

Los cuerpos vertebrales se hallan diseñados para poder soportar principalmente cargas de compresión, ofreciendo una geometría de mayores dimensiones a medida que aumenta la magnitud de las fuerzas a soportar. Así, los cuerpos vertebrales de la región lumbar presentan una mayor altura y sección que los de la columna dorsal, y éstos que la cervical.

El disco intervertebral es, probablemente, el elemento de mayor importancia mecánica y funcional del raquis. El disco es una estructura compleja cuya función fundamental es permitir la movilidad relativa entre vértebras contiguas, facilitando, al mismo tiempo, la transmisión y distribución de esfuerzos a lo largo de la columna. Se halla compuesto por tres estructuras:

- Una porción interna, el núcleo pulposo.

- Una porción externa o periférica.

- Unas láminas cartilaginosos que lo conecta con los cuerpos vertebrales.

Durante la actividad normal, el disco se ve sometido a solicitaciones complejas; en general, combinación de compresión, flexión y torsión. En este sentido, tanto la flexo-extensión como la flexión lateral de la columna vertebral provocan tensiones de tracción y compresión en el disco, mientras que la torsión induce tensiones de cizalladura.

En lo que concierne a los ligamentos que se insertan a lo largo de la columna vertebral y que contribuyen a su estabilidad extrínseca, se halla integrados fundamentalmente por fibras de colágeno, limitando su deformabilidad. Sin embargo, el ligamento amarillo, que conecta longitudinalmente los arcos vertebrales, es una excepción con una alta proporción de fibras elásticas. Ello permite su alargamiento en flexión y su acortamiento en extensión, actuando como un resorte capaz de almacenar energía de deformación en su alargamiento y de liberarla en su acortamiento.

1.4 Clasificación de las fracturas vertebrales

Históricamente han sido muchos los intentos de confeccionar una clasificación de las lesiones traumáticas toraco-lumbares con el fin de identificar la inestabilidad (primaria o secundaria) de las fracturas y por tanto conseguir encuadrar distintos patrones que nos permitiesen protocolizar la indicación para el tratamiento ortopédico o quirúrgico (instrumentación consta o larga, artrodesis o no, abordaje único anterior o posterior, abordaje combinado, necesidad de realizar gestos añadidos de descompresión, etc.). Se han propuesto clasificaciones basadas entre otros en conceptos biomecánicos[20,21] y anatomopatológicos[22].

Fue la clasificación de Holdsworth[19] la pionera en dividir en columnas las estructuras anteriores y posteriores del raquis, posteriormente Denis[23] nos incluye el concepto de las tres columnas que ha sido y sigue siendo un hito a nivel del conocimiento de las fracturas vertebrales aunque están aparecido clasificaciones más modernas que intentan valorar la necesidad de un tiempo quirúrgico, como la propuesta por la AO y descrita por Magerls-Gertzbein[24,25] y finalmente la modificada de Vaccaro[26,27] clasificaciones que serán analizadas en este artículo.

1.4.1 Clasificación de Holdsworth

Como apuntábamos anteriormente, la primera clasificación de las fracturas de la columna toraco-lumbar que tuvo en cuenta criterios de inestabilidad fue publicada por Holdsworth[19] en 1970. En dicho artículo se individualizaba la unidad vertebral en dos columnas:

- Columna anterior: Que estaba formado por el ligamento común vertebral posterior y todas las estructuras vertebrales anteriores al mismo (ligamento común vertebral anterior, disco y cuerpos vertebrales).

- Columna posterior.- Que comprendía todas las estructuras que formaban el complejo ligamentario posterior.

1.4.2 Clasificación de Denis

No fue hasta 1983 cuando Denis[23] publica su clasificación con la teoría de la estabilidad basadas en las tres columnas:

- Columna anterior.- Formada por el ligamento común vertebral anterior y la mitad anterior del cuerpo y del disco intervertebral.

- Columna media.- Constituida por la mitad posterior del cuerpo y del disco intervertebral y por el ligamento común vertebral posterior.

- Columna posterior.- Que incluía todos los elementos posteriores al ligamento común vertebral posterior (articulaciones apofisarias y arco posterior con todas sus estructuras óseas y cápsulo-ligamentosas estabilizadoras.

Denis daba una gran importancia a la columna media, pues su lesión condicionaría una inestabilidad que podría ser puramente ósea, disco-ligamentosa o mixta.

De esta forma las fracturas toraco-lumbares fueron divididas en cuatro tipos, con diferentes subtipos cada una de ellos, a saber:

I.- Fracturas por Compresión. Solamente afectan a la columna anterior. El mecanismo de producción es la compresión del cuerpo vertebral. Existen dos subtipos:

- Fracturas acuñamiento anterior.
- Fracturas acuñamiento lateral.

Son las fracturas vertebrales más frecuentes llegando prácticamente a englobar a la mitad de las mismas. Son fracturas estables, salvo que el acuñamiento anterior sobrepase el 50%.

II.- Fracturas conminutas o por estallido (Burst fractures). Son fracturas que afectan tanto a la columna anterior como a la media. Su mecanismo de producción es la compresión axial. Se subdividen en:

- Tipo A.- Son las fracturas que afectan a ambos platillos vertebrales.
- Tipo B.- Son las fracturas que afectan al platillo vertebral superior.
- Tipo C.- Son las fracturas que afectan al platillo vertebral inferior.
- Tipo D.- Son las fracturas por compresión axial más rotación vertebral.
- Tipo E.- Son las fracturas por compresión axial más flexión lateral.

Comprenden aproximadamente el 20% de las fracturas. En ellas encontramos característicamente una disminución global de la altura del cuerpo vertebral, la presencia, casi constante, de un fragmento de la porción posterior del cuerpo vertebral que invade el canal medular, una aumento de la distancia interpedicular y una fractura de trazo sagital de la lámina, muchas de las veces incompleta y que solamente se hace visible mediante la práctica de una tomografía axial computarizada o de una resonancia magnética.

III.- Fracturas por cinturón de seguridad (Seat-Belt fractures). Son fracturas raras, no superiores al 55 del total, que afectan a la columna posterior y media y están provocadas por un mecanismo de flexión asociado a distracción axial.

En estas fracturas por cinturón de seguridad se distinguen cuatro subgrupos:

- Tipo A.- Son las denominadas fracturas de Chance. La solución de continuidad es puramente ósea en sólo un nivel vertebral.

- Tipo B.- La solución de continuidad es disco-ligamentosa en sólo un nivel vertebral.

- Tipo C.- La solución de continuidad es puramente ósea en dos niveles vertebrales.

- Tipo D.- La solución de continuidad es disco-ligamentosa a dos niveles vertebrales.

IV.- Fracturas-luxaciones. Son aquellas que afectan a las tres columnas. Son fracturas inestables y constituyen aproximadamente el 25% de las fracturas. Su mecanismo de producción es múltiple interviniendo fuerzas de compresión, cizallamiento, rotación y distracción axial.

Distinguimos tres subgrupos:

- Tipo A.- Provocadas por un mecanismo de flexión rotación, bien a través del disco, bien a través del cuerpo vertebral (slice fractures).

- Tipo B.- Provocadas por un mecanismo de cizallamiento (sea fractures).

- Tipo C.- Son las fracturas-luxaciones y vienen provocadas por un mecanismo de de flexión-distracción.

1.4.3 Clasificación de Gertzbein.

También llamado sistema de clasificación integral[22,24], propuesto en 1990, es una clasificación anatomopatológica que considera que la columna falla la acción de tres fuerzas solicitadoras:

- Fuerzas de compresión.

- Fuerzas de distracción anterior o posterior.

- Fuerzas de rotación.

Es una clasificación muy completa pero a la vez compleja y extensa[22] que agrupa los traumatismos toraco-lumbares en tres grandes tipos atendiendo al fallo de la estabilidad en cada uno de los tres planos del espacio considerando por tanto sus posibles asociaciones.

De esta manera nos podemos encontrar con:

- Lesiones tipo A.- Son fracturas del cuerpo vertebral provocadas por compresión axial con o sin flexión que hacen fracasar la columna anterior y a veces también la media, se caracterizan por una pérdida de altura del cuerpo vertebra. En caso de que hubiese fractura de los elementos posteriores esta sería vertical que no influiría de forma importante en la inestabilidad de la lesión. Las partes blandas posteriores no están destruidas ni tampoco existe desplazamiento del cuerpo vertebral. Son fracturas muy frecuentes, representando aproximadamente el 70% de todas las lesiones toracolumbares. En este apartado se incluyen las fracturas acuñamiento, las fracturas separación del cuerpo y las fracturas por estallido en sus diferentes variedades.

- Lesiones tipo B.- Afectan a las tres columnas. La mayor parte de estos traumatismos implican una tracción posterior, pero pueden también provocarse por un mecanismo de extensión y tracción anterior. Son lesiones mucho más inestables que las tipo A y presentan mayor riesgo de cifosis postraumática en caso de una mala osteosíntesis.

- Lesiones tipo C.- Son lesiones provocadas por un mecanismo y de rotación o mecanismos complejos con cizalladura que destruyen las tres columna y que originan una inestabilidad multidireccional. Son fracturas poco frecuentes que necesita en muchas ocasiones instrumentaciones largas o abordajes combinados.

1.4.4 Clasificación TLCS modificada de Vaccaro.

Es la clasificación actualmente seguida prácticamente en todo el mundo por sus grandes ventajas como veremos a continuación[28-30] y es la que ha servido de base para nuestros estudios de investigación.

El sistema TLICS ha sido propuesto como clasificación de las fractura tóracolumbar como método para simplificar la indicación del tratamiento

La puntuación de la severidad de la fractura[31] tóracolumbar o lesiones toracolumbares (Thoracolumbar injury classification and severity score) TLISS (por sus siglas en inglés), es una clasificación presentada en el año 2005 que tiene las mismas funciones que las demás clasificaciones sólo que expresadas en puntos.

Las sofisticadas técnicas de diagnóstico con las que se cuenta en la actualidad permiten describir detalladamente estas lesiones, tipificarlas y planear eficientemente su tratamiento y pronóstico[32-35]

Incluye la evaluación de la resonancia y es relativamente fácil conseguir una alta fiabilidad inter e intra-observador. Además, proporciona directrices generales de tratamiento basadas en el conocimiento actual de la historia natural de las lesiones de columna toracolumbar.

Fue conceptualizado en base a una encuesta dada a la Spine Trauma Study Group, el cual está integrado por expertos de todo el mundo en el campo de traumatismo medular. El objetivo del estudio fue identificar las similitudes en los algoritmos de tratamiento para las lesiones toracolumbares comunes, así como identificar las características de las lesiones que han jugado un papel clave en el proceso de toma de decisiones[22].

Se basa en tres categorías principales: la morfología de la lesión, la integridad del complejo ligamentoso posterior, y el estado neurológico del paciente.

Para clasificar una lesión, el médico tratante describe primero la morfología de la lesión seguida de la integridad del complejo ligamentoso posterior y finalmente el examen neurológico del paciente.

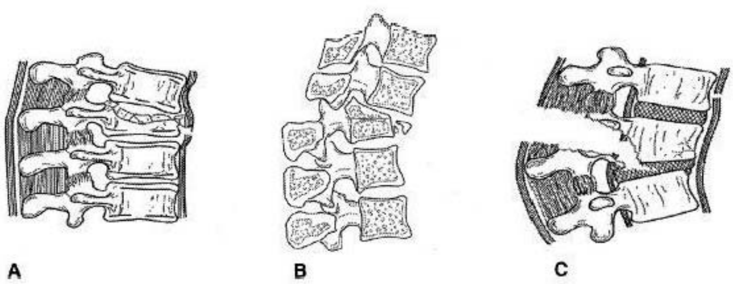
Se asignan puntos específicos, y la suma de los puntos define las posibles alternativas de tratamiento.

TLICS scoring

Parameter	Points
Morphology	
Compression fracture	1
Burst fracture	2
Translational/rotational	3
Distraction	4
Neurologic involvement	
Intact	0
Nerve root	2
Cord, conus medullaris	
Incomplete	3
Complete	2
Cauda equina	3
Posterior ligamentous complex	
Intact	0
Injury suspected/indeterminate	2
Injured	3

Management as per TLICS score

Management	Points
Nonoperative	0–3
Nonoperative or operative	4
Operative	≥5



A Compression (compression fracture or burst). B Rotation/translation. C Distraction

Figura 1.

Tabla 1. Puntos de definición de alternativas de tratamiento en la clasificación TLCS.

Management as per TLICS score

Management	Points
Nonoperative	0–3
Nonoperative or operative	4
Operative	≥5

En conjunto todas estas clasificaciones intentan darnos una idea de lo dañada que puede estar la columna vertebral y, por tanto, cual es el grado de inestabilidad que existe en la misma[23,36]. Además de la indicación o no de la cirugía[29,30,37,38] para obtener un mejor resultado final.

Una vez valorado este parámetro debemos considerar la necesidad de una vía anterior[39] o posterior (para lograr la descompresión y la estabilidad hasta obtener la consolidación y la artrodesis (la mayor parte de las veces obligada), bien a dos o más niveles[40-46], dependiendo del mismo modo de la localización[47], del tipo de fractura[23,26,27,32-35,50,] y del uso de un instrumental con sistema de atornillado transpedicular o no (alambres, ganchos, etc.)[17,43,46,50,51,52].

El reto se hace todavía mayor cuando tenemos que incluir factores tan importantes como la presencia lesión neurológica de mayor o menor grado, lo que nos puede hacer modificar la metodología del tratamiento[19,22,23,28,34,35,38,45,47,52,53,54,55,56,57,58]. Como ocurre, del mismo modo, en el caso de lesiones tumorales[59,60] o en fracturas de raquis muy osteoporóticos[61].

De una manera o de otra son las fracturas por estallido y las fracturas luxaciones las que hacen que el cirujano ortopédico tenga que agudizar todo su ingenio para elegir en cada momento cual es el tipo de tratamiento (ortopédico o quirúrgico), vía de abordaje (anterior, posterior o combinado), tipo de instrumental y montaje (sistemas de ganchos, de atornillado o mixtos), que cada paciente específico necesite para intentar solucionar su particular problema de cada paciente[23,30,38,42,47,49,58,62-64].

1.4.5 Inestabilidad vertebral toraco-lumbar

Podemos definir la inestabilidad vertebral de acuerdo con la disfunción nerviosa real o potencial y al grado de lesión estructural de la columna vertebral. Puede existir inestabilidad aguda o crónica. Según Denis[23] es necesario de la columna media y posterior para que la lesión sea rápidamente inestable.

Con estos conceptos, dependiendo de la posible evolución de las fracturas dorso-lumbares, podemos distinguir:

- Fracturas estables.- Entre ellas nos encontraríamos con las fracturas de aisladas de los elementos posteriores como las apófisis transversas, de las articulares, de la pars interarticularis, de las apófisis espinosas y las fracturas por compresión leves o moderadas.

- Fracturas inestables.- Dentro de este apartado podemos distinguir tres grupos:

  - Inestabilidad de I grado.- Sería la inestabilidad mecánica con riesgo de cifosis, como ocurriría en las fracturas por compresión severa con afectación de la columna posterior, así como, algunas lesiones por cinturón de seguridad.

  - Inestabilidad de II grado.- Inestabilidad neurológica. Típico de las fractura por aplastamiento con retropulsión de de un fragmento hacia el canal raquídeo con mayor riesgo de estenosis de canal de mayor o menor grado una vez consolidada.

  - Inestabilidad de III grado.- En este tipo existe una inestabilidad combinada mecánica y neurológica. Son las fracturas luxaciones, fracturas por aplastamiento o compresión inestable con o sin lesión neurológica.

1.4.6 Clinica

Como en cualquier patología médica para poder llegar a un diagnóstico lo más certero posible de las lesiones producidas en un traumatismo vertebral debemos de seguir una exploración sistematizada[21,65] que incluirá una anamnesis seguida de una exploración física general y posteriormente de la lesión de la lesión vertebral local y una exploración neurológica completa.

Posteriormente es cuando se realizaran las pruebas de imagen que consideremos oportunas.

a) Anamnesis.- Como en cualquier enfermedad habrá que plantear las tres preguntas clásicas al paciente de ¿qué le pasa?, ¿desde cuándo? y ¿a que lo atribuye. Es por tanto fundamental conocer la etiología de la lesión, el mecanismo que ha provocado la misma lo que nos dará una idea si nos encontramos ante fracturas de alta o baja energía y que fuerzas han intervenido en mecanismo lesional.

   Recoger los datos de la sintomatología nos dará una idea de entrada muy aproximada de la gravedad de la lesión. Haremos especial hincapié en saber la localización del dolor, la intensidad, las características del mismo (quemazón, punzadas, acorchamiento, hormigueo etc.), las posibles irradiaciones a miembros superiores, inferiores o en cinturón.

   Será importante conocer si aumenta al respirar, con determinados movimientos o está presente o disminuye en reposo. Del mismo modo se le preguntará por la posibilidad de pérdida de esfínter anal o vesical, independientemente las preguntas necesarias de sintomatologías del resto de órganos y sistemas.

Preguntaremos igualmente por los antecedentes familiares y personales, así como por las enfermedades asociadas.

b) Exploración física. Incluirá una exploración física general y una exploración física de la posible lesión de la columna vertebral.

- Exploración física general. Recogeremos, como norma general de exploración de todo traumatizado (muchas veces la lesión vertebral se incluye dentro del contexto de un politraumatizado), todos los signos vitales referidos a la ventilación, pulso, tensión arterial, estado de conciencia, etcétera. Haremos una exploración de posibles lesiones cardio-pulmonares, abdominales y cráneo-encefálicas. Exploraremos igualmente las posibles lesiones periféricas asociadas.

- Exploración física de la columna vertebral. Seremos ante todo muy cuidadosos a la hora de movilizar al paciente para evitar agravar las lesiones iniciales. Inspeccionaremos la cabeza, el tronco y las extremidades, buscando deformidades o posiciones antiálgicas. Palparemos suavemente todas las apófisis espinosas y todos los puntos dolorosos que nos indique el paciente.

  Pasaremos finalmente a valorar la movilidad activa y pasiva de todas las articulaciones, la sensibilidad y los reflejos osteo-tendinosos y bulvocavernosos[2,13,63].

  Seremos muy cuidadosos en caso de encontrar alteración motora en averiguar si la lesión es parcial[64] o completa y el grupo grupos musculares afectados y el grado de potencia muscular presente en ese momento siguiendo la escala de Frankel[18]. En fundamental conocer la posible lesión sensitiva y localizar el nivel del dermatomo correspondiente para hacernos una idea del lugar de la posible fractura vertebral. Terminaremos explorando todos los reflejos osteo-tendinosos y sensitivos.

1.4.7 Estudios de imagen

Para el diagnóstico por imagen de las fracturas toraco-lumbares se han venido utilizando diversos estudios invasivos y no invasivos que han incluido desde radiografías simples, radiografías dinámicas, tomografías simples, mielografías, gammagrafías, tomografías axiales computarizadas (TAC) y resonancia nuclear magnética (RNM).

En la actualidad prácticamente han desaparecido los estudios invasivos y la mayor parte de los radiográficos quedando limitada al uso de la radiografía simple, la TAC, SPECT-CT y la RNM que en conjunto nos dan una idea muy exacta del tipo de lesión descartando otro tipo de patologías[48,59], su estabilidad[32,35] y la táctica terapeútica a seguir ortopédica o quirúrgica dependiendo de las distintas circunstancias tanto del paciente como de la lesión.

Iremos describiendo someramente las ventajas e inconvenientes de cada prueba diagnóstica:

a) **Radiografías simples.-** La radiografía simple es de obligado cumplimiento ante la sospecha de una fractura vertebral, teniendo como axioma mientras se practica el estudio y se moviliza al paciente esta maniobras se harán siempre en bloque para evitar las flexiones bruscas de los segmentos dorso-lumbares.

   El estudio radiográfico incluirá como mínimo dos proyecciones antero-posterior y lateral y sólo ocasionalmente se completarán con radiografías oblicuas (aunque estas proyecciones suelen ser más útiles a nivel de la columna cervical al igual que las radiografías laterales dinámicas).

   En estas dos proyecciones radiográficas buscaremos la localización de la fractura, el estado de los platillos vertebrales, el ensanchamiento o no de los pedículos, posible presencia de subluxaciones en algunos de los dos planos radiográficos etcétera. Por lo tanto, con la obtención de solamente dos proyecciones podemos obtener múltiples datos que nos informarán del grado de aplastamiento, rotura o no de los pedículos, presencia de angulaciones patológicas con aumento o disminución de los distintos parámetros angulares fisiológicos[33] que serán fundamentales, como veremos posteriormente, tanto en la clasificación de la fractura como en el control evolutivo de la misma.

b) **Tomografía Axial Computarizada**.- La TAC nos va a dar una información más detallada del estado, principalmente de las estructuras óseas, y es muy útil para identificar la posible presencia por retropulsión de fragmentos en el canal medular y, la situación en la que se encuentran los elementos posteriores óseos (pedículos, laminas y apófisis transversas y espinosas), más difíciles de identificar que en las radiografías simples. Es por tanto, un complemento importante en la valoración del estado óseo de las tres columnas vertebrales de Denis[23]: Columna anterior, columna media y columna posterior.

   La TAC también nos permite detectar alteraciones de partes blandas como la presencia de hematomas epidurales o de vísceras adyacentes a la vértebra fracturada. Nos permitiría apreciar, por ejemplo, una rotura renal o la presencia de un hemoneumotórax.

   Los aparatos de TAC de última generación son capaces de realizar reconstrucciones anatómicas que simulan verdaderas preparaciones quirúrgicas de segmentos de la columna vertebral.

c) **Resonancia Nuclear Magnética**.- La aparición de la RNM ha sido una verdadera revolución en los estudios de imagen para el diagnóstico correcto de cualquier lesión del aparato locomotor pero fundamentalmente en las lesiones de partes blandas.

Podemos decir que es mandatorio, antes de plantearse la intervención quirúrgica de una fractura dorso-lumbar la práctica de una RNM, pues entre otros, nos permitirá tener información del estado del disco intervertebral, de la presencia de hematomas epidurales, de la interrupción del líquido cefalorraquídeo, de la compresión de la médula espinal e incluso de la posible contusión de la misma. Igualmente nos puede informar posible inestabilidad de la fractura al mostrarnos el estado de los ligamentos de los ligamentos amarillos, interespinosos y supraespinosos, con la importante repercusión sobre el planteamiento ortopédico o quirúrgico[29,30] a realizar al paciente.

d) **Otros estudios de imagen**.- En muy raras ocasiones se pueden utilizar otros estudios de imagen tanto en el diagnóstico de la fractura sino también como la ayuda diagnostica en posibles complicaciones postoperatorias estos estudios incluyen la ecografía, el eco-doppler, la gammagrafía e incluso la arteriografía y la flebografía[66].

1.4.8 Tratamiento general de las fracturas toraco-lumbares.

El tratamiento de las fracturas vertebrales gran parte de las veces no es un tratamiento aislado al ser en muchas ocasiones una lesión más dentro el contexto de un politraumatizado con lesiones craneoencefálica, torácicas, abdominales u otras fracturas de miembros asociadas y, por tanto, al paciente debemos enfocarlo como una persona que puede estar corriendo un riesgo vital.

Hay que solucionar de forma urgente los riesgos vitales, priorizando de forma sistemática: el mantenimiento de las vías respiratorias, el control de la hemorragia, estabilización de las fracturas y en conjunto el protocolo convencional de atención al politraumatizado.

Una vez que queramos centramos en el posible tratamiento[21,63] ortopédico o quirúrgico[20] de la fractura dorso-lumbar lo primero que habrá que plantearse es si dicha fractura la consideramos:

- Fractura estable.- La trataremos de forma ortopédica[38,47] con los diferentes tipos de ortesis[18,66] de materiales normalmente de termoplástico diseñadas para este fin y que en general dan un resultado excelente sin tener que recurrir a los antiguos tratamiento de reposo prolongado en cama (con las posibles complicaciones respiratorias, infecciones urinarias, úlceras de decúbito y demás complicaciones del decúbito prolongado) o al uso de corsés de escayola cuyas complicaciones todos los cirujanos ortopédicos conocemos.

- Fractura inestable.- En cuyo caso indicaremos una cirugía de estabilización instrumentada, bien por una única vía (normalmente posterior)[33,43,60] o en menor porcentaje por vía anterior[39] y, en ocasiones utilizaremos un doble abordaje combinado anterior y posterior[25,26,27,28,64,65,66]. A este tratamiento asociaremos la mayor parte de las ocasiones una artrodesis postero-lateral con hueso obtenido de la cresta iliaca del propio paciente o con cualquier otro material que mejore la remodelación ósea[67], como son los aloinjertos de banco de huesos[25,55,68,69,70], bien congelado[55,69,70] o radiado[57,71], los sustitutos óseos de osteoinducción u osteoconducción[56,67] e incluso pudiendo añadir también, en aquellos pacientes que por una u otra circunstancia lo necesiten, como puede ocurrir en ocasiones en los muy osteoporóticos, proteínas óseas morfogenéticas[72] o sistemas adhesivos de fibrina[73,74,75], o bien la aplicación conjunta de células troncales pluripotenciales[76].

Todo esto, sabiendo que en los casos de aloinjeto o de material extraño nos podemos encontrar con mayor posibilidad de que aumenten las complicaciones como son el mayor índice de retardos de consolidación o incluso de pseudoartrosis[55,68,55,71], los problemas de posible inmunización[77,78] o de inmunización/alergias[56], de infección profunda[70], etcétera.

1.4.9 Tratamiento de rehabilitación

El tratamiento rehabilitador es una parte fundamental en el tratamiento integral de la fractura[21] comenzará desde que el paciente queda ingresado en nuestro centro hospitalario tomándose especial cuidado en colocar dicho paciente en una cama dura y en posición de decúbito supino con una pequeña almohada que proteja la lordosis lumbar fisiológica.

Incluirá las medidas que a continuación detallaremos además de una ayuda cognitivo-conductual[21]:

a) **Periodo de reposo absoluto.-** Durante el periodo de reposo absoluto en cama se realizarán:

- Cambios posturales, evitando los decúbitos laterales con las rodillas en flexión.
- Toma de conciencia del control muscular activo del tronco: Trabajo estático suave y progresivo sin sobrepasar el umbral doloroso.
- Trabajo isométrico de la musculatura paravetebral.
- Trabajo isométrico de músculos anteriores del tronco y de los abdominales.
- Contracciones isométricas de los músculos cuádriceps y de los glúteos.
- Aprendizaje de la disociación fémoro-pélvico-lumbar. La movilización pasiva en flexión de una cadera se llevará a cabo bajo el control voluntario de la pelvis (sin mover la misma) y con la cadera contralateral en rectitud.
- Ejercicios isotónicos de los miembros inferiores sin pasar de 75º de flexión de las caderas.

- Ejercicios respiratorios costo-diafragmáticos. Aprendizaje controlado del flujo respiratorio en las amplitudes de movilidad indolora del tórax.
- Ejercicios contra resistencia de las extremidades superiores.
- Masoterapia abdominal asociada a la ventilación.
- Masaje de drenaje circulatorio de ambos miembros inferiores.

b) **Periodo de puesta en carga.-** La puesta en carga precoz y la marcha controlada no son incompatibles con la consolidación sino que la favorecen al producir presiones axiales en compresión. Comenzaremos el tratamiento rehabilitador con:

- Reinicio de la ventilación: Plano inclinado.
- Deambulación durante periodos breves y repetidos. Con aumento progresivo del perímetro de la marcha.
- Aprendizaje de los pasajes de posición. Enderezamiento con el tronco bloqueado, a partir del decúbito prono y del decúbito lateral.
- Ejercicios respiratorios de gran amplitud.
- Corrección postural del tronco a distancia del foco de fractura. Delante de un espejo y posteriormente sin ayuda del mismo.
- Mantenimiento articular periférico.

c) **Periodo de restauración de la movilidad**.- Se trata de restaurar la movilidad para obtener un resultado funcional óptimo. Este periodo se caracteriza por una fase de movilidad controlada seguida de una fase de movilidad raquídea libre, en la que el paciente utiliza el conjunto de las amplitudes de su columna vertebral.

- Fase de movilidad controlada del raquis.- Esta fase incluirá las siguientes medidas:
    - Corrección postural del conjunto del raquis.
    - Movilización global del raquis en descarga mediante:
        - Hidrocinesiterapia en piscina.
        - Reptación en decúbito supino y prono.

▪ Volteos con disociación de las cinturas escapular y pelviana.

▪ Trabajo de facilitación neuromuscular propioceptiva en diagonal de la pelvis y de la cintura escapular en activo libre y resistido.

▪ Movilización analítica del raquis en cuadrupedia de Klapp, en carga y automovilizaciones.

- Streching postural.
- Refuerzo muscular de los abdominales y espinales, en todos los sectores de movilidad indolora.
- Trabajo propioceptivo sobre planos estables y móviles (tabla basculante).
- Aprendizaje de la economía del raquis en la vida diaria.

o Fase de movilidad libre del raquis.- Que será la última fase del tratamiento rehabilitador y englobará:

- Corrección corporal de raquis. Integración del nuevo esquema corporal (automatización).
- Ejercicios de movilización del raquis de gran amplitud en carga.
- Movilización analítica del raquis.
- Refuerzo muscular de abdominales y espinales.
- Trabajo propioceptivo y de reprogramación neuromuscular.
- Aprendizaje de la economía del raquis en los gastos de fuerza de la actividad profesional y/o deportiva.

1.5 Hipotesis del trabajo

La hipótesis de nuestro trabajo es demostrar si:

¨Un estudio mucho más específico que amplíe el número de parámetros y de mediciones radiográficas realizados en una prueba de imagen simple y económica como es la radiografía en proyección lateral, prueba de imagen fácil de realizar, repetible y con datos numéricos objetivos tomada en la fase aguda postraumática, preoperatorio inmediato y en controles sucesivos junto a un análisis estadístico exhaustivo favorece el conocimiento de su evolución clínica, del posible periodo de baja del trabajador y de sus posibilidades de reincorporación laboral cual podría permitir importantes beneficios tanto para lostrabajadores, como para las empresas y, en conjunto, a la sociedad en general".

1.6 Work hipothesis

The thesis hypothesis aims to perform:

"A much more specific study which expands the number of known radiographic parameters and measurements performed in a simple and inexpensive imaging test such as the lateral plain x-ray, which is an easy-to-perform and a repeatable imaging test, gathering numerical data from the radiographs in the acute and post-traumatic phase, and also in the immediate, preoperative and follow-up period performing an exhaustive statistical analysis which favors the knowledge of its clinical evolution, the possible worker sick-period and his possibilities of returning to work, which could allow important benefits both for the workers, the companies and, as a whole, society in general ".

2. CAPÍTULO I

2.1 Objetivo General

Analizar la reincorporación laboral en pacientes con fracturas inestables toracolumbares utilizando el software RIC/PACS.

2.2 Objetivos Específicos

Analizar la evolución de seis parámetros radiológicos a lo largo de 3 años en pacientes con fracturas inestables toracolumbares.

Analizar las características epidemiológicas de las fracturas inestables toracolumbares en nuestro medio.

Analizar las complicaciones a corto, medio y largo plazo de las fracturas inestables toracolumbar.

2.3 Antecedentes y estado del arte

Las fracturas y luxaciones vertebrales torácicas y lumbares son lesiones muy serias que ocurren con frecuencia en gente joven, generalmente producidas por traumatismos de alta energía tales como accidentes de tráfico y precipitaciones.

Las lesiones neurológicas pueden ocurrir en un 15% a 40% de estas fracturas y más de un 30% de los pacientes pueden desarrollar dolor crónico que conlleva limitaciones en las actividades de la vida diaria y dificultad en la reincorporación laboral, por lo que, el manejo adecuado de dichas fracturas es fundamental.

Las fracturas toracolumbares son un gran motivo de absentismo y baja laboral, muchos pacientes están mucho tiempo de baja, mientras que otros no se reincorporan nunca.

Con la aparición de nuevas técnicas y aparataje, así como una mejor destreza quirúrgica fruto de la experiencia, el tratamiento quirúrgico de las fracturas vertebrales torácicas y lumbares se ha popularizado en los últimos años al reducir el tiempo de estancia hospitalaria, aumentar la estabilidad, conseguir una adecuada reducción, y en numerosas ocasiones, mejorar la función neurológica.

Con nuestro estudio, pretendemos hacer una análisis de seis parámetros radiológicos, medidos mediante el software PAC/RICS en la tomografía computarizada practicada a los pacientes con fracturas vertebrales inestables. Los parámetros medidos serán los siguientes:

- Ángulo fractuario: formado entre la tangente trazada a nivel del platillo vertebral superior de la vértebra superior a la vértebra fracturada y la tangente trazada a nivel del platillo vertebral inferior de la vértebra inferior a la vértebra fracturada.

- Deformidad cifótica: valor angular obtenido al trazar una tangente entre el platillo vertebral inferior de la vertebral superior a la fracturada y la línea tangente al platillo vertebral inferior de la vértebra fracturada.

- Índice sagital: valor obtenido de la diferencia entre la deformidad cifótica segmentaria y la curva sagital basal del nivel de la fractura..

- Porcentaje de compresión vertebral: ratio de la distancia en milímetros de la parte anterior de la vértebra fracturada comparado con la altura de la pared posterior del cuerpo vertebral de esta vértebra multiplicado por cien y posteriormente sustrayéndole cien..

- Grado de desplazamiento: distancia que la vértebra se ha desplazado anteriormente referida a la pared posterior de la vértebra fracturada dividido por la anchura de la vértebra normal inmediatamente inferior a la vértebra fracturada.

- Ángulo de deformación: determinado por la intersección de las líneas trazadas a lo largo de la superficies posteriores de los cuerpos vertebrales por encima y por debajo de la fractura.

Se realizará un estudio multicéntrico retrospectivo de una serie de casos no consecutivos con fracturas no osteoporóticas inestables de la columna toraco-lumbar sin clínica neurológica asociada. En este estudio retrospectivo, se revisarán las fracturas toraco-lumbares inestables tratadas quirúrgicamente y se seleccionaron las que no presenten déficit neurológico. Serán excluidos asimismo los pacientes con diagnóstico de osteoporosis y aquellos con fisis todavía abiertas.

Se calcularán las mediciones radiográficas desde el ingreso, postoperatorio inmediato, a los 12, 24 y 36 meses. Se registrarán así mismo la edad, sexo, seguimiento, localización fractuaria, tipo de fractura, vertebras instrumentadas y el tipo de montaje.

Se estudiarán los pacientes que se reincorporaron laboralmente y su relación con los parámetros radiológicos.

2.4 Metodología

2.4.1 Primera etapa

Recopilación de bibliografía y planteamiento de la hipótesis de estudio.

La primera etapa consiste en la revisión bibliográfica sobre reincorporación laboral y mediciones radiográficas en el caso de fracturas inestables toraco-lumbares, así como en la utilización del software PAC/RICS.

2.4.2 Segunda etapa

Recopilación de pacientes con fracturas inestables toraco-lumbares.

De las bases de datos hospitalarias, obtendremos los casos de fracturas inestables toraco-lumbares operadas hasta el 2013 (dado que necesitamos al menos 3 años de seguimiento). Recogeremos asimismo los distintos datos epidemiológicos citados en el estudio como objetivos (sexo, edad, mecanismo de lesión, tipo de fractura, tipo de intervención y reincorporación laboral.

2.4.3 Tercera etapa

Análisis de la baja laboral y edición de los parámetros radiológicos.

Una vez recopilados todas las fracturas, procederemos a realizar la medición de los seis parámetros radiológicos a lo largo de los 36 meses.

2.4.4 Cuarta etapa

Análisis de resultados.

Para la valoración radiográfica de la estabilidad de una fractura vertebral, clásicamente se han utilizado dos parámetros: la deformidad cifótica y el porcentaje de compresión.

Estas mediciones, con anterioridad, se realizaban practicamente mano, sin ningún software específico. La aparición de nuevos software que permiten digitalizar y realizar mediciones computerizadas abren un nuevo abanico de posibilidades en el campo de las fracturas vertebrales.

En este estudio, pretendemos realizar un análisis de la reincorporación laboral en pacientes con fracturas inestables toracolumbares y relacionarlos las mediciones radiológicas mencionadas.

Finalmente, realizaremos el análisis estadístico (veremos si los parámetros pierden corrección a lo largo de los 36 meses de seguimiento) de los diferentes parámetros mediante el programa SPSS.

2.4.5 Aporte original que supondría en el campo científico correspondiente

Este estudio pretende valorar si existen parámetros radiológicos que no han sido estudiados tradicionalmente y su relación con la reincorporación laboral. En función de los parámetros radiológicos pretendemos valorar si hay pacientes que se reincoporan o no a su puesto de trabajo.

2.5 Metodology

2.5.1 First Stage

References compilation and statement of the study hypothesis.

The first stage embraces a reference review in relation to returning to work and the radiographic measurements in the case of unstable thoraco-lumbar fractures, as well as the use of the PAC/ RICS software..

2.5.2 Second Stage

Compilation of patients with unstable thoraco-lumbar fractures.

Extracted from hospital databases, we will obtain cases of unstable thoraco-lumbar fractures who underwent spinal surgery up to 2013 (since at least a 3 year of follow-up period is needed). We will also collect the different epidemiological data referenced in the study as objectives (sex, age, mechanism of injury, type of fracture, type of intervention and return to work.

2.5.3 Third Stage

Sick leave analysis and radiological parameters edition.

After spinal fracture data base collection, we will proceed to measure the six radiological parameters throughout the 36 months.

2.5.4 Fourth Stage

Results analysis

For radiological assessment of the stability of a vertebral fracture, two parameters have traditionally been used: the kyphotic deformity and the percentage of compression.

These measurements were previously carried out by hand, without any specific software. The appearance of this new software which allows a computerized analysis opens up a new range of possibilities in the field of vertebral fractures.

In this study, we intend to perform a return to work analysis in patients with unstable thoracolumbar fractures and relate them to the afore-mentioned radiological measurements.

Finally, the statistical analysis of the different parameters will be performed (we will see if the parameters lose correction throughout the 36 months of follow-up) using the SPSS program.

2.5.5 Original contribution in the corresponding scientific field

This study aims to assess whether there are radiological parameters that have not been traditionally studied and their relationship with the return to work parameter. Depending on the radiological parameter, we intend to assess whether or not there are patients who will return to their previous job or not.

3. CAPÍTULO II

3.1 Introducción

En este capítulo vamos a presentar todos aquellos estudios científicos que hemos realizado y que están directamente relacionados con la patología y lasmediciones radiológicas tanto en la patología en general de la columna vertebral como en las fracturas vertebrales a nivel de la columna torácica y la columna lumbar (dorso-lumbar) y que nos han sido publicados en revistas tanto nacionales como internacionales y todas ellas con impacto JCR.

Con la lectura de todos estos artículos vamos a ir viendo la línea de investigación en la que se pretende llegar a conclusiones reales y fiables que nos permitan ver la gravedad que tienen las fracturas vertebrales dorso-lumbares en cualquier paciente y cualquier edad y más específicamente en el ámbito laboral. Para ello hemos ido realizando estudios de investigación previo conocimiento de la anatomía, fisiología, biomecánica, tipo de lesiones, mecanismo de producción de dichas lesiones, clínica que presentaban nuestros trabajadores lesionados, estudios de imagen tanto desde el punto de vista de las radiografías simples, las radiografías dinámicas, las radiografías en carga y las telerradiografías en bípeda-estación, así como las de bending laterales y en flexo-extensión, como pruebas mucho más sofisticadas de imagen con las tomografías axiales computarizadas (TAC) incluso con reconstrucciones y finalmente la práctica de resonancias magnéticas en aquellos pacientes en los se estimaban como conveniente larealización de la misma.

Igualmente, se valoró el tipo de fractura, el tratamiento seguido, los días de estancia hospitalaria, las posible complicaciones pre quirúrgica, durante el acto de la cirugía y en el preoperatorio del paciente. Se controló la evolución mediante parámetros clínicos del dolor fundamentalmente el EVA (Escala de Valoración Analógica del Dolor), las posibles secuelas y el tiempo de reincorporación a su trabajo habitual o a otro puesto de trabajo si fuese su caso.

Finalmente queremos señalar como una de las observaciones más novedosas de nuestro estudio ha sido (Como veremos en algunos de los artículos publicados presentados a continuación) el estudio detallado y exhaustivo le seis parámetros medidos en la radiografía simple lateral (de perfil) de la columna vertebral. No solamente en un estudio inicial y final sino que se amplió el estudio en un seguimiento periódico y prolongado (preoperatorio, postoperatorio inmediato, de los controles intermedios y de los finales. Siendo analizados estadísticamente estos valores y relacionándolos con los resultados finales y la reincorporación laboral de nuestros trabajadores.

3.2 Presentaremos continuación el resumen de los artículos publicados.

1.- LONG TERM RADIOLOGICAL OUTCOMES OF UNSTABLE THORACO-LUMBAR FRACTURES WITHOUT NEUROLOGICAL DEFICIT.

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Journal: Neurocirugía 2017; 28(5): 211-217.

Introduction

To analyze the radiological outcomes of unstable thoraco-lumbar fractures in the long term.

Materials and methods

Retrospective review of 100 patients with unstable thoraco-lumbar fractures treated with postero-lateral fusion and short screw fixation for compression and flexion-distraction type fractures, and long segment posterior fixation for fractures-dislocations or more than one vertebra fractured, between 2000 and 2010, at three different hospitals. Six radiological parameters were measured annually during a 4-year period: Fracture angle, kyphotic deformity, sagittal index, percentage of compression, degree of displacement, and deformation angle.

Results

A total of 100 patients were included with a median age of 36.4 years and a median follow-up period of 7.2 years. Fracture angle rose from 11.6° to 14.5° (25% increase), kyphotic deformity from 14.5° to 16.7° (15.17% increase), sagittal index from 8.7 to 10.8 (24.13% increase), percentage of compression from 31.8%to 36.5% (6.88% increase), degree of displacement from 2.8 mm to 4.6 mm (14.77% increase), and deformation angle from 19.7° to 21.4° (8.62% increase).

Conclusions

All radiological parameters studied lost correction throughout the 48 months of follow-up, with fracture angle being the most affect done. Nevertheless, the greatest loss of correction occurs in the first postoperative year, with parameters stabilizing afterwards over the 4 years of follow up. We routinely recommend the measurement to fall previous parameters for the follow up of unstable thoraco-lumbar fractures.

2.- RADIOLOGICAL OUTCOMES OF UNSTABLE THORACOLUMBAR FRACTURES WITHOUT NEUROLOGICAL DEFICIT TREATED THROUGH PERCUTANEOUS SURGERY

Authors and affiliation:

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Journal: Neurocirugía 2018; 29(2): 57-63.

Introduction

To analyze the radiological outcomes in the long term of unstable thoraco-lumbar fractures treated through percutaneous surgery.

Materials and Methods

Retrospective review of a series of patients with unstable thoraco-lumbar fractures treated with percutaneous minimally invasive surgery between 2010 and 2015 at three different hospitals. Six radiological parameters were measured annually during a 2-year period: Fracture angle, kyphotic deformity, sagittal index, percentage of compression, degree of displacement, and deformation angle.

Results

A total of 37 patients were included with a median age of 41.3 years and a median follow-up period of 2.2 years. Fracture angle rose from 14.8° to 17.1° (15.54%increase), kyphotic deformity from 15.9° to17.7° (11.32%increase), sagittal index from 10.1 to 2.3 (21.78%increase), percentage of compression from 32.7% to 36.8% (12.53%increase), degree of displacement from 3.0 mm to 4.4mm (50%increase), and deformation angle from 20.7° to 22.9° (10.62% increase).

Conclusions

All radiological parameters studied lost correction throughout the 24 months of follow-up, the degree of displacement and the sagittal index being the most affected ones. Nevertheless, the greatest loss of correction occurs in the first postoperative year, with parameters stabilizing afterwards over the 24 months of follow up. We routinely recommend the measurement of all previous parameters for the follow up of unstable thoraco-lumbar fractures treated through percutaneous surgery.

3.- RADIOLOGICAL EVALUATION DOES NOT REFLECT THE CLINICAL OUTCOME AFTER SURGERY IN UNSTABLE THORACOLUMBAR AND LUMBAR TYPE A FRACTURES WITHOUT NEUROLOGICAL SYMPTOMS: A COMPARATIVE STUDY OF 2 COHORTS TREATED BY OPEN OR PERCUTANEOUS SURGERY.

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6. Department of Spine Surgery of Sidney Kimmel Medical Center at Thomas Jefferson University, Philadelphia, PA.

Journal: Clin Spine Surg 2019;32:117-25

Study design:

This is a prospective study of 2 cohorts.

Objective:

Compare the clinical and radiologic outcome of 2 cohorts of unstable thoracolumbar and lumbar fractures treated by open posterior fixation (OPF) with bone graft or by percutaneous fixation (PCF) without grafting.

Summary of background data:

In recent years, PCF is the most common treatment of thoracolumbar fractures. To date, no studies have analyzed clinical outcomes in terms of return to work.

Material and methods:

Two cohorts of patients with unstable thoracolumbar and lumbar fractures fractures (type A2, A3, and A4) without neurological symptoms underwent OPF (n=91) or PCF (n=54) between 2010 and 2015. A conventional radiologic study was performed in the preoperative, immediate postoperative period, 1-year, and 2-year follow-up.

Clinical outcomes were evaluated by Visual Analog Scale and Oswestry Disability Index scores at 1-year and 2-year follow-up. The period to return to work and the type of work were also recorded.

Results:

The percentages of correction were significantly higher in cases operated by OPF: fracture angle ($P<0.001$), kyphotic deformity ($P<0.001$), vertebral compression ($P<0.001$), and displacement ($P<0.001$). Cases operated by PCF experienced greater loss of correction at 2-year follow-up, especially in fracture displacement ($P<0.001$), deformity angle ($P<0.001$), kyphotic deformity ($P<0.001$), and in the sagittal index ($P<0.001$). Besides this greater loss of correction, PCF cases showed better Visual Analog Scale ($P<0.001$) and Oswestry Disability Index scores ($P<0.001$) at final follow-up. The percentage of patients returning to the same heavy work position was higher in the PCF group ($P<0.001$) and in a shorter period of time ($P<0.001$).

Conclusions:

The greater loss of correction of patients undergoing PCF does not reflect the clinical outcomes that were significantly better as compared to patients undergoing open fixation with grafting. It would be useful to further evaluate if the radiological changes could have a long-term clinical significance.

4.- SEVERE HYPERKYPHOSIS REDUCES THE AEROBIC CAPACITY AND MAXIMAL EXERCISE TOLERANCE IN PATIENTS WITH SCHEUERMANN DISEASE.

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Journal: Spine J. 2019 Feb;19(2):330-338

Background context:

The evaluation of ventilatory functional restrictions during a maximal exercise tolerance test in patients with Scheuermann disease has never been described.

Purpose:

This study evaluated the respiratory functional capacity of patients with Scheuermann disease compared to healthy adolescents matched in age.

Study design/setting:

Prospective comparative study.

Patients sample:

Forty-one consecutive adolescents with Scheuermann hyperkyphosis (SK) and 20 healthy controls matched in age were included in the study.

Outcome measures:

Basal spirometry and dynamic ventilatory parameters were measured during a maximal cardiopulmonary exercise tolerance test. Heart rate, oxygen saturation ($SatO_2$), maximum oxygen uptake ($VO_{2\,max}$), quotient between ventilation and volume of exhaled carbon dioxide (VE/CO_2), respiratory exchange rate (RER), ventilatory capacity at maximal exercise (VE_{max}), and test duration were recorded at initium and at maximal exercise.

Methods:

The exercise tolerance test (ETT) was completed to exhaustion using a standard Bruce protocol on a ramp treadmill. Comparisons of quantitative variables between SK and control group were analyzed by statistical nonparametric test. The correlations between the magnitude of the thoracic kyphosis and both the VO_2 max/kg and VE_{max} of the SK group were also analyzed. No funds were required. The authors have no conflicts of interests.

Results:

Patients with SK started the test with a higher heart rate ($p<.01$) and reached exhaustion with a lower heart rate ($p<.05$) than healthy controls. At maximal exercise, the $SatO_2$ was declined in Scheuermann patients compared to healthy subjects ($p<.05$). The maximal aerobic power (VO_{2max}) was greater in healthy controls than in hyperkyphotic patients (50.0±6.7 vs. 43.4±11.3 mL/kg/min; $p<.05$). There was an inverse correlation between the increase in the magnitude of thoracic kyphosis and the deterioration of the maximal aerobic power. VO_{2max} and VEmax were severely deteriorated in patients with more than 75° kyphosis. Patients with >75° thoracic kyphosis also showed an impairment in their cardiovascular efficiency as measured by the heart rate/VO_2 quotient. The limited tolerance to the exercise in SK patients was reflected by a shorter duration of the exercise test and a lower energy cost measured in METS (metabolic equivalents) as compared to healthy controls.

Conclusions:

Patients with severe hyperkyphosis (>75°) show significant respiratory inefficiency together with a lower ventilation capacity and lower VO_{2max}. There is an inverse correlation between the increase in the magnitude of thoracic kyphosis and the deterioration of the maximal aerobic power.

Nota.- Esta publicación recibió el Primer Premio otorgado por la Sociedad Española de Neuroraquis en el Congreso Anual celebrado en Sevilla en 2019, al mejor trabajo de investigación publicado a nivel internacional.

5.- CARDIORESPIRATORY FUNCTION DOES NOT IMPROVE 2 YEARS AFTER POSTERIOR SURGICAL CORRECTION OF ADOLESCENT IDIOPATHIC SCOLIOSIS.

Authors and affiliation

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Journal: Spine, 15, 2017 - V 42 - p 1391-1397

Study design:

A prospective evaluation of cardiorespiratory function following spinal fusion in adolescent idiopathic scoliosis (AIS).

Objective:

To evaluate the cardiopulmonary function during exercise in patients with severe AIS, before and 2 years after undergoing a posterior spinal fusion.

Summary of background data:

After surgical correction of scoliosis, a greater cardiorespiratory adaptation to exercise would be expected from correction of the rib cage associated with the spine deformity. However, there is no clear evidence regarding whether tolerance to maximum exercise improves in the medium term after surgery in patients with severe curves.

Methods:

We include patients with AIS proposed for posterior surgical correction aging between 12 and 17 years. Every patient had a Cobb angle >45° and a Lenke type 1A scoliosis. Cardiac and respiratory functional measures,

such as heart rate and blood pressure, maximum oxygen consumption (VO_{2max}), eliminated volume of carbon dioxide (VCO_2), quotient between ventilation and volume of exhaled carbon dioxide (VE/CO_2), respiratory exchange rate, ventilatory capacity at maximal exercise (VE_{max}), were recorded before and 2 years after surgery.

Results:

Twenty patients were included in our study, 15 girls and 5 boys, with an average age of 13 years. The main scoliotic curve was corrected in the coronal plane in an average of 71.9%. The maximal aerobic power expressed by body weight normalized VO_{2max} was found preoperatively to have an average of 30.9±6.2mL/kg/minute, indicating a poor aerobic capacity, which did not improve at final follow-up, decreasing to a mean value of 29.3±5.7 but without statistical significance. However, the percentages of curve correction showed a statistically significant correlation with VO_{2max} ($r=0.534$; $P<0.05$).

Conclusion:

Patients with severe adolescent idiopathic scoliosis Lenke type 1A showed limited cardiorespiratory tolerance to maximum exercise that did not improve 2 years after surgery.

6.- NON-UNIFORM SEGMENTAL RANGE OF MOTION OF THE THORACIC SPINE DURING MAXIMAL INSPIRATION AND EXHALATION IN HEALTHY SUBJECTS

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Journal: Frontiers in Medicine, 2021. doi: 10.3389/fmed.2021.699357

Background and Objective:

To analyse the range of motion of the thoracic spine by radiographically measuring changes in the sagittal profile of different thoracic segments during maximal inspiration and exhalation. The starting hypothesis was that forced deep
breathing requires an active, but non-uniform widening of the lordotic–kyphotic range of motion of the different thoracic segments.

Methods

Cross-sectional study. Participants were 40 healthy volunteers aged 21–60. Conventional anteroposterior and functional sagittal chest radiographs were performed during maximal inspiration and exhalation. The range of motion of each spinal thoracic functional segment, global T1–T12 motion, and the sagittal displacement of the thoracic column during breathing were measured. Considering the different type of ribs and their attachment the spine and sternum, thoracic segments were grouped in T1–T7, T7–T10, and T10–T12. The displacement of the thoracic spine with respect to the sternum and manubrium was also recorded.

Results:

The mean difference from inspiration to exhalation in the T1–T12 physiologic kyphosis was 15.9+/- 4.6°, reflecting the flexibility of the thoracic spine during deep breathing (30.2%). The range of motion was wider in the caudal hemicurve than in the cranial hemicurve, indicating more flexibility of the caudal component of the thoracic kyphosis. A wide range of motion from inspiration to exhalation was found at T7–T10, responsible for 73% of T1–T12 sagittal movement. When the sample was stratified according to age ranges (20–30, 30–45, and 45–60 yr.), none of the measurements for inspiration or exhalation showed statistically significant differences. Only changes at this level showed a positive correlation with changes in the global thoracic kyphosis ($r = 0.794$, $p < 0.001$).

Conclusion:

The range of motion of the thoracic spine plays a relevant role in respiration dynamics. Maximal inspiration appears to be highly dependent on the angular movements of the T7–T10 segment.

3.3 Antecedentes y estado del arte

Las fracturas y luxaciones vertebrales torácicas y lumbares son lesiones muy serias que ocurren con frecuencia en gente joven, generalmente producidas por traumatismos de alta energía tales como accidentes de tráfico y precipitaciones.

Las lesiones neurológicas pueden ocurrir en un 15% a 40% de estas fracturas y más de un 30% de los pacientes pueden desarrollar dolor crónico que conlleva limitaciones en las actividades de la vida diaria y dificultad en la reincorporación laboral, por lo que, el manejo adecuado de dichas fracturas es fundamental.

Las fracturas toracolumbares son un gran motivo de absentismo y baja laboral, muchos pacientes están mucho tiempo de baja, mientras que otros no se reincorporan nunca.

Con la aparición de nuevas técnicas y aparataje.

4. CAPÍTULO III

4.1 Introducción

En este capítulo vamos a presentar todas aquellas comunicaciones que están íntimamente relacionadas con nuestro proyecto y línea de investigación que han llevado a la realización de este trabajo de tesis doctoral.

4.2 Comunicaciones a reuniones y congresos específicos de la investigación

19 CONGRESO NACIONAL DE LA SOCIEDAD ESPAÑOLA DE NEURORAQUIS. SEVILLA 2019

"PATOLOGÍA VERTEBRAL Y ESTUDIOS DE IMAGEN VERTEBRAL"

Autores:

Lorente R [1], Infante de la Torre JR[2],Serrano J, Palacios P, Lorente A.

Información de los autores:

Complejo Hospitalario Universitario de Badajoz y Hospital Universitario Sanchinarro Madrid (España).

Presentado como comunicación en forma de poster.

XXIX CONGRESO DE LA SOCIEDAD EXTEMEÑA DE TRAUMATOLOGÍA Y ORTOPEDIA. CÁCERES 2019.

"RESULTADOS CLÍNICO-RADIOLÓGICOS DE FRACTURAS VERTEBRALES INESTABLES TORACO-LUMBARES. COMPARACIÓN CIRUGÍA PERCUTÁNEA FRENTE A ABIERTA".

Autores:

R. Lorente Moreno, P. Palacios Cabezas, B. Rosa, C. Barrios Pitarque, A. Vaccaro, A. Lorente Gómez.

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Complejo Hospitalario Universitario de Badajoz. Hospital Universitario Sanchinarro Madrid (España). General Hospital. Philadelfia. USA

Comunicación oral

XLVI REUNION ANUAL SERN (SOCIEDAD ESPAÑOLA DE NEURORADIOLOGIA). VIGO 2017.

"C-0010 ANÁLISIS RADIOLÓGICO DE LAS FRACTURAS INESTABLES TORACOLUMBARES SIN DÉFICIT NEUROLÓGICO TRATADAS MEDIANTE CIRUGÍA PERCUTÁNEA".

Autores:

Rafael Lorente Moreno; Alejandro Lorente Gómez; Teresa Miranda García- Cuevas; María Ángeles García Gil.

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Complejo Hospitalario Universitario de Badajoz, Escuela de Ingenieria Industrial de Badajoz (Universidad de Extremadura) y Hospital Universitario Sanchinarro Madrid (España).

Comunicación oral

XLVI REUNION ANUAL SERN (SOCIEDAD ESPAÑOLA DE NEURORADIOLOGIA). VIGO 2017

"C-0011 ANÁLISIS RADIOLÓGICO A LARGO PLAZO DE LAS FRACTURAS INESTABLES TORACOLUMBARES SIN DÉFICIT NEUROLÓGICO".

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Comunicación oral

20th EUROSPINE (SOCIEDAD EUROPEA DE COLUMNA VERTEBRAL). BARCELONA, SPAIN 2018

"QF70 THE RADIOLOGICAL EVALUATION DOES NOT REFLECT THE CLINICAL OUTCOME AFTER SURGERY IN UNSTABLE THORACOLUMBAR AND LUMBAR TYPE A FRACTURES WITHOUT NEUROLOGICAL SYMPTOMS. A COMPARATIVE STUDY OF TWO COHORTS TREATED BY OPEN OR PERCUTANEOUS SURGERY"

Authors:

Alejandro Lorente-Gómez, Rafael Lorente-Moreno, Pablo Palacios-Cabezas, Bárbara Rosa, Carlos Barrios, Alexander Vaccaro

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Comunicación oral

55 CONGRESO SECOT (SOCIEDAD ESPAÑOLA DE CIRUGÍA ORTOPÉDICA Y TRAUMATOLOGÍA). VALLADOLID 2018

"COMPARACIÓN RADIOLÓGICA Y CLÍNICA DE LAS FRACTURAS INESTABLES TORACOLUMBARES Y LUMBARES POR COMPRESIÓN SIN CLÍNICA NEUROLÓGICA TRATADAS MEDIANTE CIRUGÍA CON INSTRUMENTACIÓN CORTA ABIERTA O PERCUTÁNEA".

Autores:

Alejandro Lorente Gómez, Rafael Lorente Moreno, Pablo Palacios Cabezas, Carlos Barrios Pitarque

Comunicación oral

XXXII CONGRESO NACIONAL GEER (GRUPO DE ESTUDIO DE ENFERMEDADES DE RAQUIS – SOCIEDAD ESPAÑOLA DE COLUMNA VERTEBRAL). ÀVILA 2018

"EVOLUCIÓN RADIOLÓGICA DE LAS FRACTURAS INESTABLES TORACOLUMBARES Y LUMBARES POR COMPRESIÓN SIN CLÍNICA NEUROLÓGICA TRATADAS MEDIANTE CIRUGÍA CON INSTRUMENTACIÓN CORTA ABIERTA O PERCUTÁNEA. ESTUDIO COMPARATIVO DE COHORTES".

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Comunicación Oral (Opta a premio a mejor comunicación oral dentro de las cinco mejores comunicaciones presentadas)

5. CAPÍTULO IV

5.1 Otras publicaciones y comunicaciones científicas nacionales e internacionales útiles para mejorar en el conocimiento de la patología vertebral en conjunto y en su control evolutivo.

5.1.1 Comunicaciones científicas

XXIX CONGRESO NACIONAL GEER (GRUPO DE ESTUDIO DE ENFERMEDADES DE RAQUIS. – (SOCIEDAD ESPAÑOLA DE COLUMNA VERTEBRAL). MÁLAGA 2015

LA CORRECCIÓN QUIRÚRGICA NO MEJORA LA LIMITADA TOLERANCIA PREOPERATORIA AL ESFUERZO MÁXIMO EN ENFERMOS CON ESCOLIOSIS IDIOPÁTICA.

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Fernández Pineda, Luis[1] ; Burgos Flores, Jesús[1] ; Antón Rodrigálvarez, Luis Miguel[1] ; Hevia Sierra, Eduardo[2] ; Sanpera Trigueros, Ignacio[3] ; García González, Vicente[4] ; Pérez Encinas, Cristina[5] ; Barrios Pitarque, Carlos[5]

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Comunicación Oral

XXIX CONGRESO NACIONAL GEER (GRUPO DE ESTUDIO DE ENFERMEDADES DE RAQUIS. – (SOCIEDAD ESPAÑOLA DE COLUMNA VERTEBRAL). MÁLAGA 2015

ÍNDICE DE MASA CORPORAL (IMC) Y GRASA (IMG) EN ADOLESCENTE CON ESCOLIOSIS IDIOPÁTICA. ANÁLISIS BAJO LAS PUNTOS DE CORTE DE LA CDC (CENTRES FOR DISEASE CONTROL) Y LA IOTF (INTERNATIONAL OBESITY TASK FORCE)

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Comunicación oral

XXX CONGRESO NACIONAL GEER (GRUPO DE ESTUDIO DE ENFERMEDADES DE RAQUIS – SOCIEDAD ESPAÑOLA DE COLUMNA VERTEBRAL). TOLEDO 2016

CAMBIOS EN LA FUNCIÓN CARDIORRESPIRATORIA Y EN LA TOLERANCIA AL ESFUERZO MÁXIMO EN UNA COHORTE DE ADOLESCENTES CON ESCOLIOSIS IDIOPÁTICA TRAS 2 AÑOS DE LA INTERVENCIÓN QUIRÚRGICA .

Autores:

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5.1.2 Publicaciones

"TOTAL VERTEBRECTOMY AND SPINE SHORTENING FOR THE TREATMENT OF T12-L1 SPINE DISLOCATION: MANAGEMENT WITH SUBOPTIMAL RESOURCES.¨

Journal: Neurocirugia (Astur). 2018 Nov - Dec;29(6):304-308.

Authors:

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Abstract

Total vertebrectomy with spine shortening has been reported for the treatment of difficult cases of traumatic spine dislocation, both in acute and chronic phase. We report an exceptional case of a five-week-old T12-L1 spine dislocation in a 25-year-old female with complete paraplegia as a result of trauma in Ciudad de León (Nicaragua). In view of the time since the dislocation, we performed a complete L1 vertebrectomy in order to reduce the dorsolumbar hinge. For osteosynthesis material we had only eight screws and two Steffee plates. We therefore introduced pedicle screws at levels T11, T12, L2 and L3 on the right side and T11, T12, L3 and L4 on the left, and performed manual reduction of the spine. Steffee plates were placed and we added sublaminar wires to reinforce the osteosynthesis. Fifteen months after surgery, there has been no neurological improvement.

Keywords:

Acortamiento vertebral; Luxación vertebral; Spine shortening; Trauma; Traumatismo; Vertebral dislocation; Vertebrectomy; Vertebrectomía

¨TOPHACEOUS GOUT OF THE LUMBAR SPINE IN A PATIENT WITHOUT SYSTEMIC GOUT OR NORMOURICAEMIA.¨

Journal: Neurocirugia (Astur). 2017 Sep - Oct;28(5):242-246.

Authors:

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Abstract

Gout is a common metabolic disorder typically diagnosed in peripheral joints. Tophaceous deposits in the lumbar spine is a very rare condition with very few cases reported in the literature. We present a case of tophaceous gout that originated in the lumbar spine in a patient with normal uric acid blood levels. The following case report concerns a 52-year-old patient with low back pain, left sciatica and numbness in the left leg. Serum uric acid levels were within normal range. MRI and bone scan images suggested an inflammatory-infectious process focussed at L4. After an L4-L5 decompressive laminectomy, histological examination revealed tissue infiltrated with mature plasma cells with negatively birefringent crystals using polarised light consistent with urate deposits.

Keywords:

Ciática; Columna lumbar; Dolor lumbar; Low back pain; Lumbar spine; Sciatica; Tofo gotoso; Tophaceous gout.

"VERTEBRAL INSTRUMENTATION AND PHLEGMASIA CERULEA DOLENS".

Journal: Neurocirugia (Astur). 2019 Oct 11. pii: S1130-1473(19)30093-4.

Authors:

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Abstract

Phlegmasia cerulea dolens is a very infrequent condition secondary to a deep venous thrombosis of multietiological origin usually affecting the lower extremities. It presents with pain and edema in the lower limb rapidly progressive that can compromise the perfusion of the limb, being able to cause gangrene, amputation and even death.

We present an extremely rare case of a phlegmasia secondary to a massive deep venous tombosis of the left iliofemoral axis caused by chronic compressive hematoma of a traumatic origin due to a S1 screw shearing in a patient operated three months ago of a lumbar herniated disc through a L5-S1 fussion. This article shows the need to perform a scrupulously scrutinize of the screws both intra and postoperatively when we are close to the great vessels.

Keywords:

Deep venous thrombosis; Flegmasía; Instrumentación vertebral; Phlegmasia; Trombosis venosa; Vertebral fussion

6. CAPÍTULO V

6.1 Sumario de Resultados y conclusiones finales

6.1.1 Resultados

ESTANCIA HOSPITALARIA

- La estancia media preoperatoria.
- La estancia media postoperatoria.

Valores muy altos debidos en gran manera a dos factores fundamentales, la sobresaturación hospitalaria por un lado y el ser gran parte de ellos enfermos politraumatizados que necesitaron su ingreso en la Unidad de Cuidados Intensivos y de otras intervenciones tanto a nivel de cráneo, tórax, abdomen o miembros.

COMPLICACIONES

Dependiendo del tiempo de aparición de las posibles complicaciones nos hemos encontrado con:

- Las complicaciones inmediatas
- Las complicaciones tardías

RESULTADOS RADIOGRAFICOS

Para la valoración radiológica utilizamos seis parámetros obtenidos de las radiografías laterales, así medimos el ángulo fracturario, el % de compresión vertebral, la deformidad vertebral cifótica), el grado de, el índice y finalmente el ángulo de deformación.

Estos valores fueron medidos en el preoperatorio, postoperatorio inmediato y al año de la intervención.

RESULTADOS CLINICOS

Para valorar los resultados clínicos se citaron a los pacientes y/o se les entrevistó telefónicamente. Hemos tenido en cuenta los factores correspondientes al dolor, trabajo y satisfacción del paciente.

La recogida de los datos de nuestros pacientes estudiados nos dio los siguientes resultados:

a) Dolor.- Con respecto a la presencia en la actualidad de dolor (bien lumbar o bien de la zona de la cresta iliaca dadora de injerto) y a la intensidad del mismo los pacientes se encontraban:

- Sin dolor.
- Molestias leves que no necesitaban la toma de analgésicos

- Molestias moderadas.- En las que los pacientes en ocasiones necesitaban de la toma de analgésicos

- Molestias importantes.- Dolor que obligaba al paciente a la toma de analgésicos de forma diaria:

b) Reincorporación a su trabajo habitual.- En cuanto a la reintroducción al entorno laboral, se valoró atendiendo a 2 preguntas básicas:

- Si siguen o no en el mercado laboral de modo activo.

- Si se reincorporaron o no a su trabajo (con las mismas funciones previas a la fractura).

- Dentro del grupo de pacientes que están en situación de desempleo estudiamos también si están disfrutando algún tipo de subsidio o pensión compensadora por incapacidad laboral.

c) Grado de satisfacción.- La satisfacción de nuestros pacientes por su satisfacción ante los resultado obtenidos

- Satisfechos o muy satisfechos: 83 pacientes (91 %).

- No satisfechos: Cinco pacientes (5,5 %).

- No saben o no contestan: Tres pacientes (3,5 %).

RELACIONES ESTADISTICAMENTE SIGNIFICATIVAS

En los distintos artículos estudiaron las relaciones posibles entre las variables cualitativas en las "Instrumentaciones largas", "Instrumentaciones cortas" e "Instrumentaciones percutáneas; y el resto de variables radiológicas y clínico-hospitalarias.

Tras un análisis estadístico, detallado y meticuloso de los parámetros estudiados, mediante el programa SPPS v 13.0,

6.1.2 Conclusiones

Tras el análisis de los resultados obtenidos en el tratamiento de nuestros pacientes y de los datos reflejados en las diversas publicaciones que hemos realizado, queremos terminar diciendo que:

1.- Las instrumentaciones segmentarias tipo de Cotrel-Dubousset, MOSS-Miami y Synergy se han mostrado muy útiles debido a su versatilidad lo que nos permitió su uso a nivel torácico o lumbar, tanto en montajes cortos como largos, con ganchos, tornillos o combinando ambos materiales.

2.- La radiografía lateral se nos muestra como una exploración esencial tanto para el diagnóstico como el control evolutivo del componente cifótico de las fracturas vertebrales.

3.- En todos los parámetros estudiados se ha perdido corrección que ha sido más notable en el caso del ángulo fracturario, pero podemos destacar que la corrección del ángulo cifótico, del grado de compresión y de la deformidad cifótica se perdió menos corrección en las instrumentaciones largas.

4.- Las instrumentaciones percutáneas (MIS) disminuyen el tiempo de estancia hospitalaria y aunque empeoran ligeramente las mediciones radiográficas mejoran la clínica del paciente y la reincorporación laboral de la misma.

5.- Se ha comprobado que la retirada del material de osteosíntesis es una ténica rápida sencilla y que no acarrea complicaciones

6.- Las fracturas de la columna toraco-lumbar siguen siendo hoy en día un enorme reto para el cirujano ortopédico. Creemos, por tanto, que en el futuro, mas estudios deben de ser hechos valorando mejor las instrumentaciones percutáneas (MIS), que no lesiones la musculatura vertebral posterior ni la inervación de la misma, incluyendo o no el acto añadido de una kyphoplastia o cualquier otra actuación pecutánea.

6.2 Summary of results and final conclusions

6.2.1 Results

HOSPITAL STAY

- The average preoperative stay.
- The average postoperative stay.

Very high values due mainly to two fundamental factors such as hospital oversaturation on the one hand and the fact that many patients are polytraumatized requiring admission to the Intensive Care Unit and other surgeries of the skull, thorax, abdomen or limbs.

COMPLICATIONS

Depending on the time of appearance we have found:

- Immediate complications
- Long term complications

RADIOLOGICAL FINDINGS

To asses the radiological evaluation we used six parameters obtained from the lateral radiographs, measuring the fracture angle, the percentage of vertebral compression, the kyphotic vertebral deformity, the degree of, the index and finally the angle of deformation.

These values were measured preoperatively, immediately after spinal surgery, and one year after the surgical intervention.

CLINICAL RESULTS

To assess the clinical results, the patients were summoned and / or interviewed by telephone. We have taken into account the factors in relation to pain, work and patient satisfaction. The collection of data from our studied patients gave us the following results:

a) Pain

Regarding the current presence of pain (either lumbar or in the area of the iliac crest graft donor area) and its intensity, the patients were classified as:

- Without pain
- Mild discomfort which not require pain killers
- Moderate discomfort in which patients sometimes needed to take pain killers.
- Major discomfort in which the pain forcing the patient to take pain killers on a daily basis.

b) Return to work

Reincorporation to patient´s daily work. Regarding the return to patient´s work environment, it was assessed according to 2 basic questions:

- Whether or not the patients are actively in the labor market.
- Whether or not they returned to work (with the same functions prior to the fracture).
- Within the group of patients who are unemployed, we also study whether they are enjoying some type of subsidy or compensatory pension due to work incapacity.

c) Degree of satisfaction

- Obtained results in relation to patient satisfaction:

- Satisfied or very satisfied: 83 patients (91%).
- Not satisfied: Five patients (5.5%).
- Not ansewered: Three patients (3.5%).

STATISTICALLY SIGNIFICANT RELATIONSHIPS

In the different papers the potential relationships between the qualitative variables: "Long instrumentations", "Short instrumentations" and "Percutaneous instrumentations were studied; others radiological and clinical-hospital variables were also investigated.

After a detailed and meticulous statistical analysis of the parameters studied, using the SPPS v 13.0 program.

6.2.2 Conclusions

After the general analysis of the results obtained from the treatment of our patients and based on the published articles, we would like to conclude by stating that:

1.- The Cotrel-Dubousset, MOSS-Miami and Synergy type segmental instrumentations have proven to be very useful due to their versatility, which allowed us to used them at thoracic or lumbar level, both for short and long assemblies, using hooks, screws or combining both materials.

2.- The lateral plain x-ray appears to us as an essential image test both for the diagnosis and the follow up of the kyphotic component of spinal fractures.

3.- In all parameters studied, some correction was lost, which has been more remarkable in the case of the fracture angle, nevertheless we can highlight that the lost of correction in relation to the kyphotic angle, the degree of compression and the kyphotic deformity was less marked with the implantation of long instrumentation.

4.- Percutaneous instrumentation (MIS) reduces the length of hospital stay and although they slightly imply worse radiographic results, they have shown to improve patient's symptoms and their return to work.

5.- It has been shown that the removal of osteosynthesis material is a simple and quick technique not entailing high complication rates.

6.- Fractures of the thoraco-lumbar spine continue to be an enormous challenge for the orthopedic surgeon nowadays. We think, therefore, that in the future, more studies should be done evaluating more advanced percutaneous instrumentations (MIS), which do not injure the posterior vertebral musculature or its innervation, including or not a kyphoplasty or any other pecutaneous performance.

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ANEXOS

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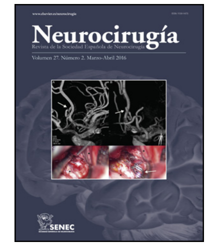

Clinical Research

Long term radiological outcomes of unstable thoraco-lumbar fractures without neurological deficit☆

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ABSTRACT

Objective: To analyse the radiological outcomes in the long term of unstable thoraco-lumbar fractures.
Material and methods: Retrospective review of 100 patients with unstable thoracolumbar fractures treated with posterolateral fusion and short screw fixation for compression and flexion-distraction type fractures, and long segment posterior fixation for fractures-dislocations or more than one vertebra fractured, between 2000 and 2010 at three different hospital centres. Six radiological parameters were measured annually during a 4-year period: Fracture angle, kyphotic deformity, sagittal index, percentage of compression, degree of displacement and deformation angle.
Results: A total of 100 patients were included with a median age of 36.4 years and a median follow-up period of 7.2 years. Fracture angle rose from 11.6° to 14.5° (increase of 25%), kyphotic deformity from 14.5° to 16.7° (increase of 15.17%), sagittal index from 8.7 to 10.8 (increase of 24.13%), percentage of compression from 31.8% to 36.5% (increase of 6.88%), degree of displacement from 2.8 mm to 4.6 mm (increase of 14.77%) and deformation angle from 19.7° to 21.4° (increase of 8.62%).

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Discussion: All the radiological parameters studied lost correction throughout the 48 months of follow-up, being the fracture angle the most affected one. Nevertheless, the greatest loss of correction occurs in the first postoperative year, stabilising the parameters afterwards over the 4 years of follow up. We routinely recommend the measurement of all previous parameters for the follow up of unstable thoracolumbar fractures.

Evolución radiológica a largo plazo de las fracturas inestables toracolumbares sin clínica neurológica

Palabras clave:
Radiología
Columna torácica y lumbar
Cifosis
Instrumentación

RESUMEN

Objetivo: Analizar la evolución radiológica de las fracturas inestables toracolumbares a largo plazo.

Material y métodos: Serie retrospectiva de 100 casos con fracturas inestables toracolumbares sin clínica neurológica tratadas con artrodesis posterolateral e instrumentación corta en el caso de fracturas por compresión y flexión-distracción e instrumentación larga para las fracturas-luxaciones o a más de un nivel entre el 2000 y 2010 en 3 hospitales diferentes. Se midieron 6 parámetros radiológicos anualmente durante un período de 4 años: ángulo fractuario, deformidad cifótica, índice sagital, porcentaje de compresión, grado de desplazamiento y ángulo de deformación.

Resultados: Se incluyeron un total de 100 pacientes de 36,4 años de media con un período de seguimiento medio de 7,2 años. El ángulo fractuario pasó de 11,6° a 14,5° (incremento del 25%), la deformidad cifótica de 14,5° a 16,7° (incremento del 15,17%), el índice sagital de 8,7 a 10,8 (incremento del 24,13%), el porcentaje de compresión del 31,8% al 36,5% (incremento del 6,88%), el grado de desplazamiento de 2,8 mm a 4,6 mm (incremento del 14,77%) y el ángulo de deformación de 19,7° a 21,4° (incremento del 8,62%).

Discusión: Todos los parámetros radiológicos estudiados perdieron corrección a lo largo de los 48 meses de seguimiento, siendo el ángulo fractuario el más marcado. Sin embargo, la mayor parte de la pérdida de corrección ocurre en el primer año postoperatorio, estabilizándose los parámetros posteriormente hasta los 4 años de seguimiento. Recomendamos la medición de todos los parámetros previos de rutina para el seguimiento de las fracturas inestables toracolumbares.

Introduction

Thoracolumbar spine fractures and dislocations are complex lesions that often occur in young people, usually as a result of high-energy traumas such as road traffic accidents and falls.[1–3]

Neurological injuries can occur in 15–40% of these fractures[4,5] and over 30% of patients may develop chronic pain that leads to limitations in activities of daily living and difficulty returning to work.[1,6,7] As a result, the adequate management of these fractures is essential.

The surgical treatment of this type of injury has gained popularity in recent years, although there is controversy regarding the optimal approach (anterior, posterior or combined) for unstable fractures.[2,8]

In the majority of studies conducted to date, radiological follow-up is based on two parameters: kyphotic deformity and percentage of compression.[9–11] In this study, we intend to perform a more exhaustive form of radiological follow-up, analysing the radiological evolution of unstable thoracolumbar fractures without neurological deficits treated with posterior instrumentation and arthrodesis by means of six measurements. Our hypothesis is that there are parameters that have not traditionally been studied which may lose correction throughout the follow-up of these fractures, and which may be important when making clinical and surgical decisions.

Material and methods

A multicentre retrospective study was conducted on a series of patients presenting unstable non-osteoporotic thoracolumbar spine fractures with no associated neurological deficits, who underwent surgery between January 2000 and December 2010 (mean follow-up of 7.2 years). During this retrospective study, the surgically-treated unstable thoracolumbar fractures were reviewed and those with no neurological deficits selected. All of the patients presented either unstable compression fractures (type A), which are deemed to be fractures with loss of more than 50% of the vertebral body height, widened interspinous distance and kyphotic deformity of over 25°[12–14]; fractures due to a tension band injury (type B); or fractures-dislocations (type C), as per the AOSpine classification modified by Vaccaro et al.,[15] which is considered the benchmark for classifying these fractures.

The age, sex, follow-up, mechanism of injury, fracture location, type of fracture (although initially classified according to Denis[16] and Magerl et al.,[17] the AOSpine classification proposed by Vaccaro was eventually included[15,18]), vertebrae fixed and type of assembly (short if it includes four levels or fewer, and long if it includes five or more levels) were recorded.

As part of the preoperative study, all of the patients were subjected to laboratory tests (blood count, basic biochemistry and coagulation), a chest X-ray, anterior–posterior and lateral X-rays of the thoracic spine, dorsolumbar hinge and lumbosacral spine, as well as computed tomography (CT) of the affected vertebral segment. As part of the initial study, a head, chest and abdomen CT or body CT scan (head, chest, abdomen and pelvis) was performed, depending on the associated injuries suspected or the intensity of the trauma. Prior to surgical intervention, none of the patients included in the study presented a neurological deficit as a result of the spinal fracture, with this deficit deemed to comprise alterations in limb sensitivity, reduced limb strength or a loss of sphincter control.

Bone mineral density was measured indirectly by means of a CT scan on the affected segment in order to assess the incidence of osteoporosis in each of the 100 patients.[19]

In all cases, the procedure consisted of a bilateral posterolateral arthrodesis using a single posterior approach, performing short-segment instrumentation (one level above and below the fractured vertebra) in cases of type A and B fractures, as per the AOSpine classification,[15] while long-segment instrumentation (two levels above and below the fractured vertebra) was chosen in type C fractures. Long-segment instrumentation was also chosen in patients with various unstable contiguous spinal fractures.

As well as the classic radiological examination, which includes kyphotic deformity and the percentage of compression,[9–11] in the study presented herein an exhaustive analysis was also performed on all of the fractures by measuring the following parameters:

Fracture angle: Formed between the tangent drawn at the superior vertebral end plate above the fractured vertebra and the tangent drawn at the inferior vertebral end plate below the fractured vertebra.

Kyphotic deformity: Angle value obtained on drawing a tangent between the inferior end plate of the vertebra above the fracture and the line tangent to the inferior end plate of the fractured vertebra.

Sagittal index: Difference in the value obtained in the kyphotic deformity and normal contour.

Percentage of vertebral compression: Ratio of the distance, in millimetres, of the anterior part of the fractured vertebra compared to the height of the posterior wall of its vertebral body, multiplied by 100, then minus 100.

Degree of displacement: Distance the vertebra has previously been displaced in relation to the posterior wall of the fractured vertebra, divided by the width of the normal vertebra immediately below the fractured vertebra.

Deformation angle: Determined by the intersection of the lines drawn along the posterior surfaces of the vertebral bodies above and below the fracture.

Table 1 – Types of fractures as per the AOSpine classification.

Type of fracture (AOSpine)	Number of cases
A	85
A2	3
A3	31
A4	51
B	4
B1	2
B2	2
C	11

All of the parameters were assessed preoperatively, in the immediate postoperative period and after 12, 24, 36 and 48 months.

The study seeks to assess whether there is a statistically significant correction loss in each of the parameters over the 48-month follow-up period. The statistical analysis was performed using the SPSS® program, v. 20.0, establishing statistically significant levels for p values <0.05.

Results

Of a total of 121 patients with unstable thoracolumbar fractures, 100 cases were recruited, corresponding to the patients who presented no neurological deficit prior to the surgical intervention.

The maximum age was 55 years and the minimum 20 years, with a mean of 36.4 years. The incidence among men was markedly higher, with a male to female ratio of 2.84:1.

The most common mechanism of injury was road traffic accidents (58%), followed by falls (35%) and direct trauma (6%).

The predominant location was the dorsolumbar hinge (T12-L1), representing 51% of the cases, followed by the lumbar and thoracic regions, with 27% and 22%, respectively.

According to the AOSpine classification,[15] 85 of our cases (85%) matched type A, 4 (4%) fell under type B and 11 (11%) under type C, i.e. fractures-dislocations. The subtypes of the fractures in the study series are shown in Table 1, as per the AOSpine classification.

Following extrapolations of bone mineral density measured in Hounsfield units as per the works by Schreiber et al.,[19] the studies obtained (a posteriori) do not reveal data that may be indicative of osteoporosis in any of the cases studied.

In relation to instrumentation and arthrodesis, the mean number of fixed and fused vertebrae was 3.5. Short-segment fixation prevailed over the long type (71% vs 29%), and spinal decompression was performed in 21 cases from the study

Table 2 – Complications based on the type of instrumentation used.

Complication	Total cases (%)	Cases of short-segment instrumentation (%)	Cases of long-segment instrumentation (%)
Paralytic ileus	23 (23)	15 (21.12)	8 (27.58)
UTI	11 (11)	7 (9.85)	4 (13.79)
Sup. Inf.	8 (8)	5 (7.04)	3 (10.34)
Deep Inf.	3 (3)	2 (2.81)	1 (3.44)
Dismounting Con.	7 (7)	4 (5.63)	3 (10.34)
Non-union	4 (4)	2 (2.81)	2 (6.89)
Neurological deterioration	5 (5)	3 (4.22)	2 (6.89)
Total reoperations	11 (11)	7 (9.85)	4 (13.79)
Reoperations due to deformity progression	6 (6)	3 (4.22)	3 (10.34)
Reoperations due to non-union	2 (2)	1 (1.40)	1 (3.44)

Deep Inf., deep infection; Dismounting Con., dismounting of construct; Sup. Inf., superficial infection; UTI, urinary tract infection.

Table 3 – Radiological parameters assessed preoperatively, postoperatively and after 12, 24, 36 and 48 months.

Parameter	Preoperative	Postoperative	12 months	24 months	36 months	48 months
Fracture angle (°)	24.1	11.6	13.9	14.1	14.3	14.5
Kyphotic deformity (°)	23.1	14.5	15.2	15.5	15.7	16.7
Sagittal index	14.4	8.7	9.6	10.1	10.3	10.8
Percentage of compression (%)	39.2	31.8	32.1	35.3	36.1	36.5
Degree of displacement (mm)	5.4	2.8	3.9	4.1	4.4	4.6
Deformation angle (°)	25.3	19.7	20.1	20.5	20.9	21.4

series, provided that spinal canal invasion was greater than 50%.

The total number of complications and their grouping according to the type of instrumentation used is shown in Table 2.

As for the radiological aspect, which represents what is novel about this study, the assessment was performed using the six parameters mentioned in the previous section, the results of which are presented in Table 3. The evolution of each of the parameters over the 48-month follow-up period is also depicted (Figs. 1–6).

The six radiological parameters assessed lost correction throughout the 48 months of follow-up, with the fracture angle being most severely affected, rising from 11.6° to 14.5° (representing a 25% increase). The least affected parameter was the percentage of compression, which went from 31.8% to 36.5% (6.88% increase). The difference in all the parameters after measurement in the immediate postoperative period and measurement after 48 months is statistically significant (Student's *t* test; $p < 0.05$).

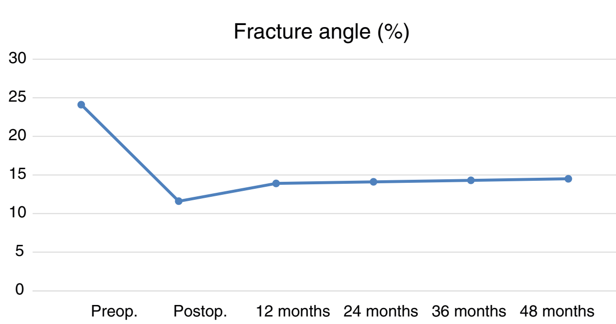

Fig. 1 – Evolution of the fracture angle.

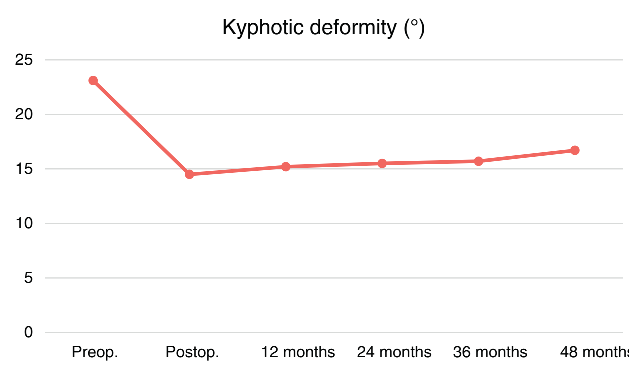

Fig. 2 – Evolution of the kyphotic deformity.

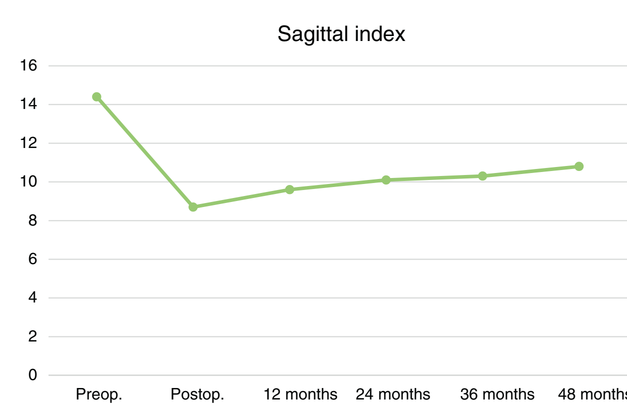

Fig. 3 – Evolution of the sagittal index.

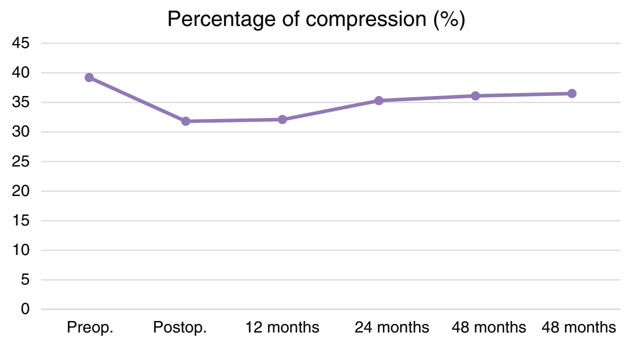

Fig. 4 – Evolution of the percentage of compression.

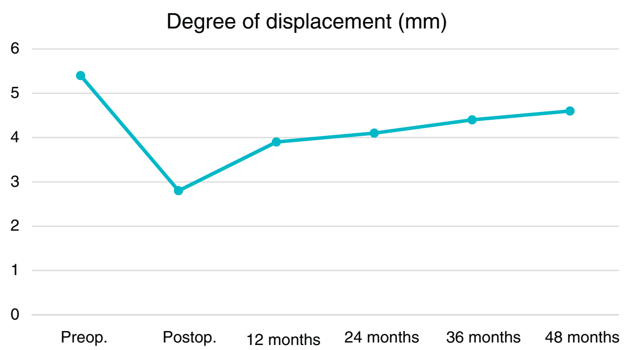

Fig. 5 – Evolution of the degree of displacement.

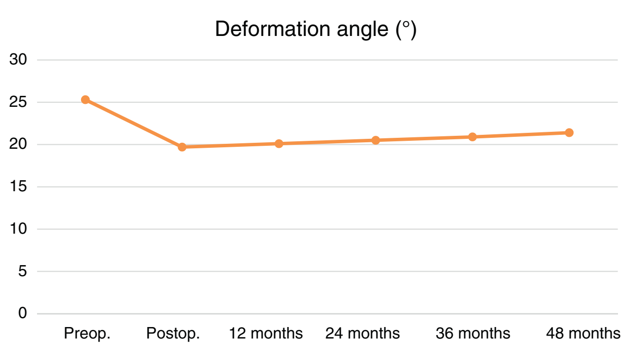

Fig. 6 – Evolution of the deformation angle.

Discussion

With respect to epidemiological data, including sex, mechanism of injury, region affected and fracture type, the series presented herein coincides with other similar studies.[9,17,20–22]

As for surgery, the fixation of burst fractures and flexion-distraction fractures via a posterior approach has generally been performed alongside posterolateral or posterior arthrodesis with good results,[23,24] though this is currently subject to debate.[1] The argument in favour of arthrodesis is that it provides greater stability, preventing reduction loss, fixation failure and pseudarthrosis. On the other hand, arthrodesis results in a permanent loss of segmental motion.[25] Dai et al.[26] achieved positive results using an open or percutaneous approach without arthrodesis in patients with thoracolumbar burst fractures. Moreover, Kim et al.[25] have published satisfactory results for flexion-distraction fractures treated with short-segment instrumentation without associated arthrodesis. In accordance with the work published by Grossbach et al.,[27] treating flexion-distraction fractures with percutaneous instrumentation is also reasonable. At present, carrying out percutaneous vs open surgery alongside arthrodesis remains controversial.[1]

As for the radiological aspect, which represents the most analysed and novel part of this study, all of the radiological parameters studied lost correction over the 48-month follow-up period. The fracture angle rose from 11.6° to 14.5° (25% increase), kyphotic deformity from 14.5° to 16.7° (15.17% increase), sagittal index from 8.7 to 10.8 (24.13% increase), percentage of compression from 31.8% to 36.5% (6.88% increase), degree of displacement from 2.8 mm to 4.6 mm (14.77% increase) and deformation angle from 19° to 21.4° (8.62% increase). Nevertheless, the greatest correction loss can be seen to occur in the first year post-surgery, with parameters subsequently stabilising over the four years of follow-up.

The most striking correction loss was observed at the levels corresponding to the thoracolumbar hinge, as it acts as a fulcrum for increasing movement between the rigid thoracic spine, supported by the ribs, and the lumbar spine, which is much more flexible, as well as in type C fractures (fractures and dislocations) and A4 (burst fractures) of the AOSpine classification, due to being inherently unstable fractures.

In most of the benchmark studies on thoracolumbar fractures, kyphotic deformity and the percentage of compression are taken as the standard from a radiological point of view, without considering other parameters such as the fracture angle, sagittal index and deformation angle.[9,10,22] In one of the studies deemed a reference work on this subject, Chou et al.[10] describe a randomised 10-year trial on thoracolumbar burst fractures treated surgically with and without arthrodesis, concluding that posterior arthrodesis need not be performed routinely in these types of fractures, as radiological outcomes were similar. Nevertheless, in this study, the radiological comparison carried out between the arthrodesis and non-arthrodesis patient groups was based exclusively on the kyphotic deformity measurement. It is thus possible that measuring additional parameters, such as those in this study, would have shown differences in the two groups. The same thing is found in similar impact studies,[9,22] in which conclusions are drawn on different types of instrumentation without taking into account values such as the fracture angle, which we have found to be the most severely affected parameter throughout the evolution of thoracolumbar fractures. As a result, even meta-analyses draw statistical conclusions without addressing other radiological parameters besides the ones mentioned.[11]

When making decisions on thoracolumbar fractures, the importance of kyphotic deformity is clear.[28] However, in this study, we have seen that there are five other parameters that vary throughout the follow-up of these fractures, which could serve as determining factors when drawing conclusions on whether to perform open surgery with arthrodesis or percutaneous surgery, as well as whether to use short- or long-segment instrumentation.

In terms of the study's limitations, we first highlight the lack of clinical and radiological correlation. Although we have observed a progressive correction loss in each of the six parameters assessed, we have not been able to establish a clear clinical repercussion. We do not know if these parameters have a functional impact on the patients, or whether they affect their quality of life or return to work. Moreover, given that all of the patients in the study underwent open surgery alongside arthrodesis, a comparison with a group of patients whose fractures were treated percutaneously is lacking. This might allow us to witness the evolution of radiological parameters and to compare them over time with patients subjected to open surgery and arthrodesis.

Based on this study, we thus confirm our initial hypothesis, establishing the existence of parameters that have not traditionally been studied and which lost correction throughout the follow-up of thoracolumbar fractures. Studying these parameters may be a determining factor for detecting differences between various types of surgery and instrumentation in the long term.

In conclusion, we argue that, as well as kyphotic deformity and the percentage of compression assessed in classic studies, there are a series of radiological parameters that undergo a correction loss over time in surgically-treated thoracolumbar fractures, and which we recommend routinely measuring when performing follow-up on these fractures, though their correlation with clinical features remains uncertain at present.

Ethical disclosures

Protection of human and animal subjects. The authors state that the procedures followed conformed to the ethical standards of the responsible human experimentation committee and to the World Medical Association and the Declaration of Helsinki.

Confidentiality of data. The authors declare that no patient data appear in this article.

Right to privacy and informed consent. The authors declare that no patient data appear in this article.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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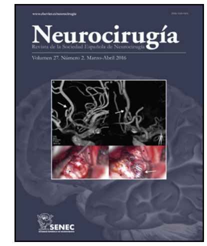

Clinical Research

Radiological outcomes of unstable thoraco-lumbar fractures without neurological deficit treated through percutaneous surgery☆

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ABSTRACT

Objective: To analyse the radiological outcomes in the long term of unstable thoracic and lumbar fractures treated through percutaneous surgery.

Material and methods: Retrospective review of a series of patients with unstable thoracic and lumbar fractures treated with percutaneous minimally invasive surgery between 2010 and 2015 in three different hospital centres. Six radiological parameters were measured annually during a 2-year period: Fracture angle, kyphotic deformity, sagittal index, percentage of compression, degree of displacement and deformation angle.

Results: A total of 37 patients were included with a median age of 41.3 years and a median follow-up period of 2.2 years. Fracture angle rose from 14.8 to 17.1 (increase of 15.54%), kyphotic deformity from 15.9 to 17.7 (increase of 11.32%), sagittal index from 10.1 to 12.3 (increase of 21.78%), percentage of compression from 32.7% to 36.8% (increase of 12.53%), degree of displacement from 3.0 mm to 4.4 mm (increase of 50%) and deformation angle from 20.7 to 22.9 (increase of 10.62%).

Conclusions: All the radiological parameters studied lost correction throughout the 24 months of follow-up; the degree of displacement and the sagittal index were the most marked. Nevertheless, the greatest loss of correction occurred in the first postoperative year, the parameters then stabilised over the 24 months of follow up. We routinely recommend the measurement of all previous parameters for the follow up of unstable thoracic and lumbar fractures treated through percutaneous surgery.

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Evolución radiológica de las fracturas inestables toracolumbares sin clínica neurológica tratadas mediante cirugía percutánea

Palabras clave:
Cirugía percutánea
Columna torácica y lumbar
Cifosis
Instrumentación

RESUMEN

Objetivo: Analizar la evolución radiológica a largo plazo de las fracturas inestables torácicas y lumbares tratadas mediante cirugía percutánea.

Material y métodos: Serie retrospectiva de una serie de casos con fracturas inestables torácicas y lumbares sin clínica neurológica tratadas mediante cirugía percutánea entre el 2010 y 2015 en 3 hospitales diferentes. Se midieron 6 parámetros radiológicos anualmente durante un período de 2 años: ángulo fractuario, deformidad cifótica, índice sagital, porcentaje de compresión, grado de desplazamiento y ángulo de deformación.

Resultados: Se incluyeron un total de 37 pacientes de 41,3 años de media, con un período de seguimiento medio de 2,2 años. El ángulo fractuario pasó de 14,8 a 17,1° (incremento del 15,54%), la deformidad cifótica de 15,9 a 17,7° (incremento del 11,32%), el índice sagital de 10,1 a 12,3 (incremento del 21,78%), el porcentaje de compresión del 32,7 al 36,8% (incremento del 12,53%), el grado de desplazamiento de 3,0 a 4,5 mm (incremento del 50%) y el ángulo de deformación de 20,7 a 22,9° (incremento del 10,62%).

Conclusiones: Todos los parámetros radiológicos estudiados perdieron corrección a lo largo de los 24 meses de seguimiento, siendo el grado de desplazamiento y el índice sagital los más marcados. Sin embargo, la mayor parte de la pérdida de corrección ocurre en el primer año postoperatorio, estabilizándose los parámetros posteriormente hasta los 24 meses de seguimiento. Recomendamos la medición de todos los parámetros previos de rutina para el seguimiento de las fracturas inestables torácicas y lumbares tratadas mediante cirugía percutánea.

Introduction

Thoracic and lumbar fractures and luxations are complex lesions that frequently occur in the young, generally caused by high-energy trauma such as traffic accidents and falls.[1–3]

Neurological lesions can occur in 15–40% of these fractures[4,5] and more than 30% of the patients may develop chronic pain that involves limitations on activities of daily life and difficulty with reintegration into the workforce,[1,6,7] so that appropriate management of these fractures is essential.

With the appearance of new techniques and apparatus and better surgical skills that are the fruit of experience, surgical treatment of thoracic and lumbar vertebral fractures has become popular in the past few years for reducing hospital stays, increasing stability, achieving adequate reduction and, on many occasions, improving neurological function. Nonetheless, there is controversy about the optimal approach (anterior, posterior or combined) for unstable fractures.[2,8]

We are currently seeing a surge in percutaneous operations in the area of the thoracic and lumbar spinal column, particularly in the field of fractures. The fixation of burst fractures and flexion-distraction fractures by a posterior approach has generally been accompanied by posterolateral or posterior arthrodesis with good results,[9,10] but this is currently controversial.[1] The argument in favour of arthrodesis is that it provides greater stability, avoiding the loss of reduction, failure of the mounting, and pseudarthrosis. Moreover, the consequence of arthrodesis is a permanent loss of segmental movement.[11]

In the majority of the studies conducted to date, radiological follow-up is based on two parameters: kyphotic deformity and percentage of compression.[9–11] In this study, we aim to conduct a more exhaustive radiological follow-up on the clinical course, analysing the radiological course of unstable thoracic and lumbar fractures without clinical neurological symptoms treated by percutaneous surgery (fixation with pedicle screw and bar system) without arthrodesis. Our hypothesis is that there are parameters that have not been studied traditionally that can lose correction over the course of follow-up on these fractures and that could be important when clinical and surgical decisions are being made.

Material and methods

A retrospective multi-centre study was conducted of a series of non-consecutive cases of unstable non-osteoporotic fractures of the thoracic and lumbar spine without associated clinical neurological symptoms. In this retrospective study, unstable thoracic and lumbar fractures treated surgically were reviewed and those that did not present with neurological deficits were selected. Patients with a diagnosis of osteoporosis (previous or by computerised tomography [CT] because of the spinal injury) and those with still-open physes were also excluded. All patients presented with unstable compression fractures (type A); these were considered to be fractures with a decrease of more than 50% in the height of the vertebral body, an increase in interspinous distance, and more than 25°

of kyphotic deformity,[12–14] in accordance with the AOSpine classification modified by Vaccaro et al.,[15] considered the reference for the classification of these fractures.

The age, sex, follow-up, mechanism of production, location of fracture, type of fracture (although initially classified according to Denis[16] and Magerl et al.,[17] the AOSpine classification proposed by Vaccaro et al.[15] was finally included), the vertebrae instrumented, and the type of mounting (short, if it includes 3 levels or fewer, and long, if it includes 4 or more levels) were recorded.

Similarly, all cases in our series were classified in accordance with the TLICS (Thoracolumbar Injury Classification and Severity) score proposed by Vaccaro et al.,[18] although the posterior ligament complex evaluation was performed indirectly by CT and not magnetic resonance imaging (MRI).

As part of the preoperative study, all patients underwent complete analysis (hemogram, basic laboratory tests, and coagulation), chest X-ray, anteroposterior (AP) and lateral X-rays of the thoracic column, thoraco-lumbar junction, and the lumbosacral column, as well as a CT of the vertebral segment affected. As part of the initial study, cranial, thoracic, abdominal or whole-body (cranium-chest-abdominopelvic) CT was performed, depending on the suspicion of associated lesions or the intensity of the trauma.

Indirect measurements of bone mineral density were made by CT of the affected segment to evaluate the incidence of osteoporosis in each of the patients.[19]

In all cases, the procedure consisted of percutaneous surgery with a pedicle screw and bar system similar to those at the various centres (CD horizon® Legacy/Solera Spinal System Medtronic Sofamor Danek), introduced under intraoperative radioscopic guidance and without arthrodesis, performing short instrumentation (one level above and below the fractured vertebra) in cases of a single fractured vertebra, whilst in the case of multi-level fractures, long instrumentation was selected (two levels above and two levels below the fractured vertebrae). Those cases in which there was greater than 50% invasion into the spinal canal were excluded from the study as they were treated by open surgery to create adequate decompression and posterior arthrodesis. Type B and C fractures according to AOSpine were also excluded, as open surgery is recommended to achieve adequate reduction and posterior fusion.[15]

Beyond the conventional radiological study that includes kyphotic deformity and the percentage of compression,[9–11] the study we are presenting performed an exhaustive analysis of all fractures by measuring the following parameters on the lateral radiography of the thoracic and lumbar spinal column:

Angle of fracture: formed between the tangent traced at the level of the upper vertebral endplate of the vertebra above the fractured vertebra and the tangent traced at the level of the lower vertebral endplate of the vertebra below the fractured vertebra.[20]

Kyphotic deformity: angular value obtained by tracing a tangent between the lower vertebral endplate of the vertebra above the fractured vertebra and the line tangent to the lower vertebral endplate of the fractured vertebra.[21]

Sagittal index: value obtained from the difference between the kyphotic segment deformity and the basal sagittal curve at the level of the fracture.[21]

Percentage of vertebral compression: ratio of the distance in millimetres from the anterior part of the fractured vertebra compared to the height of the posterior wall of the vertebral body of this vertebra, multiplied by 100 and then subtracting 100.[20]

Degree of displacement: distance that the vertebra has shifted forward compared to the posterior wall of the fractured vertebra divided by the width of the normal vertebra immediately below the fractured vertebra.[20–22]

Angle of deformation: determined by the intersection of the lines traced along the posterior surfaces of the vertebral bodies above and below the fracture.[21]

All the parameters were measured in the preoperative phase, immediate postoperative phase, and at 12 and 24 months. To decrease the variability in measurement of these parameters as much as possible, all measurements were made by a radiologist, the surgeon who performed the procedure, and a second spinal surgeon from another of the hospitals participating in the study. The measurements were made using the PACS/RIS image management system software.

The aim is to evaluate whether there is statistically significant loss of correction in each of the parameters over the 24 months of follow-up. The statistical analysis was performed using the SPSS® program, v. 20.0, establishing statistically significant levels for values of $p < 0.05$.

Results

Out of a total of 55 patients with type A unstable thoracic and lumbar fractures, we recruited 37 cases corresponding to patients who did not present with clinical neurological symptoms prior to the surgical procedure or more than 50% compression of the spinal canal, operated on between January 2010 and January 2015 (mean follow-up 2.2 years).

The maximum age was 59 years and the minimum 20 years, with a mean of 41.3 years. There was a clearly higher incidence of males, with a male:female ratio of 2.93/1.

The most common mechanism of production was a traffic accident (55%), followed by a fall (38%), and direct trauma (7%).

The predominant location was at thoraco-lumbar junction level (T12-L1), representing 59% of cases (12 cases located at T12 and 10 cases at L1), followed by lumbar with 22% (4 cases located at L5, 3 cases at L4 and one case at L3) and thoracic with 19% (4 cases at T11 and 3 cases at T10). With respect to the centres, the hospital complex with the greatest volume contributed 18 cases, whilst the others provided 10 and 9 cases.

Of the 37 cases, 8 presented with multi-level fractures (at both the adjacent and non-adjacent level) that required long instrumentation, representing 21.62% of cases of long instrumentation compared to 78.37% of cases with short instrumentation.

According to the AOSpine[15] classification, we found 37 cases falling under type A. The type B and C fractures or luxation fractures were not included in the study since they were treated by open surgery. The subtypes of fractures according to AOSpine in the series under study are shown in Table 1.

Except for A2 and A3 fractures (14 cases), all patients in the study scored at least 4 points, according to the TLICS

Table 1 – Types of fractures according to the AOSpine classification.

Type of fracture (AOSpine)	Number of cases
A	37
A2	5
A3	9
A4	23

Table 2 – Complications during follow-up in the series studied.

Complication	Total cases (%)
Paralytic ileus	6 (16.21)
UTI	5 (13.51)
Lower upper	2 (5.40)
Lower deep	2 (5.40)
Dislodging of Mat.	3 (8.10)
Neurological deterioration	2 (5.40)
Total repeat procedures	6 (16.21)
Repeat procedures due to progression of deformity	3 (8.10)

Dislodging of Mat.: dislodging of mat.; lower upper: superficial infection; lower deep: deep infection; UTI: urinary tract infection.

classification proposed by Vaccaro et al.,[18] although, as we mentioned above, the posterior ligament complex was evaluated indirectly by CT and not with MRI. The surgical treatment of the A2 and A3 fractures followed, taking into account the classic criteria for instability.[12–14]

Continuing the extrapolations of bone mineral density (BMD) based on Hounsfield units in accordance with the works by Schreiber et al.,[19] the studies obtained (*a posteriori*) show no data that could suggest osteoporosis in any case studied in the series.

The total number of complications throughout the 24 months of follow-up are summarised in Table 2. In this section, the number of repeat procedures was 16.21% (6 cases). The most common reason for repeat procedures was progression of deformity with dislodging of the material (8.10%, corresponding to 3 cases). One of these patients also presented with neurological deterioration, with an early deep infection being finally found (in the first 3 weeks after the procedure). The other 3 repeat procedures were performed due to neurological deterioration, deep infection and residual pain. All the repeat procedures took place in the first 6 months after the first surgery.

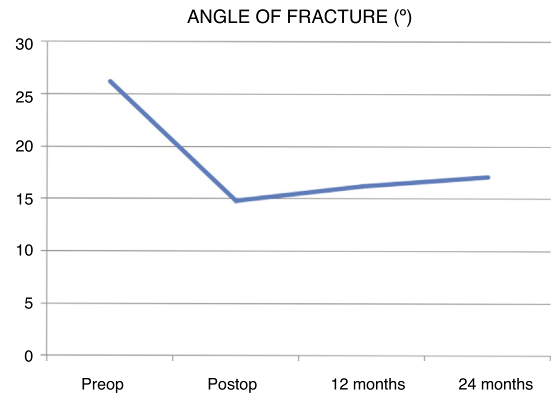

Fig. 1 – Clinical course of the angle of fracture.

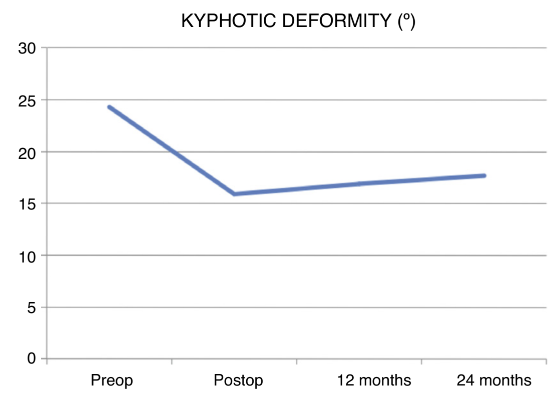

Fig. 2 – Clinical course of kyphotic deformity.

The mean time elapsed from the arrival of the patient in the Emergency Room to the surgical procedure was 2.8 days.

Focusing on the radiological aspect, which is the novel point in this study in the field of percutaneous surgery, the evaluation was made using the 6 parameters mentioned in the preceding section, the results of which are shown in Table 3. It also shows the clinical course of each of the parameters over the 24 months of follow-up (Figs. 1–6).

The 6 radiological parameters evaluated lost correction over the 24 months of follow-up; the degree of displacement – which changed from 3.0 to 4.5 mm (which implies a 50% increase) – and the sagittal index – which changed from 10.1 to 12.3 (increase of 21.78%) – were the parameters most affected.

Table 3 – Radiological parameters evaluated in preoperative phase, postoperative phase, at 12 and 24 months.

Parameter	Preop.	Postop.	12 months	24 months	*p* value (postop. *vs* 24 months; Student's t-test)
Angle of fracture (°)	26.2	14.8	16.2	17.1	0.039
Kyphotic deformity (°)	24.3	15.9	16.9	17.7	0.043
Sagittal index	14.1	10.1	11.7	12.3	0.048
Percentage of compression (%)	38.2	32.7	34.1	36.8	0.033
Degree of displacement (mm)	4.9	3.0	3.7	4.5	0.038
Angle of deformation (°)	26.4	20.7	22.1	22.9	0.037

Postop.: postoperative; Preop.: preoperative.

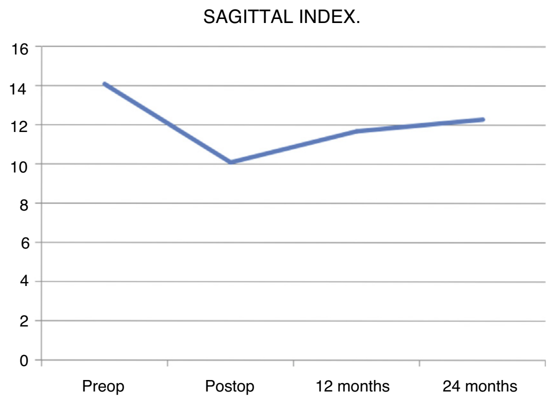

Fig. 3 – Clinical course of sagittal index.

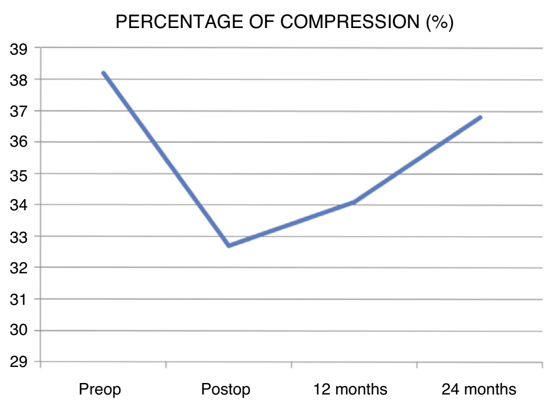

Fig. 4 – Clinical course of percentage of compression.

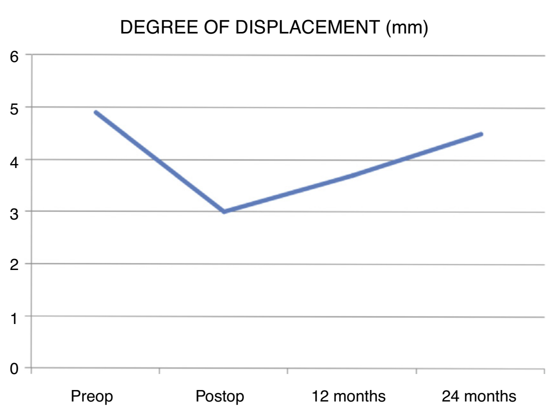

Fig. 5 – Clinical course of degree of displacement.

The least affected parameters were the angle of deformation, which changed from 20.7 to 22.9° (increase of 10.62%). The difference in all the parameters of measurement in the immediate postoperative phase and the measurement at 24 months is statistically significant (Student's *t*-test; $p < 0.05$).

Discussion

With respect to the epidemiological data, including sex, mechanism of injury, region affected and type of fracture, the series we present concurs with other similar studies.[9,23–25]

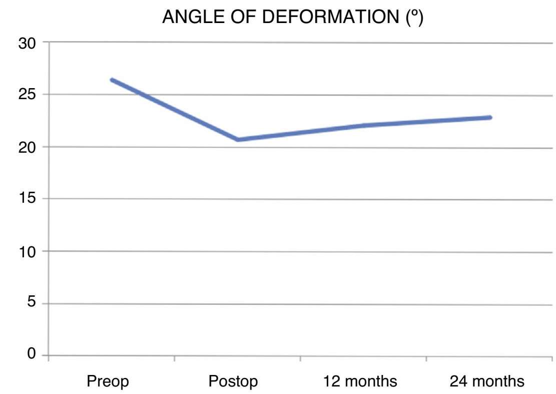

Fig. 6 – Clinical course of the angle of deformation.

As mentioned in the introduction, with respect to the surgery, the fixation of burst fractures and flexion-distraction fractures by a posterior approach was generally accompanied by posterolateral or posterior arthrodesis with good results,[9,10] but this is currently controversial.[1] The argument in favour of arthrodesis is that it provides greater stability, avoiding the loss of reduction, failure of the mounting, and pseudarthrosis. Moreover, the consequence of arthrodesis is a permanent loss of segmental movement.[11] Dai et al.[26] presented good results using an open or percutaneous approach without arthrodesis in patients with thoracic and lumbar fractures of the burst type. Tezeren & Kuru[24] published satisfactory results for flexion-distraction type fractures treated with short instrumentation without associated arthrodesis. According to the publication by Grossbach et al.,[27] it is also reasonable to treat flexion-distraction type fractures by percutaneous instrumentation.

The most striking loss of correction was observed in the levels corresponding to the thoraco-lumbar junction (T12-L1), as it acts like a fulcrum for the growing movement between the thoracic column, which is rigid and supported by the ribs, and the lumbar column, which is much more flexible, and in the A4 subtypes of fracture on the AOSpine, as they are inherently unstable fractures.

Treatment of unstable fractures by percutaneous surgery has recently been the subject of study by various authors. Chou et al.,[28] in one of the studies considered a reference for this matter, describe a randomised trial over 10 years on thoracic and lumbar fractures of the burst type (A4) treated surgically with and without arthrodesis by percutaneous surgery and conclude that there is no reason to perform posterior arthrodesis routinely on this type of fracture, as the radiological results are similar. Nonetheless, in this study, the radiological comparison made between the groups of patients undergoing and not undergoing arthrodesis was based exclusively on the measurement of kyphotic deformity. It is possible that the measurement of additional parameters, such as those in this study, would have shown differences between the two groups. This occurs with similar impact studies[9,25] in which conclusions are drawn about various types of instrumentation, without taking into consideration values such as the angle of fracture or the angle of deformation. Consequently, the meta-analyses themselves draw statistical conclusions without considering more radiological parameters than those mentioned.[11]

The importance of kyphotic deformity is clear for taking decisions on thoracic and lumbar fractures,[26] but we demonstrated in the study that there are five other additional parameters that vary throughout the follow-up on these fractures and that could be crucial when conclusions are drawn about whether to perform open surgery with arthrodesis or percutaneous surgery, as well as whether to use short or long instrumentation.

Percutaneous fixation without arthrodesis permits the removal of the instrumentation once the fracture is consolidated, which has been demonstrated by various authors in recent publications.[25,28] In the case of our series, a decision to remove the instrumentation was not made in any case, although the patient was given that option once the fracture was consolidated; it was the patients themselves who rejected a new surgical procedure.

One of the advantages of percutaneous surgery over open surgery is the lower rate of complications,[25,28] decreasing intra- and postoperative bleeding as well as the incidence of superficial and deep infections. Nonetheless, as can be seen in Table 2, the percentage of complications in the series studied is not negligible in any case, which indicates that percutaneous surgery is not free from complications.

As a consequence of the lack of clinical data from the study, we were unable to establish an adequate clinical-radiological correlation. Although we observed a gradual loss of correction in each of the 6 parameters evaluated, we were unable to establish clear clinical repercussions. We do not know whether these parameters affected each of the patents from a functional perspective nor whether they affected their quality of life or reintegration into the workforce. We currently also lack a comparison with a group of patients whose fractures were treated by the open procedure with arthrodesis that would allow us to see the clinical course of the radiological parameters and compare them over time with those from percutaneous surgery. As a limitation of the study, we must mention that the sample size in our study (n = 37) reflects a small number of cases. Numerous thoracic and lumbar fractures that reach our centres were treated by open surgery, thus decreasing the cases of percutaneous surgery.

We confirm our initial hypothesis, therefore, based on this study, establishing that there are parameters that have not been traditionally studied and have lost correction over the follow-up period of thoracic and lumbar fractures; studying these factors could be crucial for detecting differences between various types of surgery and instrumentation over the long term.

As a conclusion, we establish that beyond kyphotic deformity and the percentage of compression evaluated in classic studies, there is a series of radiological parameters that undergo a loss of correction over time in thoracic and lumbar fractures treated surgically, and which we recommend measuring routinely for follow-up on these fractures, although their correlation with clinical symptoms remains uncertain to date.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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Radiological Evaluation Does Not Reflect the Clinical Outcome After Surgery in Unstable Thoracolumbar and Lumbar Type A Fractures Without Neurological Symptoms

A Comparative Study of 2 Cohorts Treated by Open or Percutaneous Surgery

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Study design: This is a prospective study of 2 cohorts.

Objective: Compare the clinical and radiologic outcome of 2 cohorts of unstable thoracolumbar and lumbar fractures treated by open posterior fixation (OPF) with bone graft or by percutaneous fixation (PCF) without grafting.

Summary of Background Data: In recent years, PCF is the most common treatment of thoracolumbar fractures. To date, no studies have analyzed clinical outcomes in terms of return to work.

Material and Methods: Two cohorts of patients with unstable thoracolumbar and lumbar fractures fractures (type A2, A3, and A4) without neurological symptoms underwent OPF (n = 91) or PCF (n = 54) between 2010 and 2015. A conventional radiologic study was performed in the preoperative, immediate postoperative period, 1-year, and 2-year follow-up. Clinical outcomes were evaluated by Visual Analog Scale and Oswestry Disability Index scores at 1-year and 2-year follow-up. The period to return to work and the type of work were also recorded.

Results: The percentages of correction were significantly higher in cases operated by OPF: fracture angle ($P < 0.001$), kyphotic deformity ($P < 0.001$), vertebral compression ($P < 0.001$), and displacement ($P < 0.001$). Cases operated by PCF experienced greater loss of correction at 2-year follow-up, especially in fracture displacement ($P < 0.001$), deformity angle ($P < 0.001$), kyphotic deformity ($P < 0.001$), and in the sagittal index ($P < 0.001$). Besides this greater loss of correction, PCF cases showed better Visual Analog Scale ($P < 0.001$) and Oswestry Disability Index scores ($P < 0.001$) at final follow-up. The percentage of patients returning to the same heavy work position was higher in the PCF group ($P < 0.001$) and in a shorter period of time ($P < 0.001$).

Conclusions: The greater loss of correction of patients undergoing PCF does not reflect the clinical outcomes that were significantly better as compared to patients undergoing open fixation with grafting. It would be useful to further evaluate if the radiological changes could have a long-term clinical significance.

Key Words: thoracolumbar unstable fractures, open posterior fixation, percutaneous fixation, return to work

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Thoracolumbar and lumbar vertebral fractures and dislocations are complex lesions that frequently occur in young people, usually as a result of high-energy traumatisms such as rod traffic accidents and falls from height.[1–3] Neurological injuries can occur in 15%–40% of these fractures[4,5] and over 30% of patients can develop chronic pain that entails limitations in daily life activities preventing the return to work.[1,6,7]

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The surgical treatment of this type of injury has gained popularity in recent years. Internal fixation after decompression is the most common technique for cases involving neurological injuries. There is controversy regarding the optimal approach (anterior, posterior or combined) for unstable fractures.[2,8] The fixation of flexion-distraction spine fractures by a posterior approach is commonly performed by a posterior or posterolateral fusion with bone grafting with good clinical results.[9,10] The argument in favor of the segmental posterior fusion is to provide greater stability at the injured site, avoiding complications such as loss of fracture reduction, failure of the implants, and pseudoarthrosis. The drawback is that this procedure requires extensive detachment of the paraspinal muscles that causes fibrosis of the soft tissue, leading to postoperative chronic pain. In addition, this traditional approach increases intraoperative blood loss (derived in part from the required bone grafting supplementation), prolongs hospital stay, and results in a permanent loss of segmental motion.[11–16]

Currently, minimally invasive surgery of thoracolumbar and lumbar fractures is widely recognized. Percutaneous pedicle screwing inflicts less damage to the paraspinal muscles, less intraoperative blood loss and no requires bone grafting. The potential benefits ultimately determine a shorter hospital stay, a lower rate of perioperative complications, less postoperative muscle atrophy and subsequent back pain.[17–19]

In most of studies conducted to date, radiologic follow-up is based on 2 parameters: kyphotic deformity and percentage of compression.[9–11] A recent systematic review and meta-analysis evaluated differences in outcome variables between percutaneous and open pedicle screws for traumatic thoracolumbar fractures. According to this study, patients with thoracolumbar fractures can be equally managed with percutaneous or open pedicle screw placement. There were no differences in vertebral height and kyphosis angle restoration, or pain experience between the 2 groups. Blood loss and operative time were decreased in the percutaneous group, which reflect the potential clinical benefits, particularly in the polytraumatized patient.

In this study, a more exhaustive radiologic follow-up of unstable thoracolumbar and lumbar fractures without neurological deficits treated with posterior instrumented fusion was intended by monitoring 6 different parameters. It was first hypothesized that some of the parameters that have never been studied could better reflect the loss of correction throughout the follow-up, and could be more useful when making clinical and surgical decisions. The second hypothesis was that a less stable fixation, such as that provide by percutaneous fixation (PCF) without bone grafting, could determine a progressive loss of fracture reduction that could have clinical implications.

The purpose of this study was hence to compare the clinical and radiologic outcome of 2 cohorts of unstable thoracolumbar and lumbar fractures treated by open posterior short fixation (OPF) with bone graft or PCF without grafting. In addition to Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores, the clinical outcome was assessed by recording the number of patients returning to the previous job and the time period to start the working activities.

MATERIALS AND METHODS

Participants

This prospective study was conducted on a series of 145 patients with unstable nonosteoporotic toracolumbar spine fractures with no associated neurological deficits who underwent surgery between January 2010 and December 2015. All patients presented unstable compression fractures (type A) as per the AOSpine classification modified by Vaccaro et al.[20] Type A fractures were considered unstable when showing widened interspinous distance or a kyphotic deformity of over 25 degreea. Type B and C fractures were not considered for this study.

Patients underwent either posterior instrumented fusion by open surgery (n = 91) or PCF (n = 54). The allocation of patients for surgery was only dependent of the preference of the surgeon in duty. The age, sex, follow-up, mechanism of injury, fracture location, type of fracture, number of fixed vertebrae, and type of assembly (short if it includes 4 levels or fewer, and long if it includes 5 or more levels) were recorded.

Initial Evaluation

As part of the preoperative study, all of the patients were subjected to laboratory tests (blood count, basic biochemistry, and coagulation), a chest x-rays, anterior-posterior and sagittal x-rays of the thoracic spine, thoracolumbar hinge, and lumbosacral spine, as well as computed tomography (CT) of the affected vertebral segment. At the initial evaluation, a head, chest and abdomen CT or body CT scan (head, chest, abdomen, and pelvis) was performed, depending on the associated injuries suspected or the intensity of the trauma. MRI was also performed in all patients to explore the integrity of the posterior ligament complex. We defined instability as widening of the interspinous process distance on the lateral plain x-ray. These patients also demonstrated evidence of edema within the posterior ligament complex which may represent incompetence to this structure.

Before surgical intervention, none of the patients included in the study presented a neurological deficit as a result of the spinal fracture, with this deficit deemed to comprise alterations in limb sensitivity, reduced limb strength or a loss of sphincter control.

Surgical Procedures

In cases operated by open instrumented fixation (OPF), the procedure consisted of a bilateral posterolateral fusion using a single posterior approach, performing short-segment instrumentation (one level above and below the fractured vertebra). Long-segment instrumentation was also chosen in patients with various unstable contiguous spinal fractures. In these OPF patients, bone grafting technique consisted in the application of a mixed autologous spinous

TABLE 1. Radiologic Parameters Evaluated in the Study

Parameter	Definition
Fracture angle	Formed between the tangent drawn at the superior vertebral end plate above the fractured vertebra and the tangent drawn at the inferior vertebral end plate below the fractured vertebra
Kyphotic deformity	Angle value obtained on drawing a tangent between the inferior end plate of the vertebra above the fracture and the line tangent to the inferior end plate of the fractured vertebra
Sagittal index	Difference in the value obtained in the kyphotic deformity and normal contour
Percentage of vertebral compression	Ratio of the distance, in millimeters, of the anterior part of the fractured vertebra compared to the height of the posterior wall of its vertebral body, multiplied by 100, then minus 100
Degree of displacement	Distance the vertebra has previously been displaced in relation to the posterior wall of the fractured vertebra, divided by the width of the normal vertebra immediately below the fractured vertebra
Deformation angle	Determined by the intersection of the lines drawn along the posterior surfaces of the vertebral bodies above and below the fracture

process bone and different commercially available synthetic bone grafts.

The percutaneous surgery (PCF) consisted in a minimally invasive transpedicular fixation using the same instrumentation systems in the different centers (CD Horizon Legacy/Solera Spinal System, Medtronic Sofamor Danek Inc., Menphis, TN, and ROMEO2 MIS, SpineArt, Geneva, Switzerland). Pedicle screws were introduced by fluoroscopy and without adding any bone graft. Short instrumentation (one level above and below the fractured vertebra) was used in cases of a single fractured vertebra, whereas in the case of multilevel fractures, a long instrumentation was chosen (2 levels above and below the fractured vertebrae). Bone graft was never used in this PCF group.

Clinical Outcomes

Each patient was followed-up prospectively from the immediate postoperative period, to 12 and 24 months after surgery. At 12 and 24-month evaluation, patients filled a self-administered questionnaire, including a VAS for lumbar pain (0–10 cm) and the ODI (0%–100%). Patients were also asked about the return to their previous work or the possible change to other less heavy activity. The period of time from surgery to the start of working activities was also recorded.

Radiologic Outcomes

In addition to the classic radiologic examination, which includes kyphotic deformity and the percentage of compression 9–11, the current study included other 4 radiologic parameters that were monitored along the whole period of study. The Table 1 summarized the 6 radiologil parameters measured. All of the parameters were assessed preoperatively, in the immediate postoperative period and after 12, and 24 months.

Statistical Analysis

The statistical analysis was performed using the SPSS package v. 24.0 (IBM, USA), establishing statistically significant levels for P values <0.05. Descriptive analysis of continuous variables was reported as the means and standard deviations. Independent 2-tailed sample *t*-tests and the Chi-square test were used to compare the outcomes between the two groups.

RESULTS

A total of 6 patients in the OPF group and 3 in the PCF were excluded from the study because they did not attend the follow-up examinations, and therefore the periodic x-rays measurements could not be recorded. The study finally included 136 patients (91 men and 45 women) who underwent either posterior instrumented fusion by open surgery (n = 85) or PCF (n = 51).

The mean age of patients was almost similar in both cohorts (Table 2). The incidence among men was markedly higher in both cohorts, with a comparable two thirds proportion of males involved. There were no differences between the 2 cohorts regarding work loading, injury mechanism, affected spine region, fracture classification, and number of vertebrae involved (Table 2). More than half of the fractures were related to traffic accidents in both series.

The predominant location was the thoracolumbar region, particularly at the transitional area (T12–L1), representing 49.4% of the cases operated on by OPF and 54.9% in the PCF group.

TABLE 2. Clinical Characteristics of the 2 Cohorts

	Surgical Technique		
Variables	OPF (n = 85)	PCF (n = 51)	Significance
Age (y)	36.3 ± 7.3	37.5 ± 7.0	0.355*
Sex (male %)	67.1	66.6	0.962†
Injury mechanism			
Traffic accident	50	30	0.733†
Falls from height	29	19	
Direct trauma	6	2	
Spine region			
Thoracolumbar	60	38	0.622†
Lumbar	25	13	
Classification			
A2	3	6	0.154†
A3	31	15	
A4	51	30	
Vertebral involvement			
One level	71	42	0.518†
Multiple fracture	14	9	
Work loading			
Low	31	18	0.720†
Moderate	28	20	
Heavy	26	13	

**T* test.
†χ^2 test.

TABLE 3. Postoperative Complications According to the Surgical Technique

Adverse Events	n (%) OPF	n (%) PCF	χ^2 Test 2-tailed *P*
Paralytic ileus	23 (27.1)	8 (15.7)	0.144
Urinary tract infection	11 (12.9)	7 (13.7)	1.000
Superficial infection	8 (9.4)	2 (3.9)	0.319
Deep infection	3 (3.5)	2 (3.9)	1.000
Implant failure	7 (8.2)	4 (7.8)	1.000
Nonunion	4 (4.7)	—	0.296
Neurological deterioration	5 (5.9)	2 (3.9)	0.711
Total reoperations	11 (12.9)	7 (13.7)	1.000
Reoperations due to deformity progression	6 (7.1)	4 (7.8)	1.000

OPF indicates open posterior fixation; PCF, percutaneous fixation.

According to the AOSpine classification, the most frequent fracture type was A4 (60% in the OPF group and 58.8% in the PCF). There was a low proportion of multiple vertebral fractures (16.5% in the OPF group and 17.6% in the PCF).

In relation to the number of instrumented vertebrae, the mean number of fixed and fused levels was 3.5 in the OPF group. Short-segment fixation prevailed over the long type (71% vs. 29%), and spinal decompression was performed in 21 cases from the study series, provided that spinal canal invasion was >50%. In the PCF group, the mean number of fused levels was 3.4 with an almost similar distribution of short (24%) and long constructs (76%) as compared with OPF.

The total number of complications and their grouping according to the type of instrumentation used is shown in Table 3. There were no differences between the 2 surgical techniques in the distribution of adverse events.

As for the radiologic aspect, which represents what is novel about this study, the assessment was performed using the 6 parameters mentioned in the previous section. The results regarding the percentage of correction from the preoperative to the immediate postoperative period presented in Table 4. In both groups, all radiologic parameters showed a significant improvement immediately after surgery ($P<0.001$). The percentages of correction were significantly higher in the cases operated by open surgery: fracture angle (52.6% ± 3.7% open surgery vs. 43.1% ± 1.9% in percutaneous, $P<0.001$), sagittal index (39.3% ± 2.3% vs. 28.0% ± 2.7%, $P<0.001$), kyphotic deformity (37.2% ± 4.2% vs. 34.5% ± 2.2%, $P<0.001$), vertebral compression (18.7% ± 3.0% vs. 14.2% ± 2.8%, $P<0.001$) and correction of displacement (47.8% ± 5.6% vs. 37.9% ± 3.8%, $P<0.001$). There were no differences among the A2–A3 fractures and those involving the posterior vertebral wall (A4) in the amount of correction when they were analyzed intragroup. Comparing both surgical techniques, the behavior of these 2 types of fractures was similar to the overall results.

Both cohorts showed the same behavior along the follow-up periods in 2 radiologic measurements: vertebral body compression and degree of displacement. Concerning vertebral compression, the 2 cohorts showed a progressive lost of correction, being statistically significant at 12-month (OPF, 33.5% ± 2.5%; PCF, 34.5% ± 0.7%) and 24-month follow-up (OPF, 35.3% ± 2.9%; PCF, 35.7% ± 0.8%) as compared with that found after surgical correction (OPF, 31.9% ± 2.4%; PCF, 32.7% ± 0.9%) (Fig. 1A).

As regard, the degree of displacement, both cohorts also showed a progressive increase in the displacement achieved postoperatively (OPF, 2.8% ± 0.2%; PCF, 3.8% ± 0.2%) (Fig. 1B). At 12-month postsurgery, the displacement increase significantly in both cohorts (OPF, 3.8% ± 0.3%; PCF, 3.9% ± 0.2%). At the 24-month measurements, the displacement increases also significantly (OPF, 4.2% ± 0.3%; PCF, 4.4% ± 0.4%).

In the other 4 radiologic measurements (segmental kyphosis, fracture angle, angle of displacement, and sagittal index), patients operated on by PCF showed a statistically significant higher loss of correction during follow-up as compared to patients treated by open approach. Notably, the angle of the fracture, the segmental kyphosis and the angle of displacement remained stable from 12- to 24-month follow-up in the OPF group (Figs. 2A, B). However, in the PCF group, the correction loss was progressive until the end of the follow-up.

As compared with the initial amount of correction, the cases operated by PCF experienced a greater correction loss at 2 years of follow-up (Table 5), being notable in the displacement (54.8% ± 18.8% in OPF vs. 74.2% ± 28.5% in PCF; $P<0.001$), in the angle of the deformity (15.2% ± 4.0% vs. 41.5% ± 11.4%, $P<0.001$), in the kyphotic deformity (12.9% ± 3.0% vs. 21.5% ± 4.9%, $P<0.001$) and in the sagittal index (26.2% ± 14.1% vs. 56.1% ± 13.2%, $P<0.001$). Differences in the amount of correction loss were statistically significant between both groups.

TABLE 4. Percentage of Fracture Correction From the Preoperative to the Immediate Postoperative Period Provided by the Different Radiologic Measurements

% Correction	OPF Mean ± SD	OPF 95% CI	PCF Mean ± SD	PCF 95% CI	Paired *t* test Significance
Fracture angle	52.6 ± 3.7	51.8–53.4	43.1 ± 1.9	42.5–43.6	0.000*
Sagittal index	39.3 ± 2.3	38.8–39.8	28.0 ± 2.7	27.2–28.8	0.000*
Kyphosis	37.2 ± 4.2	36.3–38.1	34.5 ± 2.1	33.9–35.1	0.000*
Compression	18.7 ± 3.0	18.0–19.5	14.2 ± 2.8	13.4–15.0	0.000*
Displacement	47.8 ± 5.6	46.6–49.0	37.9 ± 3.8	36.8–39.0	0.000*
Deformity angle	21.9 ± 2.6	21.4–22.5	21.5 ± 1.7	21.1–22.0	0.290

CI indicates confidence interval; OPF, open posterior fixation; PCF, percutaneous fixation.
*$P<0.01$.

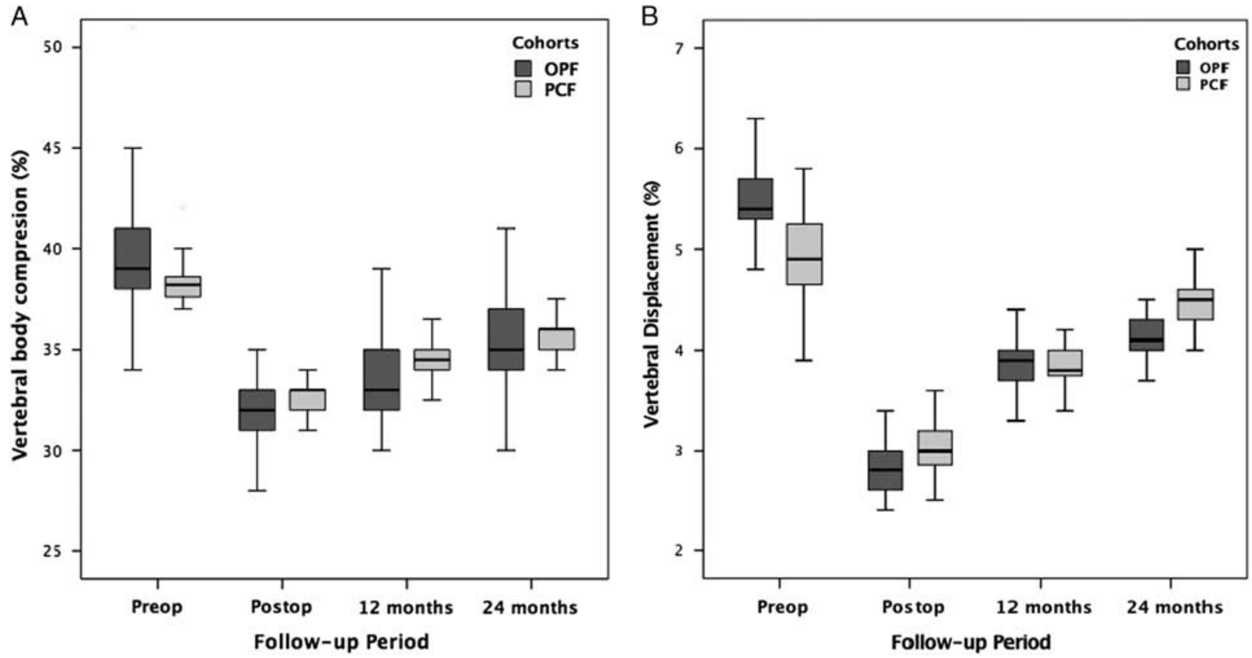

FIGURE 1. A, Percentage of vertebral body compression before surgery, immediately after fracture fixation, and at 12- and 24-month follow-up in the 2 cohorts of patients. B, Vertebral fracture displacement (%) at the same stages. OPF indicates open posterior fixation; PCF, percutaneous fixation.

The lost of kyphosis during follow-up was inversely related to the amount of the initial kyphosis correction in both cohorts (Fig. 3A). Similarly, the loss of the initial vertebral decompression was inversely correlated with the amount of postoperative decompression (Fig. 4B).

As to clinical outcomes, patients operated by PCF showed lower VAS and ODI scores at both 12- and 24-month follow-up, being differences highly significant (Table 6). The effect size of the differences was large for VAS scores, particularly at 24-month follow-up. Differences in ODI scores

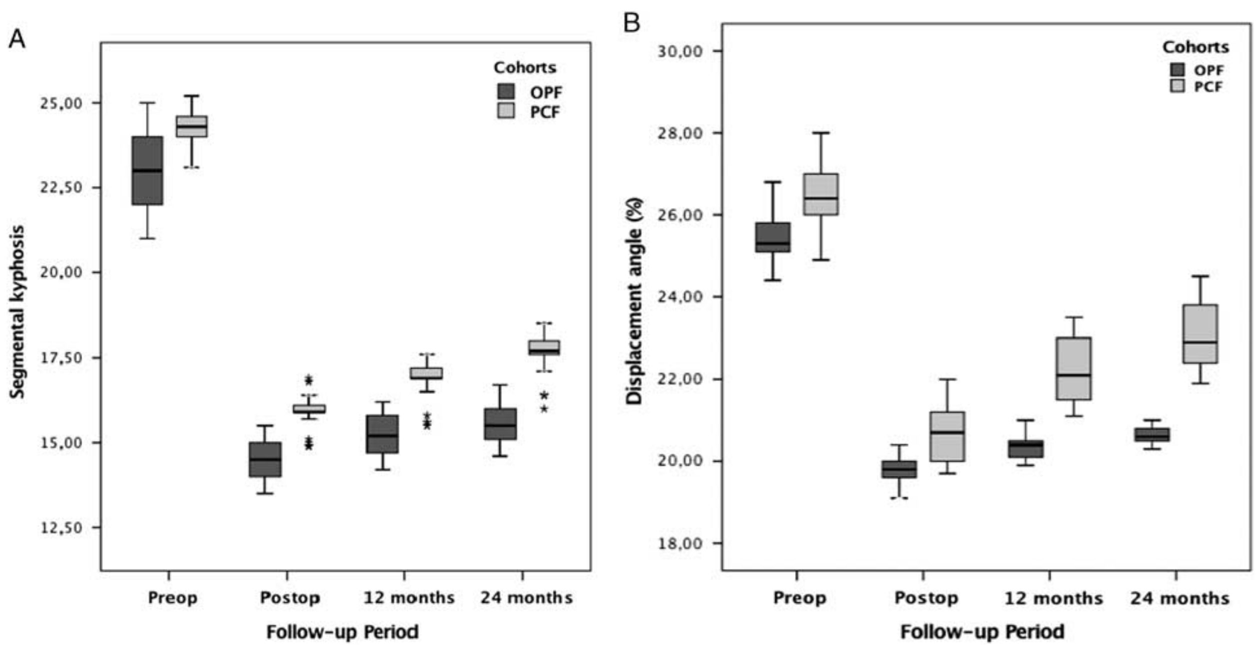

FIGURE 2. A, Variations in segmental kyphosis (degrees) before and after surgery, and along the follow-up in the 2 cohorts. B, Variation of the displacement angle at the same stages. OPF indicates open posterior fixation; PCF, percutaneous fixation.

TABLE 5. Loss of Correction From the Immediate Postoperative Period to 2-Year Follow-up

	OPF		PCF		
Loss of Correction (%)	**Mean ± SD**	**95% CI**	**Mean ± SD**	**95% CI**	**Paired *t* test Significance**
Fracture angle	20.0 ± 4.9	18.9 – 21.1	18.5 ± 2.9	17.7 – 19.3	0.043*
Sagittal index	26.2 ± 14.1	23.1 – 29.2	56.1 ± 13.2	52.4 – 59.8	0.000**
Kyphosis	12.9 ± 3.0	12.3 – 13.6	21.5 ± 5.0	20.1 – 22.9	0.000**
Compression	48.0 ± 22.7	43.1 – 52.9	55.6 ± 16.2	51.0 – 60.2	0.039*
Displacement	54.8 ± 18.8	50.7 – 58.9	74.2 ± 28.5	66.2 – 82.7	0.000**
Deformity angle	15.2 ± 4.0	14.4 – 16.1	41.5 ± 11.5	38.3 – 44.8	0.290

CI indicates confidence interval; OPF, open posterior fixation; PCF, percutaneous fixation.
*$P < 0.05$.
**$P < 0.01$.

between the 2 techniques were moderate at 12-month follow-up (Cohen $d = 0.62$), and large at 24-month evaluation (Cohen $d = 0.88$).

At the end of follow-up, an almost similar proportion of patients of both groups have not returned to work (Table 6). A total of 52 patients (61.2%) in the OPF cohort have return to the same work activities as compared to 37 (72.5%) in the PCF group. Overall results showed no statistically significant difference. However, the return to work was analyzed depending the previous type of activity, there was a clear difference in the percentage of patients returning to a heavy activity in the PCF group as compare with OPF (76.9% vs. 50.0%) (Fig. 4).

The overall period of time to return to work was also faster in the PCF group (14.5 ± 4.7 mo, 95% confidence interval, 13.0–16.1 vs. 17.5 ± 5.2 mo, 95% confidence interval, 13.0–16.1; $P < 0.01$). The effect size was moderate (Cohen $d = 0.60$) (Table 7). Analyzing the period of time to return to work depending of the type of activity, there were differences between the 2 surgical techniques in the 3 job activities, and among these 3 activities within each group (Table 7). The effect size was large, specially in the heavy work group (Cohen $d = 4.14$).

The period to return to work did not correlated with any of the parameters measuring the loss of correction.

DISCUSSION

Patients with thoracolumbar or lumbar burst fractures showing no neurological damage can be surgically treated indistinctly by percutaneous or open pedicle screw placement. The minimally invasive procedure is being now recommended because of some benefits (less bleeding, less damage to the paraspinal muscles, etc.) that make the process more comfortable for the patient from a clinical point of view with similar outcome than the open surgery. In our study, clinical outcomes using PCF were better than those found in patients receiving OPF as measured by VAS, ODI scores and the period to return to previous working activities. This critical point, the regain of the same working activity, has never been study when dealing with thoracolumbar fractures. The clinical benefit of PCF

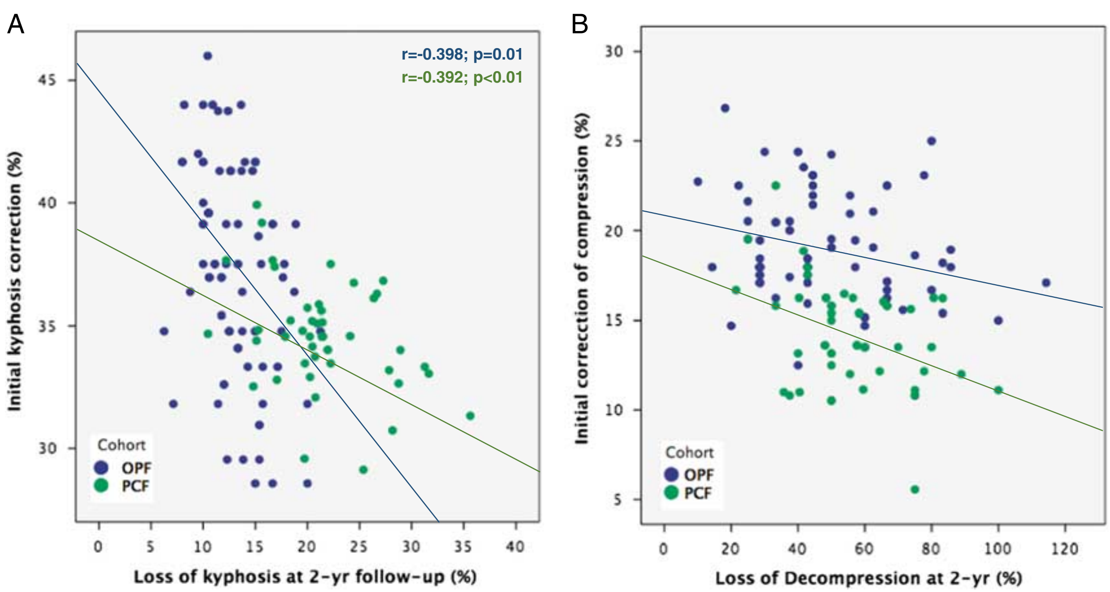

FIGURE 3. A, Loss of kyphosis reduction (%) at 24-month follow-up depending of the intitial kyphosis correction (%). B, Loss of decompression reduction (%) at 24-month follow-up depending of the initial percentage of vertebral compression correction. OPF indicates open posterior fixation; PCF, percutaneous fixation. full color online

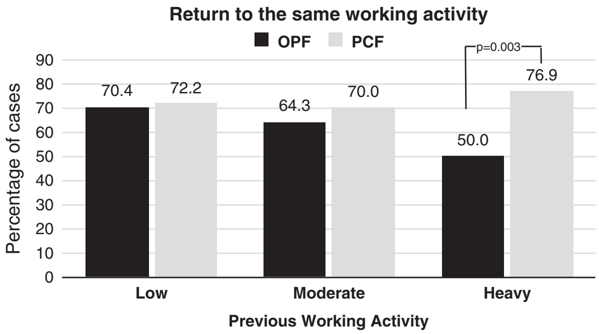

FIGURE 4. Percentage of patients returning to the same previous working activity in each cohort. OPF indicates open posterior fixation; PCF, percutaneous fixation.

was specially detected in patients with a heavy work. More than parts of these patients returned to their previous activity as compared with only 50% of patients operated by conventional open fusion. Notably, the length of the period to return to work was also clearly shorter in the PCF group than in the open fusion in the 3 loading work activities. These data confirm the clinical advantage of percutaneous surgery for type A thoracolumbar fractures without neurological involvement. In our opinion, return to work is a more accurate measure than VAS or ODI to define the clinical impact of the surgical intervention.

The classical open instrumented fixation usually implies a posterior or posterolateral fusion. This segmental fusion has claimed to provide higher stability to the fracture reduction. However, an updated systematic review and meta-analysis found no differences between the 2 technique when radiologic measurements were compared.[11] Most of the studies based the radiologic follow-up in the monitoring of the kyphotic deformity and the percentage of compression. The current study introduces four other radiologic measurements that were able first to detect the loss of correction along the follow-up, and second reveal differences between open and PCF techniques.

TABLE 6. Clinical Outcomes at 12- and 24-month Follow-up and Return to Work

Outcomes	Mean ± SD OPF	Mean ± SD PCF	*t* Test Significance	Effect Size Cohen *d*
VAS 12 mo	2.1 ± 0.7	0.9 ± 0.6	0.000*	1.82
VAS 24 mo	2.3 ± 0.6	0.8 ± 0.5	0.000*	2.68
ODI 12 mo	23.4 ± 8.3	18.8 ± 7.7	0.001*	0.62
ODI 24 mo	24.3 ± 7.3	17.7 ± 7.9	0.000*	0.88
Return to work	n (%)		Chi-square test (*P*)	
To the same work	52 (61.2)	37 (72.5)	0.281	
Change to a less active work	13 (15.3)	3 (5.9)	0.169	
No return	20 (23.5)	11 (21.6)	0.957	

ODI indicates Oswestry Disability Index; OPF, indicates open posterior fixation; PCF, percutaneous fixation; VAS, Visual Analog Scale.
*$P<0.01$.

TABLE 7. Mean Period for Return to Work in Relation to the Type of Activity Before the Fracture

Types of Work	Mean ± SD OPF	Mean ± SD PCF	*t* Test Significance	Effect Size Cohen *d*
Return to work (mo)	17.5 ± 5.2	14.5 ± 4.7	0.001*	0.60
Low activity	12.2 ± 1.6	9.5 ± 0.7	0.000*	2.16
Moderate activity	17.1 ± 0.9	14.6 ± 1.0	0.000*	2.71
Heavy activity	25.1 ± 0.9	21.1 ± 1.1	0.000*	4.24
ANOVA among groups	*F* = 410.5	*F* = 415.3		
	Significance: 0.000	Significance: 0.000		

ANOVA indicates analysis of variance; OPF, open posterior fixation; PCF, percutaneous fixation.
*$P<0.01$.

According to proposed radiologic parameters, OPF in thoracolumbar and lumbar compression fractures provided better radiologic correction percentages in the immediate postoperative period than PCF surgery. This better deformity correction applied for the decrease in the angle of the fracture, the amount of kyphotic deformity restoration, the higher vertebral body decompression, and correction of vertebral displacement. Notably, the most relevant finding of the current study was that the radiological measurements were able to show a greater loss of correction at 2-year follow-up in cases undergoing PCF as compared with OPF patients. Differences were statistically significant for the increase in the vertebral body compression and displacement. In both groups of patients, the correction loss of these 2 parameters could be observed at the first postoperative year, with subsequent progression until the 24-month follow-up in both, being greater in PCF patients. However, in cases operated by OPF the loss of correction stabilized at 12-month follow-up and remained stable until the end of follow-up in 4 of the measurements: segmental kyphosis, angle of the fracture, angle of displacement, and sagittal index.

In most of the studies on thoracolumbar fractures, kyphotic deformity and the percentage of compression are taken as the gold standard assessment from a radiologic point of view. To our knowledge, none study considers other parameters such as the fracture angle, sagittal index, and deformation or displacement angle.[9,10,21] Even a recent meta-analyses draw statistical conclusions without addressing other radiologic parameters beyond those commonly measured.[11]

The argument in favor of posterolateral instrumented fixation is that fusion provides greater stability, preventing reduction loss, fixation failure, and pseudoarthrosis providing good clinical outcomes.[22,23] The data of the current study are in agreement with that statement. Furthermore, fusion results in a permanent loss of segmental motion.[24] Although this fact could predispose to long-term sequels at the adjacent disk that deserve future studies, the segmental stiffness provided by the fusion may be a preventing factor for loss of correction, redisplacement and further vertebral fracture compression. The stability of most of the radiological measurements found in the OPF series of the current study support that theory in contrast with the progressive loos of correction detected in the PCF group without fusion.

Taking into consideration all these data, it is not easy to interpret the positive results reported by Dai et al[25] using an open or percutaneous approach without fusion in patients with thoracolumbar burst fractures. Moreover, Kim et al[24] have published satisfactory results for flexion-distraction fractures treated with short-segment instrumentation without associated arthrodesis. Tezeren and Kuru[26] have published satisfactory results for flexion-distraction type fractures treated with short instrumentation without associated arthrodesis.

The treatment of unstable fractures by means of percutaneous surgery without fusion has recently been proposed as reasonable by several authors.[1,10,27] In one of the studies considered as reference on this topic, Chou et al[10] describe a 10-year randomized trial of thoracic and lumbar A4 fractures surgically treated with and without fusion using percutaneous surgery. The authors concluded that posterior fusion should not routinely required in this type of fractures, since the radiological results are similar. In this study, the radiologic comparison between the fused and nonfused patients was based exclusively on the measurements of the kyphotic deformity. Most likely, measuring additional parameters such as those of the present study, differences in the 2 groups could have been detected. Similarly, other studies[21,22] draw conclusions about different types of instrumentation without taking into account parameters such as the angle of the fracture, the angle of displacement or the sagittal index. As a consequence, some of the few meta-analyzes made conclusions addressing only the commonly used radiological parameters: vertebral compression in height and kyphotic deformity.[24]

PCF without fusion allows the removal of the instrumentation once the fracture is consolidated.[10,25] In the current series, the removal of the instrumentation was never primary intended. This option was given only to the patients of the PCF group if they asked expressly for that, once the fracture was consolidated. Nevertheless, the patients themselves rejected a new surgical intervention during the period of follow-up.

One of the advantages of percutaneous over open surgery has been claimed the lowest rate of complications,[10,25] the decrease in intraoperative and postoperative bleeding, as well as the incidence of superficial and deep infections. However, in our hands, there was no difference in the percentage of complications of both series. It is clear that percutaneous surgery for vertebral fracture fixation is not free of complications.

Finally, although a progressive correction loss in each of the 6 assessed radiologic parameters was detected, there was not a clinical repercussion or functional impact on the patients as measured by the time period to return to work. Patients operated on by PCF showed larger radiologic loss of correction during follow-up, but they returned early to work than OPF patients. The lack of association of the impaired radiologic behavior and the return to work (an indicator of good functional outcome) is an issue for discussion and deserve future research. According to our findings, loos of radiologic correction seems to be no clinically relevant.

CONCLUSIONS

In summary, our initial hypothesis establishing the existence of parameters that have not traditionally been studied but that are able to monitor loss of the correction throughout the follow-up of surgically treated thoracolumbar fractures was confirmed. In addition to the kyphotic deformity and the percentage of compression assessed in classic studies, other radiologic parameters such as fracture angle, sagittal index, angle of the deformity, and vertebral displacement should be recommended to assess the follow-up of these cases. These parameters may be a determining factor for detecting long-term differences between various types of surgery and instrumentation. The second hypothesis was also confirmed in part: a less rigid fixation method as percutaneous surgery without bone grafting implies a greater loss of fracture correction along the follow-up. However, their clinical relevance does not seem relevant at present.

It would be useful to further evaluate if these radiologic changes could have a long-term clinical significance.

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Clinical Study

Severe hyperkyphosis reduces the aerobic capacity and maximal exercise tolerance in patients with Scheuermann disease

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Abstract

BACKGROUND CONTEXT: The evaluation of ventilatory functional restrictions during a maximal exercise tolerance test in patients with Scheuermann disease has never been described.

PURPOSE: This study evaluated the respiratory functional capacity of patients with Scheuermann disease compared to healthy adolescents matched in age.

STUDY DESIGN/SETTING: Prospective comparative study.

PATIENTS SAMPLE: Forty-one consecutive adolescents with Scheuermann hyperkyphosis (SK) and 20 healthy controls matched in age were included in the study.

OUTCOME MEASURES: Basal spirometry and dynamic ventilatory parameters were measured during a maximal cardiopulmonary exercise tolerance test. Heart rate, oxygen saturation ($SatO_2$), maximum oxygen uptake (VO_2 max), quotient between ventilation and volume of exhaled carbon dioxide (VE/CO_2), respiratory exchange rate (RER), ventilatory capacity at maximal exercise (VEmax), and test duration were recorded at initium and at maximal exercise.

METHODS: The exercise tolerance test (ETT) was completed to exhaustion using a standard Bruce protocol on a ramp treadmill. Comparisons of quantitative variables between SK and control group were analyzed by statistical nonparametric test. The correlations between the magnitude of the thoracic kyphosis and both the VO_2 max/kg and VEmax of the SK group were also analyzed. No funds were required. The authors have no conflicts of interests.

RESULTS: Patients with SK started the test with a higher heart rate ($p<.01$) and reached exhaustion with a lower heart rate ($p<.05$) than healthy controls. At maximal exercise, the $SatO_2$ was declined in Scheuermann patients compared to healthy subjects ($p<.05$). The maximal aerobic power (VO_2max) was greater in healthy controls than in hyperkyphotic patients (50.0 ± 6.7 vs. 43.4 ± 11.3 mL/kg/min; $p<.05$). There was an inverse correlation between the increase in the magnitude of thoracic kyphosis and the deterioration of the maximal aerobic power. VO_2max and VEmax were severely deteriorated in patients with more than 75° kyphosis. Patients with >75° thoracic kyphosis also showed an impairment in their cardiovascular efficiency as measured by the heart rate/VO_2 quotient. The limited tolerance to the exercise in SK patients was reflected by a shorter duration of the exercise test and a lower energy cost measured in METS (metabolic equivalents) as compared to healthy controls.

CONCLUSIONS: Patients with severe hyperkyphosis (>75°) show significant respiratory inefficiency together with a lower ventilation capacity and lower VO_2max. There is an inverse

FDA device/drug status: Not applicable.

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correlation between the increase in the magnitude of thoracic kyphosis and the deterioration of the maximal aerobic power.

Keywords: Cardiopulmonary exercise test; Hyperkyphosis; Maximal oxygen uptake; Respiratory function; Scheuermann disease; Ventilatory efficiency.

Introduction

Scheuermann disease (SD) is a spinal disorder named after Dr Holger Werfel Scheuermann, who, in 1921, first described a structural thoracic kyphosis mainly affecting adolescents [1]. The best-known manifestations are multiple wedged vertebrae and thoracic kyphosis known as Scheuermann kyphosis (SK). The classic diagnostic criteria include "three or more consecutive wedged thoracic vertebrae," as proposed by Sorensen in 1964 [2]. However, SD pathological changes also include disc and endplate lesions, primarily Schmorl's nodes and irregular vertebral endplates [1,2].

In contrast to the extensive investigation concerning the influence of idiopathic scoliosis on the respiratory function [3,4], few reports have addressed the impact of SK on pulmonary physiology. Murray et al. [5] reported decreased vital capacity and restrictive lung disease in cases with kyphosis greater than 100°. Diminished pulmonary function was classically defined by Weng and Levison [6] as less than 80% of the expected forced vital capacity (FVC) and/or forced expiratory volume in 1 second (FEV1). Abbi et al. [7] found that the percentage of the predicted FVC decreased significantly with increasing degrees of kyphosis from 105% in cases with kyphosis ranging 71° to 80°, to 83% in those from 81° to 90°, and 73% in cases with kyphosis greater than 90°. These authors also showed that the greatest kyphosis revealed a fairly weak but significant correlation with the percentage of predicted FVC.

All previous studies addressing pulmonary function in SK patients used static or baseline spirometry determinations. The small restrictions found at rest do not seem to limit the functional ventilatory capacity for daily activities [5,7]. As in adolescents with idiopathic scoliosis, the slight baseline ventilatory restrictions found by conventional spirometry can be amplified by a cardiopulmonary maximal exercise tolerance test (CPET), as the demands of pulmonary function are severely increased during intensive physical work [8]. In addition to this advantage, the evaluation of cardiorespiratory functional restrictions during a maximal CPET has never been described in patients with SK.

To our knowledge, there is a lack of information about tolerance to maximal exercise in patients with hyperkyphosis related to SK. We therefore conducted a study to evaluate the cardiorespiratory functional capacity of patients with SK compared to that of healthy adolescents matched in age. The hypothesis was that severe hyperkyphosis could reduce the aerobic capacity and maximal exercise tolerance in these patients.

Materials and methods

Patient inclusion criteria

We performed a prospective study including a series of consecutive patients with Scheuermann disease from our daily spine outpatient clinic who had more than 60° Cobb degrees and were aged between 12 and 17 years. The objective of the research was explained to all subjects, and the proper informed consent was obtained. None of the patients refused to participate. The study protocol was approved by the clinical research ethics committees at the main institution (Ref. #v1:08/05/2016).

Patients were eligible for inclusion if they had a diagnosis of Scheuermann disease and had not yet received surgical intervention. In all patients, the function of the lower extremities was neurologically examined to exclude signs of a possible myelopathy, specifically in high degree kyphosis patients. Other exclusion criteria were the presence of congenital heart disease or other pulmonary diseases, such as asthma or bronchiectasis. Volunteers who were healthy boys and girls matched in age participated in the study as a control group. Healthy controls were recruited from the group of patients referred to our orthopedics outpatient clinic by pediatricians or general practitioners for suspicion of orthopedic pathology other than spine disorders or complaints (usually lower extremity or foot complaints). All these volunteers were first screened for the exclusion of vertebral pathology through a clinical exam and X-ray studies of the whole spine in coronal and sagittal views.

Both groups were also clinically assessed to exclude cases with acute or chronic respiratory conditions such as asthma that could introduce distortions in the results. A basal 12-lead electrocardiogram was registered in all cases to determine the presence of unknown cardiac dysfunction according to standardized guidelines [9].

Healthy controls were only active within regular school-prescribed twice per week activities. Healthy volunteers exceeding these limits for any reason were excluded from the study since regular athletic training induces better aerobic parameters that could introduce bias into the study. Scheuermann patients were also determined to have the same habits of practicing sports as the healthy population (they were involved in school sports activities and in leisure sports). Both the healthy controls and the Scheuermann patients were European Caucasian individuals.

At the time of collecting the sample of patients with SK, 62 patients were initially assessed. A total of 21 cases were excluded for different reasons. Four patients exhibit associated scoliotic deformity; 3 patients had congenital cardiopathy; in 3 patients, the hyperkyphosis was part of a musculoskeletal syndromic pathology; 11 patients showed large thoracolumbar hypokyphotic curves with apex at T11 or below. These last patients were excluded because the thoracic spine below T10 has almost no participation in the respiratory movements [10,11].

Radiographic assessment

Two spine surgeons independently measured the magnitude of the total T2−T12 thoracic kyphosis on a full-length lateral radiograph according to the Cobb method [12] and reached a consensus. The radiograph was made with the patient in a standing position. The radiographic assessments were made <4 weeks before the ETT.

Cardiopulmonary exercise test

CPETs were conducted using a Schiller Cardiovit CS-200 Ergo-Spiro Stress Test System (Baar, Switzerland), which allowed measurement of both spirometric static parameters and cardiorespiratory functional parameters. Baseline pulmonary function was measured on the same day, immediately before administration of the CPET. FEV1 was recorded as a spirometric static parameter.

CPETs were conducted under similar conditions than those of previous studies [3] following a standard Bruce protocol [13] for each of the patients and with the use of a motorized treadmill adapted to the ergometer to take measurements during the test. Standard conditions of temperature, humidity, and atmospheric pressure were maintained according to normalized guidelines [9]. Continuous 8-lead electrocardiogram monitoring was used during exercise. The study protocol began with a 5-minute warm-up period at a speed of 0.75 m/s (2.7 km/hr). Subsequently, the speed was increased by increments of 0.2 m/s (0.72 km/hr) per minute. The slope of the treadmill was constantly maintained at 1.5%, resembling the normal resistance of air.

Three types of variables reflecting cardiovascular function, ventilatory capacity, and metabolic gas exchange were all measured during the CPET. Cardiovascular function was assessed by recording the heart rate (HR), blood pressure (BP), and oxygen saturation ($SatO_2$) at the beginning and the end of the test. Metabolic gas exchange and ventilatory parameters were measured ‘‘breath by breath’’ using a respiratory valve and face mask (Hans Rudolph, Inc., Kansas City, MO, USA), through a Schiller gas analyzer (Baar, Switzerland). The test duration was also recorded.

Finally, the metabolic equivalents of tasks (METS) were considered to quantify the energy cost that require the participants to reach their maximal functional capacity. A MET is defined as the resting metabolic rate, that is, the amount of oxygen consumed at rest, estimated approximately in 3.5 mL O_2/kg/min (1.2 kcal/min for a 70-kg person) [14]. As such, work at 5 METS requires five times the resting metabolism, that is 17.5 mL O_2/kg/min and 10 METS requires ten times the resting metabolism (35.0 mL O_2/kg/min), and so on.

Statistical analysis

The sample size was estimated to detect a difference between two means using VO_2max as the most pertinent variable. A difference greater than 5 mL/min/kg was considered clinically relevant [15]. To have an 80% power to detect, and assuming a variance of 32 mL and a 0.050 two-sided significance level, the minimum required sample size was 20 patients in each group. Statistical analysis was performed using the SPSS 21.0 statistical package (IBM, Chicago, IL, USA). The Kolmogorov−Smirnov test confirmed the abnormal distribution of some of the variables. This required the use of the nonparametric Mann−Whitney test to compare the quantitative variables (Scheuermann vs. control group). The Z value was also calculated. The correlation between the magnitude of the thoracic kyphosis and the VO_2max/kg and thoracic kyphosis and VE of the Scheuermann group was analyzed. The probability level (p value) was considered statistically significant for values <.05.

Results

The study included a total of 41 patients with SK and 20 healthy participants as a control. There were no differences in the gender distribution of the two groups. Table 1 shows

Table 1
Anthropometric characteristics and maximal kyphosis magnitude of the healthy subjects and patients with Scheuermann hyperkyphosis

	Healthy (n = 20)		Scheuermann (n = 41)		Mann−Whitney test	
	Mean ± SD	95% CI	Mean ± SD	95% CI	Z	p
Age (y)	13.9 ± 1.1	13.4−14.5	14.3 ± 7.7	14.1−14.5	−1.531	0.126
Weight (kg)	57.1 ± 4.5	54.9−59.1	59.5 ± 7.1	57.3−61.8	−1.771	0.077
Height (cm)	163.7 ± 4.5	161.6−165.8	168.1 ± 8.5	165.4−170.8	−2.129	0.033*
BMI (Kg/m^2)	21.3 ± 1.4	20.6−21.9	21.2 ± 3.4	20.2−22.3	−0.015	0.988
Maximal kyphosis (Cobb)			70.9 ± 9.2	68.1−73.9		

* p<.05.
** p<.01.

Table 2
Characteristics of the curves in patients with Scheuermann hyperkyphosis

	Spine levels	n (%)
Limits of the curve	T1−T12	1 (2.4)
	T2−L1	2 (4.8)
	T2−T12	20 (48.8)
	T3−L1	3 (7.3)
	T4−L1	8 (19.5)
	T4−T12	7 (17.1)
Apex	T6	14 (34.1)
	T7	16 (39.0)
	T8	7 (17.1)
	T9	4 (9.7)

the anthropometric characteristics of the two samples and the severity of the thoracic kyphosis. Mean age, weight, and BMI did not show statistically significant differences between the healthy subjects and patients with SK. However, individuals in the latter group were slightly taller than the controls ($p<.05$).

Table 2 shows the characteristic of the kyphotic curves in SK patients. The most common curve comprised T2-T12 levels (48.8%), with apex at T7 level (39.0%).

Table 3 discloses the cardiac, metabolic, and ventilator results obtained during the CPET. Regarding cardiovascular parameters, patients with hyperkyphosis started the test with higher average heart rates ($p<.01$) and reached exhaustion with lower average heart rates ($p<.05$) than did healthy controls. At maximal exercise, the average systolic BP was slightly higher in Scheuermann patients than in healthy subjects ($p<.05$). The decrease in $SatO_2$ at exhaustion was higher in individuals with hyperkyphosis than in healthy controls ($3.5 \pm 2.5\%$ versus $1.9 \pm 1.4\%$; Mann−Whitney test, Z:−2.328; p = .01). However, PuO_2, a relation between oxygen uptake and heart rate, was similar in both groups.

The maximal aerobic power, expressed by the body weight normalized VO_2max, was greater in healthy controls than in hyperkyphotic patients (50.0 ± 6.7 vs. 43.4 ± 11.3 mL/kg/min; $p<.05$), but there were no differences in the total VO_2 maximal volume (Table 3). There was an inverse correlation between the increase in magnitude of the thoracic kyphosis and the deterioration of the maximal aerobic power (Fig. 1).

The mean ventilatory capacity at maximal exercise, measured by VEmax, was slightly higher in hyperkyphotic individuals, but the results were not statistically significant (Table 2). In the SK group, 9 cases (21.9%) exhibited VE values >48 L/min, considered under the lower limit of normality [13,14]. None of the healthy controls had VE max values below that limit (Fisher's exact test, $p<.05$). In hyperkyphotic females, the VEmax values were inversely correlated with the severity of the thoracic kyphosis (Fig. 2). This correlation did not apply for males. When

Table 3
Results of the tolerance exercise test in healthy controls and patients with Scheuermann thoracic hyperkyphosis

	Exercise tolerance test		Mann−Whitney test	
	Healthy	Scheuermann		
Variables	Mean ± SD	Mean ± SD	Z	p
Cardiovascular				
HR basal	100.2 ± 13.2	112.8 ± 17.1	−2.831	0.005**
HR max	191.1 ± 8.5	186.8 ± 13.2	−2.070	0.038*
Syst. BP	113.7 ± 7.7	117.8 ± 11.5	−0.972	0.331
Syst. BP max	146.0 ± 13.2	153.0 ± 13.2	−2.101	0.036*
Sat O_2 basal	97.5 ± 0.8	97.4 ± 1.5	−0.359	0.720
Sat O_2 final	95.6 ± 1.6	93.9 ± 2.5	−2.593	0.009**
PuO_2, mL/min/bpm	15.2 ± 3.3	15.1 ± 4.9	−0.430	0.667
Metabolic				
VO_2 max mL	2883.0 ± 531.2	2820.1 ± 876.2	−0.592	0.554
VO_2 max/kg	49.9 ± 6.7	43.4 ± 11.3	−2.792	0.005**
VCO_2	2.9 ± 0.5	3.4 ± 1.1	−2.436	0.015*
R	1.10 ± 0.05	1.21 ± 0.08	−4.308	0.000**
Ventilatory				
FEV1	3.9 ± 0.8	4.3 ± 1.0	−1.560	0.119
VE	64.7 ± 8.9	67.2 ± 17.8	−1.521	0.128
VE/VCO_2	20.7 ± 2.4	19.5 ± 1.9	−2.444	0.015*
Efficiency				
VE/VO_2	22.9 ± 3.9	24.3 ± 3.2	−1.890	0.059
HR/VO_2	68.9 ± 15.7	74.2 ± 31.7	−0.430	0.667

SD, standard deviation; SE, standard error; HR, heart rate; BP, blood pressure; PuO_2, pulse of oxygen; VO_2 max, oxygen uptake at maximal exercise; VCO_2, carbon dioxide production; R, rate of gas exchange; VE, ventilation; VE/VCO_2, respiratory equivalent carbon dioxide; VE/VO_2, ventilatory efficiency; HR/VO_2, cardiovascular efficiency.

* $p<.05$.

** $p<.01$.

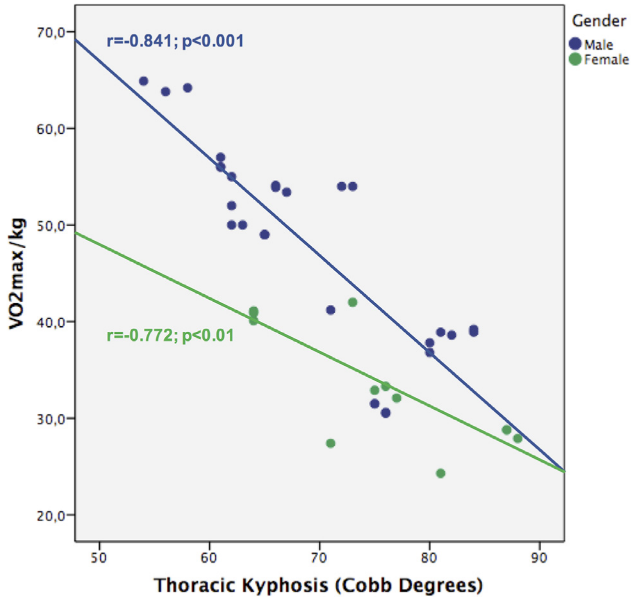

Fig. 1. Correlation between the increase in magnitude of the thoracic kyphosis and the deterioration of the maximal aerobic power in patients with Scheuermann thoracic hyperkyphosis.

ventilatory efficiency was considered using the VE/VO_2 ratio, both groups exhibited mean values that indicated an efficient ventilation pattern.

Table 4 displays the results of the exercise tolerance test in healthy controls and patients with Scheuermann kyphosis according to gender. Males with hyperkyphosis differed from healthy controls in some parameters: higher basal heart rates, higher BP at maximal exercise, greater VCO_2, VE/VO_2 ratios, and respiratory coefficients. Females with hyperkyphosis differed from their healthy counterparts in

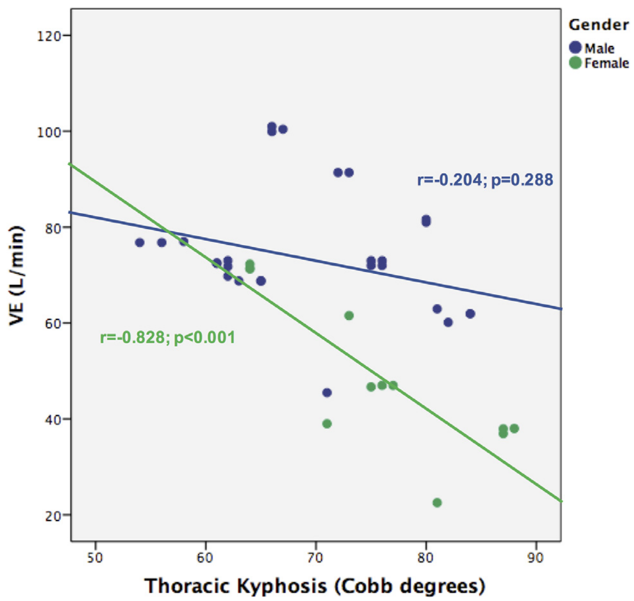

Fig. 2. Correlation between the increase in magnitude of the thoracic kyphosis and the ventilation at maximal exercise (VE) in patients with Scheuermann thoracic hyperkyphosis.

other parameters: lower HR, slightly higher $SatO_2$, and greater oxygen uptakes (all three at maximal exercise).

Analyzing cardiovascular, ventilatory, metabolic, and respiratory efficiency parameters by stratifying the sample of patients with Scheuermann kyphosis according to the magnitude of the hyperkyphosis revealed some interesting findings (Table 5). Patients with more severe hyperkyphosis (>75˚) were seriously disturbed in their cardiorespiratory function, showing a decline in O_2 saturation at maximal exercise compared to patients with less than 75˚ of kyphosis. The oxygen pulse was consequently decreased in these severe hyperkyphotic patients. VO_2max and VEmax were severely deteriorated in patients with more than 75˚ of kyphosis. Aerobic maximal power impairment was already present in cases with hyperkyphosis between 65˚ and 75˚ (VO_2max/kg: 44.5 ± 9.9 mL/kg/min) and was severe in cases with more than 75˚ of kyphosis (33.3 ± 5.0 mL/kg/min) (Kruskal−Wallis test, p<.001). Patients with more severe thoracic kyphosis also showed impairment in their cardiovascular efficiency as measured by the HR/VO_2 quotient (Table 5).

This deterioration in cardiorespiratory function in relation to the severity of the thoracic hypokyphosis resulted in a limited tolerance for the exercise test that was reflected in the duration of the exercise test and the energy cost measured in METS (metabolic equivalents of task). Fig. 3 shows the differences between healthy controls and the three groups of hyperkyphotic patients concerning these two parameters: duration of the exercise test and MET consumption. Both parameters showed statistically significant differences between groups according to a nonparametric Kruskal−Wallis test (Table 5).

Discussion

This study is the first to describe cardiorespiratory functional limitations in a relatively large series of adolescent patients with SK underdoing a maximal CPET. As has been shown in AIS patients, CPET has the ability to amplify the small restrictions of the respiratory function that are often undetectable at rest by conventional spirometry, and do not affect ventilatory capacity for daily activities [3]. During a maximal exercise tolerance test, the demands of pulmonary function are severely increased as physical work is intensified, becoming therefore clearly apparent the respiratory limitations. This is the value of CPET, a more refined method than basal spirometry to assess in more detail the respiratory function.

According to our results, SK patients do not exhibit pulmonary restrictions in baseline static conditions compared to age-matched healthy individuals. However, patients with severe hyperkyphosis (>75˚) showed respiratory intolerance to maximal exercise expressed by a lower aerobic power and shorter duration of the CPET compared to the healthy controls or patients with mild to moderate hyperkyphosis. This respiratory functional impairment was related

Table 4
Results of the tolerance exercise test according to gender in the two samples of individuals

	Males				Females			
	Healthy n = 12	Scheuermann n = 29	Mann−Whitney test		Healthy n = 8	Scheuermann n = 12	Mann−Whitney test	
Variables	Mean ± SD	Mean ± SD	Z	P	Mean ± SD	Mean ± SD	Z	p
Cardiovascular								
HR basal	112.6 ± 12.3	112.9 ± 18.9	−2.911	0.004**	110.2 ± 3.6	93.5 ± 13.2	−1.199	0.231
HR max	175.8 ± 7.0	191.4 ± 12.4	−1.191	0.234	198.0 ± 2.3	186.6 ± 8.1	−3.724	0.000**
Syst. BP	111.7 ± 7.5	120.3 ± 11.9	−1.286	0.199	113.1 ± 9.2	114.2 ± 7.0	−0.355	0.723
Syst. BP max	138.3 ± 7.8	159.1 ± 9.7	−2.626	0.009**	143.1 ± 10.3	147.9 ± 14.9	−1.058	0.290
Sat O_2 basal	96.7 ± 2.2	97.7 ± 1.0	−1.409	0.159	97.9 ± 0.6	97.3 ± 0.9	−1.326	0.185
Sat O_2 final	92.0 ± 2.2	94.7 ± 2.3	−1.539	0.124	95.4 ± 1.68	95.8 ± 1.5	−2.800	0.005**
PuO_2, mL/min/bpm	16.8 ± 4.6	17.1 ± 2.6	−1.003	0.316	12.4 ± 3.0	15.1 ± 4.9	−1.003	0.316
Metabolic								
VO_2 max mL	1940 ± 564	3184 ± 709	−0.774	0.439	2448 ± 361	3173 ± 417	−2.122	0.034*
VO_2 max/kg	33.3 ± 6.2	47.6 ± 10.3	−1.491	0.136	44.6 ± 2.3	53.5 ± 6.3	−3.474	0.001**
VCO_2	2.2 ± 0.6	3.8 ± 0.8	−3.671	0.000**	2.6 ± 0.2	3.2 ± 0.4	−1.506	0.132
R	1.19 ± 0.07	1.21 ± 0.08	−3.776	0.000**	1.12 ± 0.04	1.09 ± 0.05	−1.897	0.058
Ventilatory								
FEV1	3.3 ± 0.7	4.8 ± 0.7	−1.922	0.055	3.8 ± 0.2	4.1 ± 1.0	−1.312	0.190
VE	49.3 ± 16.3	74.7 ± 12.5	−1.750	0.080	57.2 ± 5.6	69.7 ± 6.9	−1.390	0.165
VE/VCO_2	20.9 ± 1.7	18.9 ± 1.7	−1.319	0.187	22.2 ± 1.6	19.8 ± 2.5	−1.471	0.141
Efficiency								
VE/VO_2	22.2 ± 2.6	23.8 ± 2.6	−2.178	0.029*	24.3 ± 3.2	25.7 ± 4.2	−0.694	0.487
HR/VO_2	59.9 ± 10.4	63.0 ± 14.7	−1.003	0.316	82.5 ± 12.3	101.3 ± 44.6	−1.003	0.316

SD, standard deviation; SE, standard error; HR, heart rate; BP, blood pressure; PuO_2, pulse of oxygen; VO_2 max, oxygen uptake at maximal exercise; VCO_2, carbon dioxide production; R, rate of gas exchange; VE, ventilation; VE/VCO_2, respiratory equivalent carbon dioxide; VE/VO_2: ventilatory efficiency; HR/VO_2, cardiovascular efficiency.

* p<.05.

** p<.01.

Table 5
Parameters of the tolerance exercise test showing relevant changes according to the severity of the hyperkyphosis

		Scheuermann (Maximal thoracic kyphosis)				
	Normokyphotic n = 20	<65° n = 13	65°−75° n = 14	>75° n = 14	Kruskal−Wallis test	
Variables	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Chi-square	p
Exercise efficiency						
Exercise test duration (min)	11.3 ± 2.3	10.9 ± 1.2	10.2 ± 1.4	8.9 ± 0.5**,‡	20.775	0.001
METS (1 = 3.5 mL O_2/kg/min)	13.9 ± 1.8	15.3 ± 2.2	12.7 ± 2.8	9.6 ± 1.4**,‡	29.365	0.001
Cardiovascular						
Decrease in Sat O_2	1.9 ± 1.4	2.5 ± 2.9	3.6 ± 1.9	4.2 ± 2.3	10.023	0.018
PuO_2, mL/min/bpm	15.2 ± 3.2	15.8 ± 1.6	17.5 ± 6.6	12.1 ± 3.5*,‡	9.850	0.020
Metabolic						
VO_2 max/kg	49.9 ± 6.7	53.1 ± 8.6	44.5 ± 9.9	33.3 ± 5.0**,‡	29.257	0.001
Ventilatory						
FEV1	4.1 ± 0.6	4.7 ± 0.4	4.6 ± 1.3	3.6 ± 0.8*,‡	14.161	0.003
VE	64.7 ± 8.9	72.8 ± 2.5	73.4 ± 20.9	56.0 ± 18.1*,†	12.800	0.005
Efficiency						
HR/VO_2	68.9 ± 15.6	63.7 ± 6.5	65.0 ± 25.0	93.1 ± 43.0*,‡	9.850	0.020

SD, standard deviation; METS, Metabolic equivalents of tasks; PuO_2, pulse of oxygen; VO_2 max, oxygen uptake at maximal exercise; VE, ventilation; HR/VO_2, cardiovascular efficiency.

Comparing to the subgroup of hyperkyphosis 65°−75°:

Comparing to the subgroup of hyperkyphosis <75°:

* p<.05.

** p<.01.

† p<.05.

‡ p<.01.

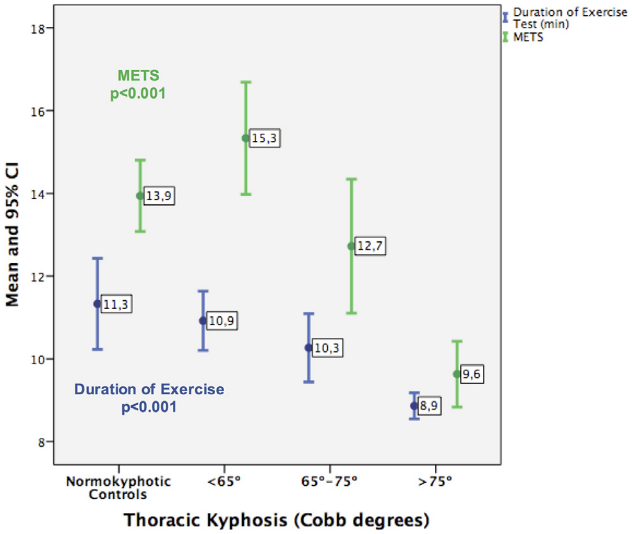

Fig. 3. Duration of the exercise test and the required metabolic equivalents of task (METS; 1 = 3.5 mL O_2/kg/min) in healthy controls and patients with Scheuermann disease stratified according to the magnitude of the hyperkyphosis.

to ventilatory restriction and inefficiency at maximal exercise.

The pulmonary function in patients with SK has been poorly studied. To our knowledge, there are only two previous reports describing the impact of Scheuermann hyperkyphosis on pulmonary function [5,7]. Researchers in both studies analyzed pulmonary function with basal spirometry and found restrictive lung disease in adult patients with kyphosis greater than 90°. Both studies also showed that the percentage of patients with moderate to severe functional respiratory impairment was higher at higher ranges of kyphosis magnitude. Using a slightly different stratification range, our findings confirm the previous results of Murray et al. [5] and Abbi et al. [7] concerning the deterioration of pulmonary volume in SK with severe curves (>75°). Regarding functional respiratory deterioration, there were no cases of severe impairment (<50% of predicted FEV1) in our series.

Few previous studies have evaluated the effects of hyperkyphosis on airway restriction, and most of those that have focus on the osteoporotic older spine, particularly in women [16−18]. In these osteoporosis-related kyphotic patients, pulmonary compromise was associated with multiple factors, including kyphosis angle, level of the kyphosis apex, and number of involved vertebrae. In the Harrisson et al. [19] series, pulmonary function was significantly compromised when kyphosis angle was greater than 55°. Even in congenital kyphosis and/or kyphoscoliosis, more than half of the investigated patients exhibited different grades of respiratory function compromise [20]. In these cases, the severity of respiratory impairment was associated with the degree of kyphosis.

Considering only baseline respiratory parameters, some of our Scheuermann patients with light or moderate curves (<75°) had higher average values than did healthy controls for some pulmonary function parameters. In other words, slightly or moderately hyperkyphotic patients with Scheuermann kyphosis showed normal or above-normal expected values in their respiratory function. A feasible explanation for this finding is the increased longitudinal dimension of the thorax in nonsevere hyperkyphosis, which could be responsible for a functional increase in chest volume. This finding is also in accordance with our baseline data, in which compared to control subjects, patients with less than 75° kyphosis disclosed an average increase of 422 mL in FVC.

Ventilatory restrictions during maximal exercise at different stages of thoracic kyphosis in adolescent patients have not been described so far. In our series, 18 of the 41 patients with SK (43.9%) had VO_2max scores below the 40 to 50 mL/kg/min range, which is the expected result for adolescents who are not engaged in regular aerobic training [21]. In 12 patients, the VO_2max values were below 35 mL/kg/min, indicating an extremely low tolerance to exercise that was related to a greater magnitude of kyphotic curvature. Furthermore, the VEmax scores of 9 Scheuermann cases (22%) were below the expected values for healthy adolescents (range, 50−90 L), indicating ventilatory limitation at maximal exercise.

According to our findings, there is a relationship between the magnitude of thoracic kyphosis and both aerobic capacity and ventilation. VO_2max values decrease as hyperkyphosis increases. The decrease in VO_2max was evident in the two groups with moderate and severe hyperkyphosis, the latter showing extremely low VO_2max values. In addition, VEmax exhibited a correlation with the magnitude of hyperkyphosis, also showing an increase in the slight and moderate hyperkyphosis groups compared to healthy controls and greatly decreasing in hyperkyphotic cases with more than 75°. These findings are in accordance with the inverse correlation observed in the current study between the magnitude of the hyperkyphosis and the basal FEV1 (r: −0.506; p<.001), reflecting the restrictive influence that hyperkyphosis has on ventilatory mechanisms.

In severe hyperkyphotic patients with SK, restrictive ventilatory impairment due to a reduced thoracic volume is a probable mechanism for explaining the effect of increasing kyphosis severity on declining pulmonary function. Katzman et al. [22] found that men with worse kyphosis have a lower spinal muscle density than men with less thoracic curvature. Both excessive kyphosis and muscle weakness may disrupt the thoracic cage mechanics and lead to reduced lung function. In brief, mechanical limitations on the respiratory system imposed by hyperkyphosis, such as reduced inspiratory muscle strength and abnormal shape and movement of the rib cage, could explain these ventilation abnormalities during exercise. The overall structural stiffness of the chest cage and the spine imposed by the SK may contribute to the mechanical inefficiency and impairment of pulmonary function found in these patients.

The role of the diaphragm in the respiratory function has been considered of crucial importance [23]. The hyperkyphotic thoracic deformity of patients with SK could increase the abdominal pressure, limiting therefore the functionality of the diaphragm, that is, impairing its ability to expand the lower rib cage. This mechanism has been previously analyzed in patients with hyperkyphosis in which inspiratory muscle strength was clearly reduced [24]. However, no correlation was found between inspiratory muscle function and spine deformity. In any case, the dysfunction of the diaphragm could be considered, at least, an additional factor behind the respiratory functional restriction detected in this group of patients.

In young patients, severe kyphosis may not only compress the lungs, which directly leads to restrictive ventilation function, but can also affect the development of alveoli and capillary vessels, which further affects oxygenation. Furthermore, over time, it has been observed that patients with thoracic hyperkyphosis are prone to experience multiple episodes of acute respiratory failure or chronic respiratory failure requiring prolonged ventilatory support [25,26]. Recently, data regarding respiratory events requiring hospitalization and poor prognosis have been reported in patients with thoracic hyperkyphosis who did not undergo corrective surgery [27]. Since the severity of the kyphosis angle was correlated with respiratory insufficiency, surgical correction may be desirable and therefore indicated in young patients to prevent respiratory impairment due to severe curve progression. However, this was not investigated in the current study.

This study has some limitations that include the limited number of Scheuermann patients with severe hyperkyphosis ($>75^\circ$). This series may therefore underrepresent individuals with the most severe kyphosis and/or pulmonary restrictions. A second limitation is the variability of measuring pulmonary function accurately during a maximal exercise tolerance test. This limitation is inherent to all studies measuring oxygen uptake at maximal exercise. A third limitation is that the diaphragmatic function was not analyzed. The thoracic vertebral disposition of patients with SK could increase the abdominal pressure on the diaphragm, limiting its functionality. This mechanism could be considered at least as an additional factor behind the respiratory restriction presented by this group of patients. However, the evaluation of the diaphragm function requires, at least, semi-invasive technology. Finally, the Scheuermann patients were slightly taller than the control patients but also slightly older (6 months). At these ages, small differences in age (only a few months) can explain small differences in height but not in respiratory function.

In summary, these results indicate that patients with mild or moderate hyperkyphosis do not exhibit baseline pulmonary restrictions, and they have a similar tolerance to maximal exercise as healthy controls have. Most patients with more severe hyperkyphosis ($>75^\circ$) show baseline respiratory limitations and, subsequently, intolerance to maximal exercise as expressed by reduced aerobic power and a shorter duration of the exercise test, both of which are related to ventilatory restriction and respiratory inefficiency at maximal exercise. Maximal oxygen uptake and ventilation parameters are strongly related to the magnitude of the thoracic kyphosis, with higher restrictions in curves surpassing 75° Cobb.

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DEFORMITY

Cardiorespiratory Function Does Not Improve 2 Years After Posterior Surgical Correction of Adolescent Idiopathic Scoliosis

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Study Design. A prospective evaluation of cardiorespiratory function following spinal fusion in adolescent idiopathic scoliosis (AIS).

Objective. To evaluate the cardiopulmonary function during exercise in patients with severe AIS, before and 2 years after undergoing a posterior spinal fusion.

Summary of Background Data. After surgical correction of scoliosis, a greater cardiorespiratory adaptation to exercise would be expected from correction of the rib cage associated with the spine deformity. However, there is no clear evidence regarding whether tolerance to maximum exercise improves in the medium term after surgery in patients with severe curves.

Methods. We include patients with AIS proposed for posterior surgical correction aging between 12 and 17 years. Every patient had a Cobb angle >45° and a Lenke type 1A scoliosis. Cardiac and respiratory functional measures, such as heart rate and blood pressure, maximum oxygen consumption (VO_2max), eliminated volume of carbon dioxide (VCO_2), quotient between ventilation and volume of exhaled carbon dioxide (VE/CO_2), respiratory exchange rate, ventilatory capacity at maximal exercise (VEmax), were recorded before and 2 years after surgery.

Results. Twenty patients were included in our study, 15 girls and 5 boys, with an average age of 13 years. The main scoliotic curve was corrected in the coronal plane in an average of 71.9%. The maximal aerobic power expressed by body weight normalized VO_2max was found preoperatively to have an average of 30.9 ± 6.2 mL/kg/minute, indicating a poor aerobic capacity, which did not improve at final follow-up, decreasing to a mean value of 29.3 ± 5.7 but without statistical significance. However, the percentages of curve correction showed a statistically significant correlation with VO_2max ($r = 0.534$; $P < 0.05$).

Conclusion. Patients with severe adolescent idiopathic scoliosis Lenke type 1A showed limited cardiorespiratory tolerance to maximum exercise that did not improve 2 years after surgery.

Key words: adolescent idiopathic scoliosis, exercise limitation, exercise tolerance test, lung function, maximal oxygen uptake, ventilatory efficiency.

Level of Evidence: 3

Spine 2017;42:1391–1397

Adolescent idiopathic scoliosis (AIS) accounts for 80% of the types of scoliosis and is clearly more common in girls.[1,2] Adolescents with Cobb angles above 40° that do not respond or cannot tolerate bracing or those with curves greater than 45° are routinely managed with spinal fusion surgery.[3]

The distortion of the rib cage associated with vertebral deformity contributes to altered ventilatory mechanics and decreased exercise capacity of patients with AIS.[4] The reduced work capacity in patients with AIS could be related to reduced ventilator capacity, reduced muscularity, and cardiovascular deconditioning.[5] Barrios *et al*[6] have shown that patients with mild and moderate scoliosis have a limited exercise tolerance with reduced ventilatory efficiency and maximal oxygen up-take.

It is known that surgery treatment can stop progression of the deformity, improve curve correction, and achieve a better rib cage realignment, improving physical appearance.[7] However, the surgical benefits for cardiorespiratory function have not been clarified. The influence of posterior spinal fusion on pulmonary function in patients with AIS has been the subject of various studies. Some studies shown

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improvement,[8,9] while other did not show any improvement on pulmonary function after spinal fusion.[10,11]

The purpose of this study is to evaluate the cardiac and pulmonary function, during exercise, in patients with severe AIS, before and after undergoing posterior spinal fusion.

MATERIALS AND METHODS

Patient Inclusion Criteria

We performed a prospective study including consecutive patients with adolescent idiopathic scoliosis with more than 45 Cobb degrees proposed for posterior surgical correction and aging between 12 and 17 years. A radiologist, who had no contact with any patient, measured all Cobb angles, kyphosis angles, and apical vertebra rotation using a Perdriolle torque meter for patients on standing, anteroposterior and lateral radiographs of the spine. To homogenize the sample, we included only Lenke type 1A scoliosis.

Patients without indication for surgical treatment or who have undergone prior spine surgery were excluded from our study. All the patients signed informed consents. Every patient was subjected to a standard physical examination by the same pediatrician and a baseline 12-lead electrocardiogram was performed to exclude any respiratory or cardiac dysfunction, according to standardized guidelines.[12] Weight and height of the patients were also recorded. Patients who performed more than 2 to 3 hours per week of sports activity as part of their school education were also excluded. Preoperatively, every patient had preoperative blood tests, spine radiographs, spine magnetic resonance imaging, and cardiorespiratory functional tests.

Exercise Tolerance Test

Preoperative and postoperative exercise tolerance test (ETT) were conducted using a Schiller Cardiovit CS-200 ergospirometer (Baar; Switzerland) which allowed measurement of both spirometric static parameters and cardiorespiratory functional parameters. Baseline pulmonary function was measured on the same day, immediately before realization of the effort test. As a spirometric static parameter, only forced expiratory volume in one second (FEV1) was recorded.

The exercise test was conducted under conditions similar to previous studies,[6] with a standard Bruce protocol[13] for each of the patients and using a motorized treadmill adapted to the ergometer to take measurements during the test. The ergometer was calibrated precisely at regular intervals. Standard conditions of temperature, humidity, and atmospheric pressure were maintained according to normalized guidelines.[12] Continuous 8-lead electrocardiogram monitoring was used during exercise. The study protocol began with a 5-minute warm-up period at a speed of 0.75 m/s (2.7 km/hr). Subsequently, increments of 0.2 m/s (0.72 km/hr) per minute were introduced. The slope of the treadmill was constantly maintained at 1.5%, resembling the normal resistance of air. During the exercise, patients went from walking to running by themselves. The validity and reproducibility of the Bruce test has been universally accepted.[12,13]

Three types of variables reflecting the cardiovascular function, the ventilatory capacity, and the metabolic gas exchange were measured during the ETT. The definition of all these parameters is summarized in Table 1. Cardiovascular function was assessed by recording the heart rate (HR), blood pressure (BP), and oxygen saturation ($SatO_2$) at the beginning and at the end of the test. The metabolic gas exchange and ventilatory parameters were measured ‘‘breath by breath’’ using a respiratory valve and face mask (Hans Rudolph, Inc, Kansas City, MO), through the Schiller gas analyzer (Baar, Switzerland). Since ventilation reflects the balance between optimization of the mechanics of breathing and maintenance of gas exchange, the interrelationship of some of these parameters expressed a fourth group of variables indicating the ventilatory and cardiovascular efficiency: VE/VO2 ratio, HR/VO2, and the breathing reserve (BR) (Table 1).

Surgery and Postoperative Protocol

Between 8 and 12 weeks after the effort test, the patients underwent surgery. The same surgical team executed all surgeries by performing an instrumented posterior fusion with an all pedicle screw construct. Nine patients required T4-L2 instrumentations, five patients had T3-L2 instrumentations, and six patients benefitted from T3-L1 instrumentations All surgeries were performed using continuous neurophysiological monitoring and electromyography (EMG). We had one postoperative complication because of screw misplacement that required revision.

Each patient was discouraged from practicing strenuous physical activities during the first 6 months and contact sports for up to 12 months. There was not any sport-training program designed for the patients. Between 18 and 24 months after surgery, physical examination, radiological measurements, and a new cardiopulmonary functional test were performed.

Statistical Analysis

Sample size was estimated to detect a difference between two means using VO_2max as the most pertinent variable. A difference greater than 5 mL/min/kg was considered clinically relevant. To have 80% power to detect, and assuming a variance of 32 mL and a 0.050 two-sided significance level, the required sample size was 19 patients. Statistical analysis was performed using the SPSS 21.0 statistical package (IBM, Chicago, IL). The Kolmogorov–Smirnov test confirmed the abnormal distribution of some of the variables. This fact, together with the sample size, required the use of the nonparametric Wilcoxon Rank Test to compare the quantitative variables before and after surgery. The Z value was calculated. The correlation between curve correction and improvement of cardiopulmonary function during exercise was analyzed.

The probability level (P value) was considered statistically significant for values <0.05.

TABLE 1. Definition of the Key Cardio-Respiratory Parameters Assessed in This Study

Parameters	Definition
Cardiovascular	
HR (bpm)	Heart rate
Syst. BP (mm Hg)	Systolic blood pressure
Sat O_2 (%)	Pulse oximetry (% O_2 saturation): 90% indicative of diminished ability to adequately increase alveolar-pulmonary capillary oxygen transfer during exercise
PuO2, mL/bpm	Oxygen pulse: refers to the volume of oxygen taken up by the pulmonary blood per heartbeat. The oxygen pulse can be used as an alternate measure for stroke volume. The normal value depends on the size of the subject but can range between 8 and 18 mL O_2/heart beat
Metabolic	
VO_2 max (mL/min)	Maximal oxygen uptake: characterizes the ability of exercising muscle to extract oxygen. A low VO_2max suggests cardiac or pulmonary impairment, or deconditioning
VO_2 max/kg	Maximal oxygen uptake in relation to body weight. This is the measure of aerobic capacity; normal values are influenced by age, sex, and physical condition
VCO_2 (mL/min)	Carbon dioxide output: level of CO_2 in the air exhaled from the body. Reduced values are consistent with worsening cardiac or pulmonary disease severity
RER (VCO_2/VO_2)	Respiratory exchange rate: the quotient of exhaled CO_2 to inhaled O_2. It provides a means to quantify subject effort during ETT. An RER = 1.00 indicates good effort and RER >1.10 indicates excellent effort
Ventilatory	
FEV1 (% of predicted)	Maximal amount of air forcefully exhaled in 1 s. Based on height, weight, and race, FEC1 is converted to a percentage of normal. FEV1 is one of the most common indices used to assess airway obstruction (if <80%)
VE max (L/min)	Ventilation capacity at maximal exercise. Peak VE can help to determine if exercise intolerance or dyspnea relate to a pulmonary limitation
Efficiency	
VE/VCO_2	Ventilatory equivalents for carbon dioxide. Quotient between minute ventilation and expelled volume of CO2. This is a measure of ventilatory efficiency. The normal value is around 25–30 at the start of exercise and increases once the person reaches their ventilatory threshold. Abnormally high values are a marker of inefficient ventilation. Because VE and VCO2 both have the same units (L/min), the term VE/VCO2 has no units
VE/VO_2	Ventilatory equivalents for oxygen. It refers to the number of liters of ventilation per liter of oxygen consumed. The normal value is typically around 25–30 and increases once the person reaches their ventilatory threshold. High values are a marker of inefficient ventilation, and are a marker of poor gas exchange
BR (VE/FEV1 $\times$ 40)	Breathing reserve: this term refers to the difference between the maximum minute ventilation reached by the subject at peak exercise and their maximum voluntary ventilation. The VE/FEV1 $\times$ 40 ratio is normally 0.70 (and consistent with the premise that the pulmonary system is not limiting the exercise capacity); a ratio >0.80 suggests pulmonary limitation

ETT indicates exercise tolerance test; HR, heart rate; RER, respiratory exchange ratio.

RESULTS

Patients Profile

A total of 23 patients were included in the study. Three patients were excluded; one for having asthma and two did not perform the functional test as required. Thus, the final sample was composed of 20 patients, 15 girls and 5 boys, with an average age of 13 years.

Table 2 shows the anthropometric characteristics of the sample and the severity of the scoliotic curves before surgery and 2 years after surgery. Statistically significant differences were not found in weight or BMI before and after the surgery. Every scoliotic angle was improved 2 years after surgery with statistical significance according to the Wilcoxon Rank Test. The main scoliotic curve was corrected in the coronal plane in an average of 71.9%. The T5-T12 sagittal angle increased from $25^\circ \pm 6^\circ$ to $30^\circ \pm 6^\circ$ Cobb, a rate improvement of 18.8%. The vertebral axial rotation showed an average correction of 55.3%.

Exercise Tolerance Test

Table 3 discloses the cardiac, metabolic, and ventilator results. Regarding cardiovascular parameters, there were no significant differences between the two exercise tests with respect to basal and maximum heart rates as well as basal and maximal systolic blood pressures.

The maximal aerobic power expressed by body weight normalized VO_2max was found preoperatively to have a median of 31.3 ($\pm$ 6.2 IQR) mL/kg/min (95% CI: 28.5–33.5), decreasing by an average of 8.7% to a median value of 28.9 ($\pm$ 7.2 IQR) mL/kg/min (95% CI: 26.6–31.9) in the 2-year follow-up examination. Thirteen patients (65%) showed a negative change in VO_2max (L/kg/min) in the 2-year test compared with the preoperative value (Figure 1). The ventilatory capacity at maximal exercise measured by VE

TABLE 2. Demographic, Anthropometric, and Cobb Angle Values Assessed in the Participants by the Two ETTs

	Exercise Tolerance Test		Wilcoxon Rank Test	
	Preoperative Median ± IQR	2-Year Follow-Up Median ± IQR	*Z*	*P*
Age (yr)	13 ± 2	15 ± 1.7	−3.999	0.000†
Weight (kg)	48.5 ± 11.2	52.5 ± 13.2	−1.916	0.055
Height (cm)	155 ± 11.7	161.5 ± 12.5	−2.008	0.045*
BMI (kg/m^2)	20.2 ± 2.5	20.5 ± 3.1	−0.859	0.391
Curve severity (Cobb)	59 ± 9.2	17 ± 3	−3.922	0.000†
T5-T12	26 ± 5.2	31 ± 4.7	−2.103	0.035*
Axial rotation	20 ± 3.7	9 ± 3.7	−2.617	0.015*

**P* < 0.05.
†*P* < 0.01.
ETT indicates exercise tolerance test; IQR, interquartile range.

max was extremely low in most cases, both preoperatively and 2 years after surgery. In the first ETT, the VE max scores ranged from 28 to 62 L/min with a median value of 42.5 L/min (± 18 IQR). Only two cases (10%) exhibited VE values >60 L/min, considered the lower limit of normality.[14,15]

When ventilatory efficiency was considered using the VE/VO_2 ratio, these scoliotic patients exhibited a median value of 28.7 (± 8.2 IQR) (95% CI: 25.8–31.0) in the preoperative test, indicating poor but efficient ventilation. At the 2-year follow-up, the VE/VO_2 ratio changed to a median of 31.4 (± 5.9 IQR) (95% CI: 29.6–33.4), reflecting a slight but statistically significant worsening in the efficiency of ventilation (Z: −2.837; $P < 0.05$). The increased ventilatory inefficiency, together with lower VO_2max, may be

TABLE 3. Results of the Tolerance Exercise Test, Before and 2 Years After Surgical Correction of the Scoliosis

	Exercise Tolerance Test		Wilcoxon Rank test	
Variables	Preoperative Median ± IQR	2-Year Follow-Up Median ± IQR	*Z*	*P*
Cardiovascular				
HR basal (bpm)	104 ± 24	100 ± 27	−0.037	0.970
HR max (bpm)	172.5 ± 19	165 ± 23.5	−0.081	0.936
Syst. BP (mm Hg)	115 ± 13.7	110 ± 5	−0.548	0.584
Syst. BP max (mm Hg)	140 ± 10	140 ± 21.2	−0.608	0.543
Sat O_2 initial (%)	97 ± 2.7	96.5 ± 3	−1.434	0.152
Sat O_2 final (%)	96 ± 4	95 ± 4.7	−2.422	0.015*
PuO2, mL/bpm	9.1 ± 2.8	9.9 ± 3.3	−0.112	0.911
Metabolic				
VO_2 max (mL/min)	1530 ± 350	1675 ± 560	−0.355	0.723
VO2 max/kg	31.3 ± 9.5	28.9 ± 7.2	−0.896	0.370
VCO_2 (mL/min)	1660 ± 290	1890 ± 730	−1.329	0.184
RER (VCO_2/VO_2)	1.1 ± 0.2	1.2 ± 0.1	−2.092	0.036*
Ventilatory				
FEV1 (% of predicted)	1.2 ± 1.1	1.6 ± 1	−0.355	0.723
VE (L/min)	42.5 ± 18	50.5 ± 14.5	−1.581	0.114
Efficiency				
vVE/VCO_2	25.2 ± 6.2	23.2 ± 6.3	−1.195	0.232
VE/VO_2	28.7 ± 8.2	31.4 ± 5.9	−2.837	0.005†
BR (VE/FEV1 × 40)	0.76 ± 0.7	0.78 ± 0.6	−0.784	0.433

**P* < 0.05.
†*P* < 0.01.
BP indicates blood pressure; bpm, beats per minute; BR, breathing reserve; HR, heart rate; IQR, interquartile range; L/min: liters per minute; mm Hg, millimeters of mercury; Pu02, pulse of oxygen; RER, respiratory exchange ratio; Sat O_2, saturation O_2; VC02, carbon dioxide output; VE, ventilation; VE/VCO_2, expiratory volume and carbon dioxide output ratio; VE/VO2, ventilatory efficiency; VO2 max, oxygen uptake at maximal exercise; % of predicted, percentage of predicted FEV1 according to age, sex, height, mass and ethnicity.

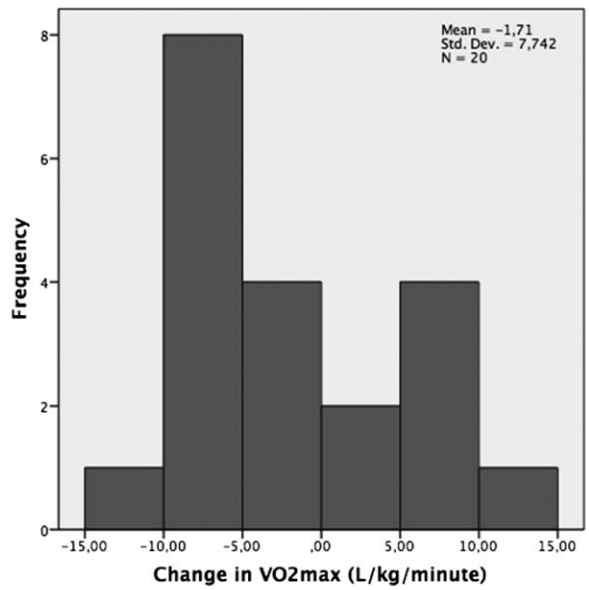

Figure 1. Changes in the VO2max (L/kg/min) in the 2-year test compared with the preoperative examination.

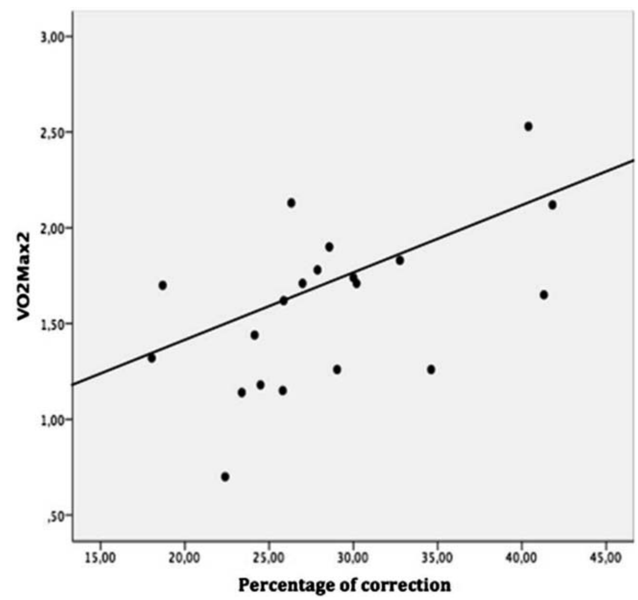

Figure 2. Correlation between oxygen consumption at maximum effort (L/min) and the percentage of curve correction 2 years after surgery ($r = 0.547$; $P < 0.05$).

responsible for reduced tolerance to exercise in AIS patients undergoing surgical correction of the deformity.

The percentages of curve correction 2 years after surgery showed a statistically significant correlation with VO_2max ($r = 0.534$; $P < 0.05$). The higher the percentages of curve correction the higher VO_2max (Figure 2).

DISCUSSION

Most research concerning improvement of the pulmonary function in patients with idiopathic scoliosis undergoing surgical correction of the deformity is based on the evaluation forced vital capacity and total lung capacity and FEV1.[8,9,16–20] For many years, these tests provided relevant insights into the interactions of spine deformity and pulmonary function.[6,21–24]

The use of ETTs, which more precisely detect the true functional capacity of individuals in daily life activities requiring physical effort, is becoming common for assessing the cardiopulmonary function in these patients. Barrios *et al*[6] showed that the limitation of cardiorespiratory function in mild to moderate AIS is only apparent and measurable during incremental progressive exercise, but not at rest. Recently, Sperandio *et al*[4] reported similar functional exercise limitations during a walking-based aerobic exercise test in AIS patients. The reduced peak VE and VO_2max observed in that study was attributed in part to restrictive ventilatory disorders of patients with AIS. The authors suggested that the decrease in functional exercise capacity in patients with AIS might be related to cardiovascular deconditioning and/or peripheral muscle dysfunction. These findings were also reported by other authors.[4,6,11,23,25]

Although scoliosis is a three-dimensional deformity affecting the thoracic cage, there is no consensus regarding the possible relationship between respiratory function and AIS severity. In resting conditions, Kearon *et al*[5] did not find a correlation between pulmonary function and spinal structural factors such as severity of scoliosis, number of vertebrae involved, cephalic location of the curve, spinal column rotation, and loss of normal thoracic kyphosis. However, other authors showed that the main thoracic Cobb angle is the best predictor of impaired lung function in patients with AIS.[26] Analyzing basal ventilatory parameters, Barrios *et al*[6] observed that the magnitude of thoracic axial rotation showed an inverse correlation with the FEV1/FVC ratio, suggesting that chest rotation may have a restrictive influence on air expiration. Thus, the association between spinal deformity and pulmonary impairment is still unclear. When ventilatory efficiency was analyzed during an ETT instead of resting examinations, patients with more severe curves had greater limitations of ventilatory capacity.[4,6,11]

Apart from the potential deconditioning of AIS patients, a recent study demonstrated that young patients with AIS involving pronounced spinal deformity have generalized skeletal muscle weakness and exercise limitation, even in the absence of major ventilatory defects.[25] In that study, most of the patients with AIS (83%) had respiratory muscle dysfunction characterized by reduced maximal inspiratory and expiratory pressures generated at the mouth during maximal efforts. The authors concluded that the causes of this muscle function impairment still remain obscure, but their data strongly suggest that they are related to systemic factors. Notably, the authors did not detect any significant correlations between respiratory muscle function and the severity of the spinal deformity.

Considering the three-dimensional character of the scoliotic deformity and the poor and inefficient ventilation that AIS patients exhibited during maximal exercise, it could be hypothesized that surgical correction might benefit respiratory function in these cases because of chest cage realignment, spinal derotation, ribs opening at the concavity, and subsequent enlargement of lung volumes.[19] However, potential changes in metabolic and ventilatory efficiency following surgery have been scarcely investigated.[4,6,11] Some of these studies, using indirect measures of oxygen up-take and few ventilatory parameters during exercise test, revealed that the majority of patients with AIS undergoing spinal fusion did not improve their postoperative ventilatory efficiency,[11] which is corroborated by our study. The maximal aerobic power expressed by body weight normalized VO_2max was found preoperatively to have a median value of 31.2 mL/kg/min, indicating a poor aerobic capacity.[13,14,27] In these AIS cases, maximal oxygen uptake did not improve in the 2-year follow-up examination. These patients with scoliotic curves requiring surgery exhibited even lower aerobic capacity than AIS girls with moderated curves treated only by conservative treatment, and much lower than age-matched healthy adolescents who followed the same VO2max evaluation protocol.[6] As proposed by Lindh[10] the decrease in VO_2max could be related to an increase in vital capacity. We did not measure the vital capacity, so we cannot establish this correlation. Lenke *et al*[11] also found a decrease maximum oxygen consumption (VO_2max) in patients with AIS 2 years after a spinal fusion. Additionally, we verified that patients with more percentage of deformity correction showed a higher VO_2max and better VE/VCO_2 coefficient, which could indicate better pulmonary function. This last result does not have statistical significance.

Medoff *et al*[28] demonstrated the utility of the breathing reserve (VE/FEV1 × 40) in discriminating a ventilatory limitation to exercise in very different populations of patients with respiratory disorders or cardiac disease and even in healthy subjects. In the current study, breathing reserve also showed utility in AIS patients, in which exercise limitation is due to unknown underlying mechanisms. In the current series, 11 of the 20 AIS patients (55%) showed a breathing reserve higher than 0.80 at maximal effort, a value that has been considered the upper level for people having no ventilatory limitations. These 11 cases did not change their breathing reserve coefficient 2 years after surgery, remaining above 0.80, which indicates that most AIS patients had a true pulmonary dysfunction limiting exercise.

The fact that our patients did not improve after surgery in most of the functional respiratory parameters may be explained by an additional lack of cardiovascular conditioning. This lack of improvement may be justified by the absence of a rehabilitation protocol after surgery that would improve cardiorespiratory fitness parameters. Moreover, dos Santos Alves *et al*[29] described the benefits of rehabilitation therapy conducted for 4 months prior to surgery. Patients who followed the protocol of functional rehabilitation improved certain cardiorespiratory parameters (heart rate, blood pressure, oxygen saturation, and walk distance) compared with patients who did not receive such therapy. However, the curves of the patients were inhomogeneous.

There are a number of potential limitations to this study, most relating particularly to the definition of thresholds used. Some patients could not exercise to a maximum level. Four patients had R coefficients between 0.96 and 0.99 in the preoperative ETT, indicating that the test was not strictly maximal. However, all four cases performed a clearly maximal postoperative test (R ranging from 1.01 to 1.21). This was the reason for not eliminating them. If *R* value would have played an important role, this would be in favor of better results in the postoperative test, and these were not the findings. All four patients showed a decreased VO2max in the ETT after surgery. A second controversial point is the criteria used for defining a ventilatory limitation to exercise. Among exercise physiologists, there is not a well-accepted criterion to establish the upper limit of breathing reserve at maximal exercise considered as normal. Although a widely used breathing reserve cutoff is 0.70,[28,30] we were not as restrictive and fixed the cutoff at 0.80. Other methods of determining an exercise ventilatory limitation have been studied but have not been standardized.[31] In any case, this study provides a means to identify AIS patients who have a ventilatory limitation to exercise. Finally, as statistical limitation, the sample size was calculated using the VO2max as a reference parameter. This number 19 could not be high enough for the other parameters used in the study.

In summary, patients with severe AIS before surgery show a limited tolerance to maximal cardiorespiratory exercise that remains essentially unchanged 2 years after surgical correction. The percentages of curve correction 2 years after surgery showed a statistically significant correlation with the oxygen uptake measured by VO_2max. However, no conclusion can be drawn from this data because of the small sample size. This correlation will need further evaluation in a study with a larger sample. Most of the AIS patients showed a clear exercise ventilatory limitation as measured by the breathing reserve coefficient. These findings suggest that the reduced cardiopulmonary function during maximal exercise is not strictly associated with spinal deformity and can be due to other factors: ventilatory limitation may be related to the recently suggested muscle weakness or lack of fitness of these patients. The introduction of measures to improve exercise tolerance in AIS patients before and after surgery by an aerobic training program appears to be highly desirable. Finally, the improvement in aerobic capacity cannot be ruled as an indication for surgery in AIS patients.

➢ Key Points

- ❑ Patients with mild and moderate scoliosis have a limited exercise tolerance with reduced ventilatory efficiency and maximal oxygen up-take.
- ❑ Surgery can stop the progression of the deformity, correct the curve, and achieve a better rib cage realignment.
- ❑ Surgical benefits for cardiorespiratory function have not been clarified.
- ❑ It seems that the limited tolerance to maximal cardiorespiratory exercise of patients with AIS remains essentially unchanged 2 years after surgical correction.

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ORIGINAL RESEARCH
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Non-uniform Segmental Range of Motion of the Thoracic Spine During Maximal Inspiration and Exhalation in Healthy Subjects

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Background and Objective: To analyse the range of motion of the thoracic spine by radiographically measuring changes in the sagittal profile of different thoracic segments during maximal inspiration and exhalation. The starting hypothesis was that forced deep breathing requires an active, but non-uniform widening of the lordotic–kyphotic range of motion of the different thoracic segments.

Methods: Cross-sectional study. Participants were 40 healthy volunteers aged 21–60. Conventional anteroposterior and functional sagittal chest radiographs were performed during maximal inspiration and exhalation. The range of motion of each spinal thoracic functional segment, global T1–T12 motion, and the sagittal displacement of the thoracic column during breathing were measured. Considering the different type of ribs and their attachment the spine and sternum, thoracic segments were grouped in T1–T7, T7–T10, and T10–T12. The displacement of the thoracic spine with respect to the sternum and manubrium was also recorded.

Results: The mean difference from inspiration to exhalation in the T1–T12 physiologic kyphosis was $15.9° \pm 4.6°$, reflecting the flexibility of the thoracic spine during deep breathing (30.2%). The range of motion was wider in the caudal hemicurve than in the cranial hemicurve, indicating more flexibility of the caudal component of the thoracic kyphosis. A wide range of motion from inspiration to exhalation was found at T7–T10, responsible for 73% of T1–T12 sagittal movement. When the sample was stratified according to age ranges (20–30, 30–45, and 45–60 yr.), none of the measurements for inspiration or exhalation showed statistically significant differences.
Only changes at this level showed a positive correlation with changes in the global thoracic kyphosis ($r = 0.794$, $p < 0.001$).

Conclusion: The range of motion of the thoracic spine plays a relevant role in respiration dynamics. Maximal inspiration appears to be highly dependent on the angular movements of the T7–T10 segment.

Keywords: thoracic spine, respiratory dynamics, forced ventilation, inspiration and active expiration, kyphotic angle

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INTRODUCTION

There is no evidence of any functional active participation of the thoracic spine in respiratory mechanics. However, diverse alterations of respiratory function have been described in patients with spinal disorders such as scoliosis and hyperkyphosis. Such studies have addressed only ventilatory and gas exchange, overlooking respiratory mechanical movements. Restrictions in the range of motion (ROM) imposed by rib attachments establish the thoracic spine as a passive stabilizer during breathing movements. Conversely, the diaphragm, the intercostals, and other accessory respiratory muscles have active and determinant roles in respiratory function (1, 2).

During inspiration, the ribs move up and expand laterally, increasing the anterior–posterior and lateral diameter of the thoracic cage. In contrast, the ribs move down and medially during exhalation. In these vertical movements, the thoracic spine is considered to have a restricted ROM because of its anatomic skeletal junctions. The sternum and ribs display a continuous and harmonious mobility during breathing, representing a significant participation in respiratory dynamics (3). These bony structures are, therefore, components of the mobile chest area during breathing. However, the role of the thoracic spine in respiratory function has so far been poorly studied and is not understood.

A previous study has contended that the thoracic spine is fixed during tidal breathing as the pivot of the ribcage (4). However, the functional ROM of the thoracic spine on the sagittal plane is wider than expected. Recently, a mean ROM of 31.7° was measured in 50 healthy adults via CT scanning of the thoracic spine in forced flexion and extension (5). Previous studies have analyzed the movements of the thoracic cage during breathing (6–8), but none have measured angular variations at thoracic segmental levels on the sagittal plane, especially during deep breathing. Our hypothesis was that the thoracic spine ROM has a relevant role in respiratory mechanics during maximal inspiration and exhalation. Support of this hypothesis would lead to several important clinical implications especially for the understanding of respiratory limitations in patients with spinal deformities, as well as for the surgical treatment of these patients requiring thoracic fusion.

Therefore, the purpose of this study was to analyze the ROM of the thoracic spine during forced respiratory dynamics. Changes in the sagittal profile of the thoracic spine during maximal inspiration and exhalation movements were radiographically measured at all spinal segments, and spatial relationships between the thoracic spine and the sternum during deep breathing were evaluated. This work proposes a new set of radiographic parameters that could be incorporated into the clinical analysis of respiratory function, particularly in patients with thoracic spine diseases.

MATERIALS AND METHODS

Ethics Statement

The study protocol was approved by the Institutional Review Board of the Hospital Ramón y Cajal (Madrid, Spain) with protocol number: V1-08/05/2016. All participants were informed about the purpose of the research and were asked to sign a consent form before taking part in the study. Procedures were in accordance with the ethical standards of the national ethics guidelines for research involving humans and with the Helsinki Declaration revised in 1983. Confidentiality was ensured during data collection and subsequent publication of the results.

Participants

This study was conducted in 40 healthy adult volunteers, 23 women and 17 men ranging in age from 21 to 60 years, after proper informed consent was obtained. Before the radiological exam, all subjects were screened to ensure no known history of back pain, lung disease, heart disease, or any other health problem that might have affected the study. Exclusion criteria were the presence of severe anterior osteophytes and degenerative discopathies and thoracic kyphoscoliosis as well as an inaccurate quality of the radiographic exams which complicates the measurement of all radiological parameters included in the study. **Table 1** shows the anthropometric characteristics of the sample.

Radiographic Measurements

Conventional anteroposterior and functional sagittal chest radiographs were performed during the maximal inspiratory and expiratory phases. The anteroposterior radiographs were used to identify the number of ribs per participant and to rule out previous vertebral or pulmonary pathologies, whereas the functional sagittal radiographs were used to measure the different parameters included in this study.

In all cases, the same conventional procedure for obtaining lateral radiographs of the thoracic in standing position was carefully respected by the same technicians at the hospital radiology department. The patients were instructed to look straight ahead with the chin up maintaining their arms raised over the shoulder level by holding the hands to a support incorporated to the image detector panel. The left side of the thorax was positioned against the image receptor to minimize cardiac magnification. The central ray was always centered at the level of the T7 vertebra. The patient was first asked to take a deep breath and hold the breath while the exposure for maximal inspiration was taken. Afterwards, the patients were asked to

TABLE 1 | Sample characteristics.

	Total sample $n = 40$
Age (years)	40.8 ± 13.6
Sex (Male/Female)	17/23
Weight (kg)	71.7 ± 13.3
Height (cm)	168.1 ± 18.0
BMI (kg/m^2)	24.0 ± 3.3

BMI, body mass index.

TABLE 2 | Definition of the radiological parameters assessed in this study.

Parameters	Definition
I. Mobility of the thoracic spine	
T1–T12 thoracic kyphosis angle	Angle measured from the T1 cranial or cephalic epiphyseal plate to the T12 caudal epiphyseal plate. This parameter assesses how the thoracic spine behaves during maximal inspiration and exhalation movements, showing the T1–T12 global ROM.
Kyphosis angle of the cephalic thoracic hemicurve	Angle from the T1 cranial endplate to the bisector of the endplates of the apex vertebra of the physiologic thoracic kyphosis.
Kyphosis of the caudal thoracic hemicurve	Angle between the previous bisector of the apex vertebra of the kyphosis to the T12 caudal endplate.
Apex	Apex level of the kyphosis at maximal inspiration and exhalation.
T12 distal endpate angle	The angle between the caudal T12 endplate and the horizontal. This angle monitors changes in the inclination of the last vertebra of the thoracic spine during peak respiratory movements.
T1 proximal endplate angle	The angle between the proximal or cephalic T1 endplate and the horizontal. This angle identifies the spatial displacement of the T1 vertebra, that is, the proximal end of the thoracic spine, during peak respiratory movements.
T1–T12 centroid distance	The distance from the centroid of the T1 vertebra to that of the T12 vertebra. This measurement indicates changes in the height of the thoracic spine at maximal inspiration and exhalation.
T1–T12 centroids vertical angle	The angle formed between the line of the T1–T12 centroids and the vertical line at the T1 centroid. This parameter shows the spatial displacement of the thoracic spine on the sagittal plane with respect to the vertical axis from inspiration to exhalation.
II. Displacement of the thoracic spine with respect to the sternum and manubrium	
Sternum T1–T2 angle	The angle of the anterior cephalic border of the sternum with the line joining the anterior edges of the T1 and T2 vertebral bodies.
Inferior distance sternun/T12	The distance from the posterior–inferior edge of the sternum to the T12 centroid.
Lower sternun slopping	The angle of the horizontal with the line formed by the posterior–inferior edge of the sternum to the T12 centroid.
Anterior-superior distance sternun/T1	The distance from the anterior–superior edge of the sternum to the T1 centroid.
Upper sternun slopping	The angle of the horizontal with the line formed by the anterior–superior edge of the sternum and the T1 centroid.
Distance T12 to horizontal sternum line	The vertical distance from the T12 centroid to the horizontal line from the anterior–superior end of the sternum.

perform and maintain for a few second a maximal exhalation to take the second lateral radiograph.

Digital images were measured in a computer by using the Surgimap Spine software (Nemaris Inc., Methuen, Massachusetts, USA). Two spine surgeon specialists with extensive experience in the measurement of sagittal profile of the thoracic spine in radiographs perform the measurements. Often there were difficulties to visualize the upper thoracic levels (T1–T3) and therefore impossibility for measuring kyphotic angles. In such cases our protocol was first to change the characteristics of the digitalized image by the acquisition software until the anatomic bony structures were satisfactorily visible and measurements could be registered. In case of failure, the radiographs were excluded from the study.

The first group of radiological parameters assessed the displacement of the thoracic spine during inspiration and exhalation, which indicates the mobility of the thoracic spine (**Table 2**; **Figure 1**). The ROM of each functional thoracic spine segment was measured by the angle that formed between the proximal and the distal endplates of the adjacent vertebral bodies (9). Results were also grouped in three spine sectors (T1–T7, T7–T10, and T10–T12) corresponding to the three anatomic rib attachments. The ROM of the global T1–T12 ROM was also measured. The second group of parameters intended to evaluate the relationship of the thoracic spine to the sternum during the breathing process (**Table 2**; **Figure 2**).

Statistical Analysis

Statistical analyses were performed using the SPSS, version 21 (IBM Corp., Armonk, NY). As all measurements comprise continuous numeric data, descriptive results are expressed as the mean ± standard deviation (SD). Based on the limited sample, changes between maximal inspiration and exhalation were analyzed using the non-parametric paired Wilcoxon signed-rank test. To assess differences in thoracic spine stiffness related to age, patients were divided into three age ranges: 23–30, 30–45, and 45–60 yr. Differences between the three age groups was analyzed by the Kruskal-Wallis test. The possible correlations between different radiological measurements were tested by the Spearman' *rho*. Results with a p-value ≤ 0.05 were considered as statistically significant.

RESULTS

Mobility of the Thoracic Spine

Table 3 shows the mean ± SD values of all parameters reflecting the ROM of the thoracic spine during breathing. Statistically significant differences between inspiration and exhalation were observed in all evaluated parameters. The mean difference from inspiration to exhalation in the T1–T12 physiologic kyphosis was $15.9^\circ \pm 4.6^\circ$ (a range of 9°-27° Cobb), reflecting the relatively high flexibility of the thoracic spine (30.2%).

The apex of the expiratory thoracic kyphosis descended 1.3 ± 0.5 levels from that at inspiration. This change is attributable to

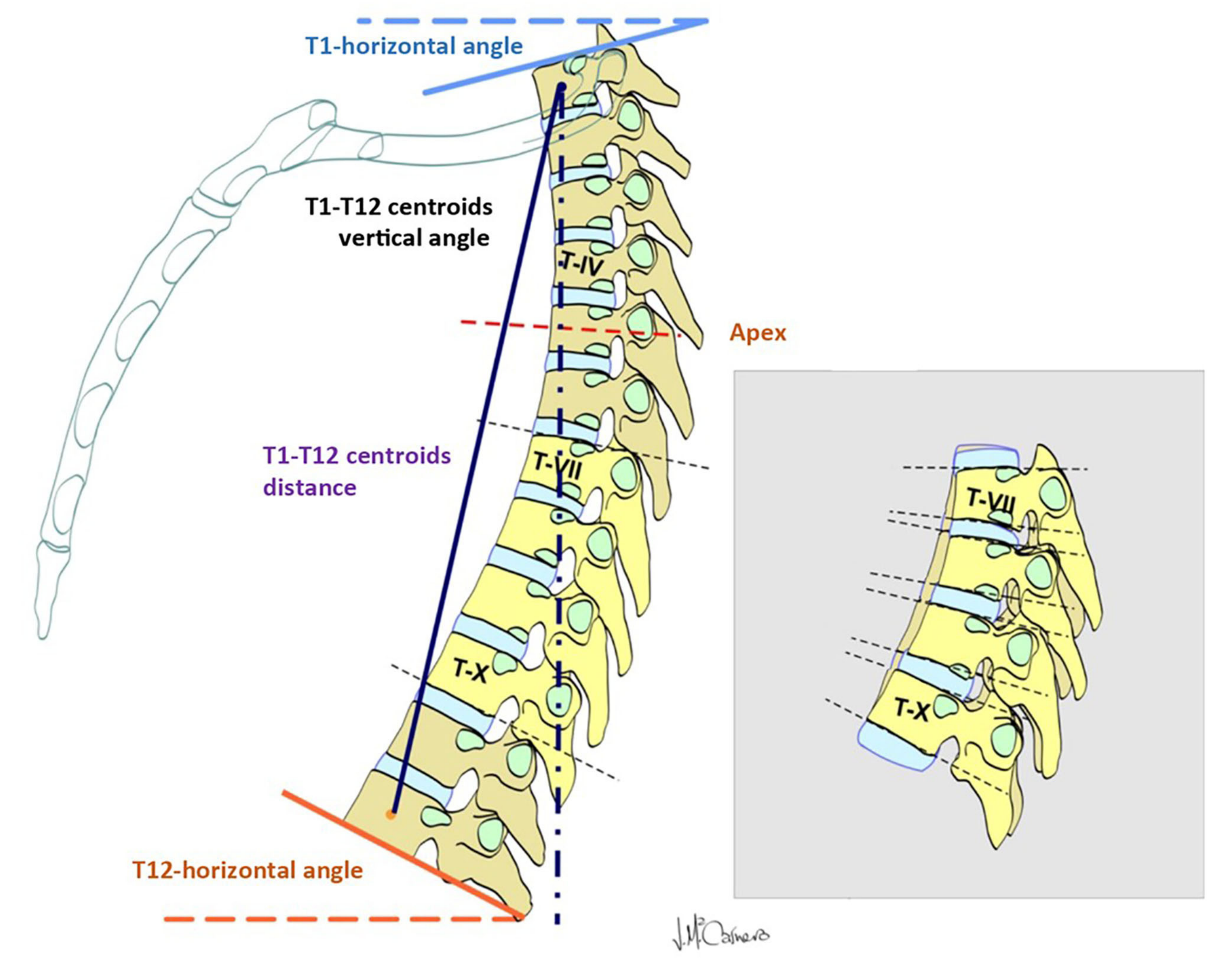

FIGURE 1 | Parameters measured to evaluate the mobility of the thoracic spine.

the asymmetrical motion of the cranial and caudal hemicurves, and it is related to their different degrees of stiffness. The inclination of the T12 and T1 vertebrae from the horizontal increased at exhalation, being higher at the upper levels, with a mean ROM of 11.1° ± 4.8° for T1 vs. 3.6° ± 2.9° for T12. **Figure 3** shows some the measurements taken by the surgimap software from the lateral radiographs of the thoracic spine in one of the cases. Changes in T1–T7, T7–T10, and T10–T12 from inspiration to exhalation are clearly apparent.

From exhalation to forced inspiration, the increment in the distance from the T1 centroid to the T12 centroid was 13.2 ± 2.9 mm (4.7%). The angle of the line joining the T1 and T12 centroids with the vertical showed a relevant mean increment of 18.5° ± 6.1° during exhalation, indicating a displacement in the flexion of the thoracic spine. When the sample was stratified according to age range, none of the measurements for inspiration or exhalation showed statistically significant differences.

Figure 4 illustrates the ROM of the functional spinal units of the thoracic spine. In all disc levels, changes from forced inspiration to exhalation were statistically significant. The T4–T7 segment, corresponding to the central thoracic, conform the greatest part of the physiological kyphosis; however, the discs included in this segment showed little change, but still statistically significant, during inspiration and exhalation. Large differences in the ROM from inspiration and exhalation were observed at the discs of the T7–T10 segment. At this level, the mean ROM of the three discs involved was 4.1°, higher than at upper levels (mean ROM of the discs T1–T7 = 1.1°). The discs of the T10–T12 segment (theoretically the most flexible in the thoracic spine) displayed almost similar mobility during forced respiratory movements (mean ROM = 1.3°). The T1–T3 segment showed minimal respiratory mobility, indicating greater stiffness in the thoracic spine.

The compiled ROM of the T1–T7, T7–T10, and T0–T12 segments are given in **Figure 5**. The global ROM during deep

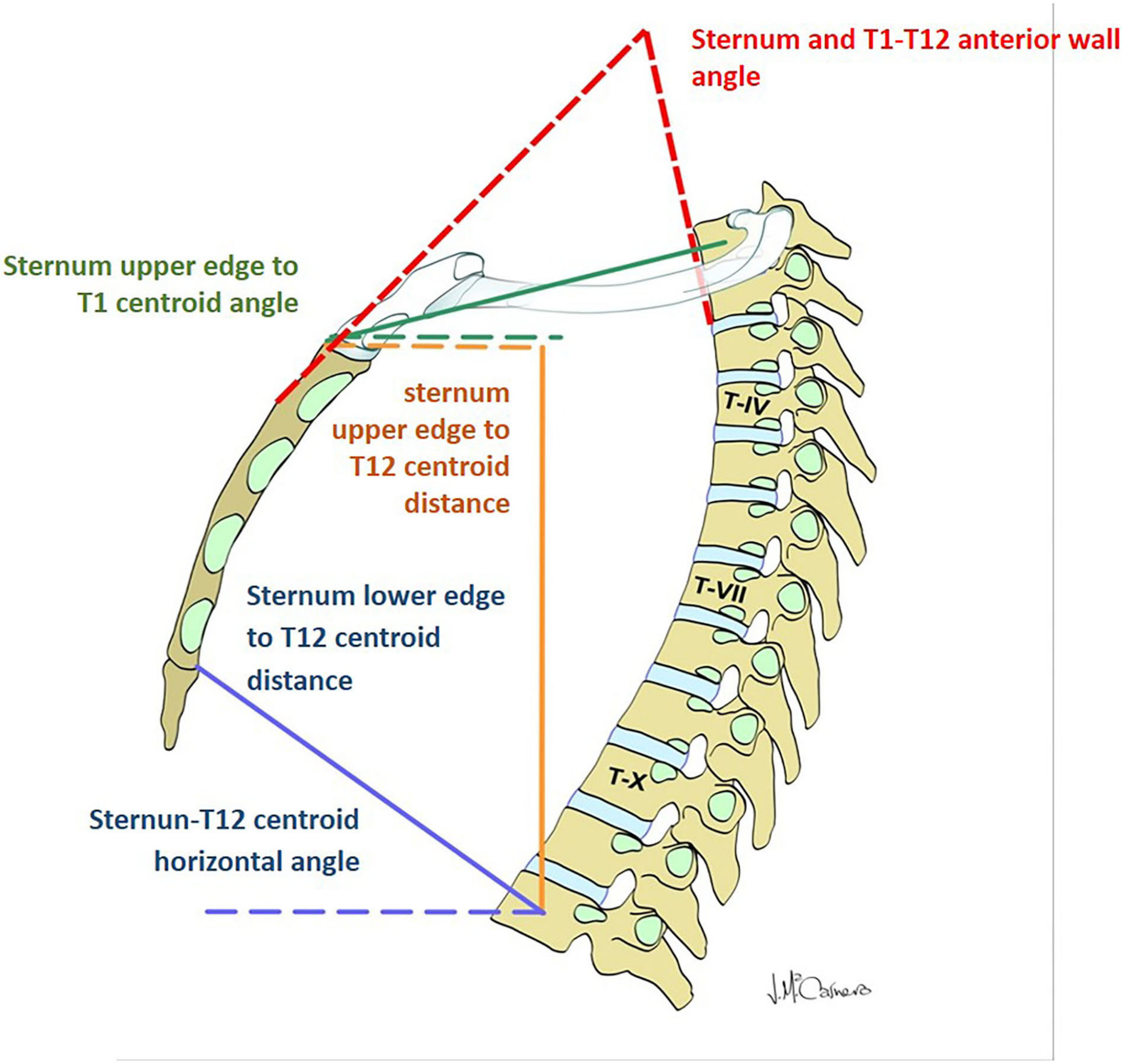

FIGURE 2 | Parameters evaluating the displacement of the thoracic spine with respect to the sternum and manubrium.

TABLE 3 | Movements of the thoracic spine on the sagittal plane.

	Inspiration		Exhalation		ROM		Wilcoxon signed-rank test	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Z	*p*
T1–T12 kyphosis (degrees)	36.8 ± 7.3	25–50	52.6 ± 7.6	37–66	15.9 ± 4.6	9–27	−5,513	0.000
Upper hemicurve (degrees)	15.8 ± 4.8	10–28	21.9 ± 5.0	11–34	6.1 ± 3.3	0–15	−5,096	0.000
Lower hemicurve (degrees)	21.0 ± 5.0	11–29	30.8 ± 5.2	22–45	10.2 ± 4.0	5–22	−5,449	0.000
Apex level	5.4 ± 1.1	3–7	6.7 ± 1.0	4–8	1.3 ± 0.5	1–3	−5,742	0.000
T12 angle *h* (degrees)	21.2 ± 6.7	8–34	24.5 ± 6.2	11–36	3.6 ± 2.9	0–10	−4,683	0.000
T1 angle *h* (degrees)	15.4 ± 6.6	6–28	26.1 ± 6.8	15–39	11.1 ± 4.8	1–22	−5,446	0.000
T1–T12 centroid (mm)	293.1 ± 24.7	245–341	281.9 ± 24.8	228–336	13.2 ± 2.9	6–18	−4,822	0.000
T1–T12 line angle (degrees)	22.9 ± 6.4	11–37	41.4 ± 8.3	24–57	18.5 ± 6.1	4–29	−5,514	0.000

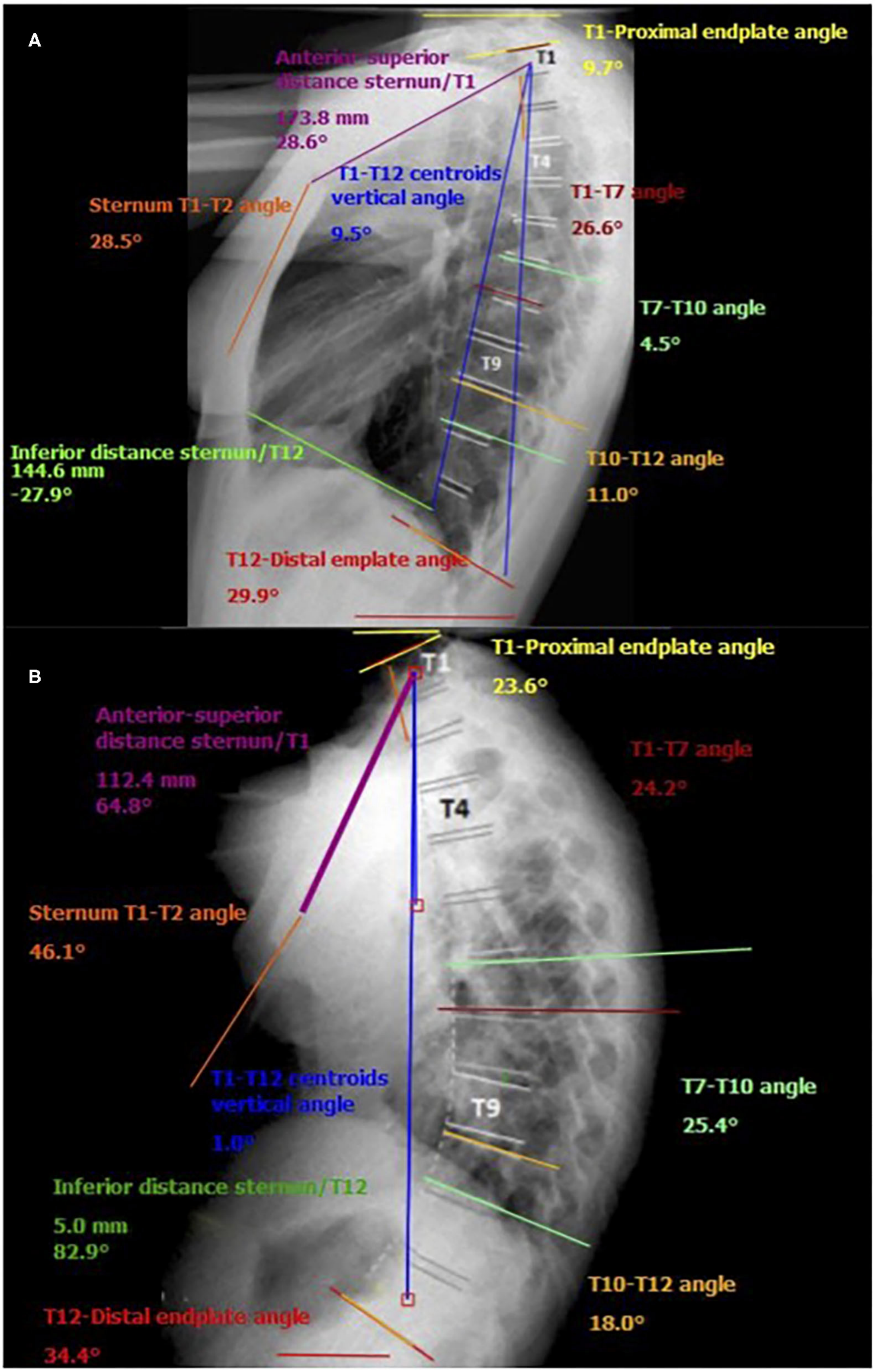

FIGURE 3 | Example of measurements taken by the surgimap software from the lateral radiographs of the thoracic spine in one of the participants. **(A)** forced inspiration; **(B)** forced exhalation.

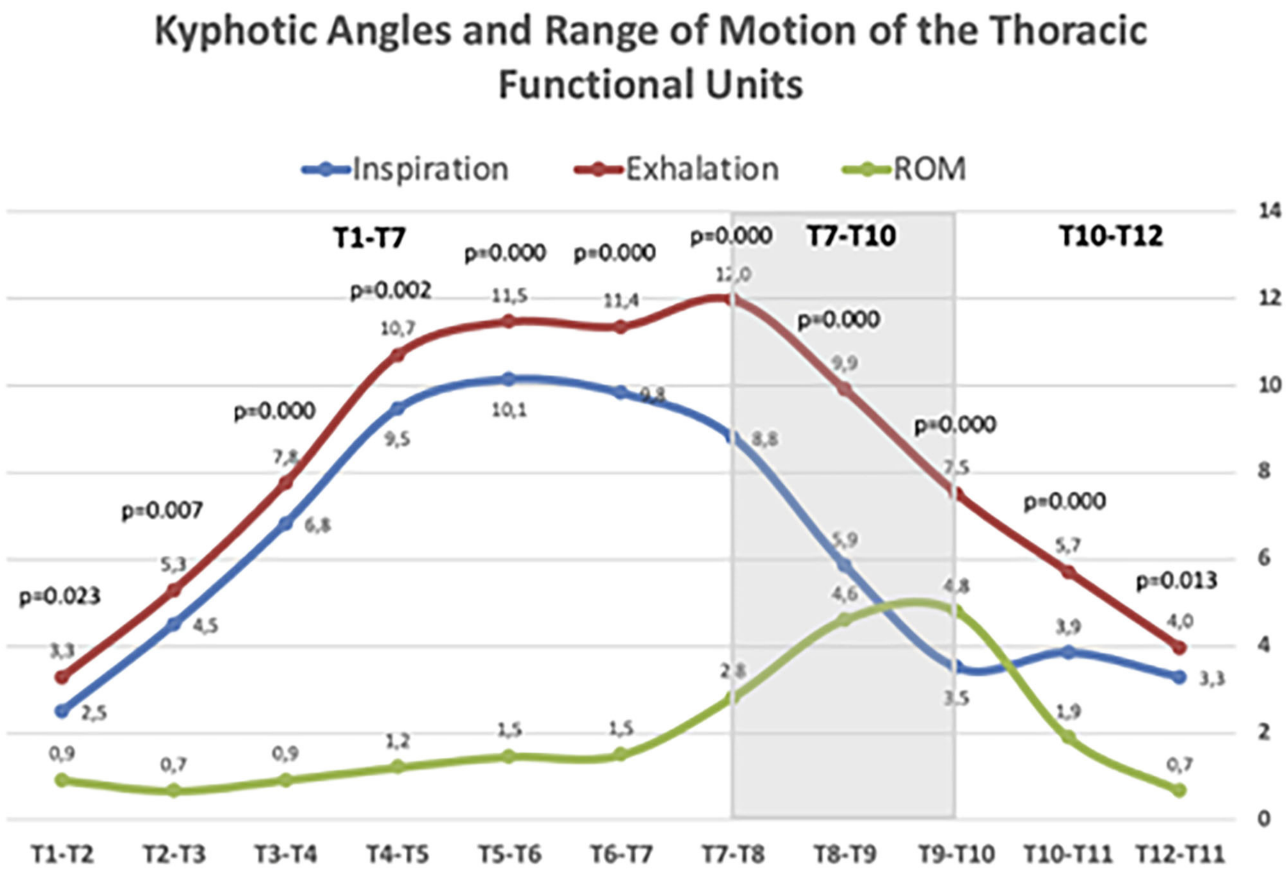

FIGURE 4 | Kyphotic angles and Range of motion (ROM) of thoracic spine segments during maximal forced inspiratory and expiratory phases. Values age given in mean Cobb angle. Statistically significant differences between inspiratory and expiratory angles are given for each segment according to the Wilcoxon rank test.

breathing in each thoracic sector is presented both for the whole sample and by discriminating the three age ranges (20–30, 30–45, and 45–60 yr.). There no statistically significant differences in ROM among the three age ranges in any of the thoracic segments. In the three age ranges, ROM of T7–T10 was greater than that found at T1–T7 segment, but differences were not statistically significant, except for the older participants. In this older age range, T7–T10 ROM was greater that T1–T7 ROM (Wilcoxon rank test: Z = 2.205; $p = 0.027$) (**Figure 5**).

Overall, the ranges of motion of the three discs of the T7–T10 segment were responsible for 74% of the T1–T12 sagittal movement. This figure slightly decreases as increases the age range: in younger participants (20–30 yr.) the contribution of the T7–T10 segment to the total T1–T12 ROM was 78.5%; in the age range 30–45 yr. was 72.8% and in the older participants 69.8%. However, the differences were not statistically significant.

An analysis of the contribution of the three main segments to the global T1–T12 kyphosis that only changes in the ROM of the T7–T10 segment showed a positive correlation with changes in the global thoracic kyphosis (Spearman's *rho* = 0.794, $p < 0.001$). **Figure 6** shows that the correlation between T7–T10 ROM and the change of global T1–T12 kyphosis applied for the three age ranges: 20–30, 30–45, and 45–60 yr.

Displacement of the Thoracic Spine With Respect to the Sternum and Manubrium

Table 4 displays the results of measurements assessing the relationship between the thoracic spine and the sternum during breathing. As with the thoracic ROM, these measurements revealed statistically significant differences between inspiration and exhalation in all evaluated parameters.

The angle formed by the body of the sternum and the anterior line of the T1 and T2 vertebral bodies increased during forced exhalation by 13.7% from the angle during inspiration. The distance from the inferior–posterior edge of the sternum to the T12 centroid decreased during forced exhalation by an average of 43.8 ± 10.7 mm (24%). The angle between the horizontal plane and the line joining the inferior–posterior edge of the sternum and the T12 centroid decreased significantly during exhalation by an average of 13.3° ± 5.4° (34.5%). The distance from the upper anterior edge of the sternum to the T1 centroid decreased during exhalation by a mean of only 5.1 ± 1.7 mm (4%), showing again that this upper aspect of the thorax is quite rigid.

During forced exhalation, there was an inferior displacement of the upper aspect of the thorax, as the angle of the line from the upper anterior edge of the sternum to the T1 centroid increased by an average of 18.6° ± 6.4° (80.8%) in relation to the horizontal plane. This descent of the thorax during exhalation was also

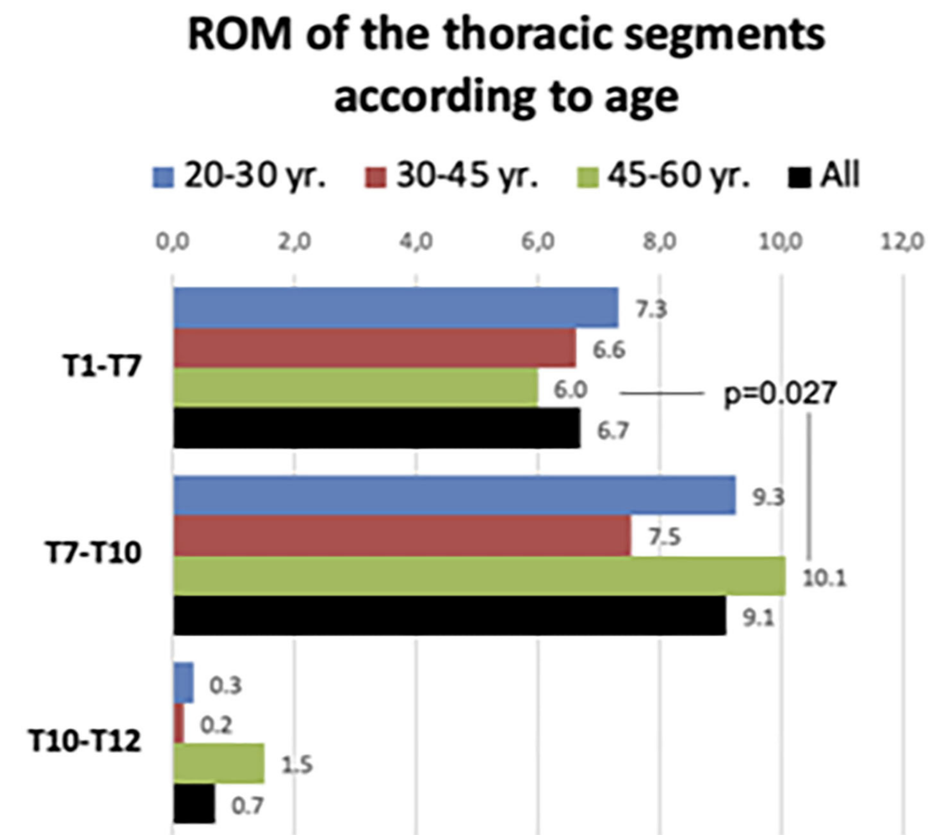

FIGURE 5 | Range of motion of the three main thoracic segments in the whole sample and according to age range.

shown by a decrease of 18.9% in the distance between the T12 centroid and the horizontal line starting at the front–superior edge of the sternum (**Table 4**).

DISCUSSION

The respiratory dynamics of the thoracic spine during forced ventilation were analyzed in this study. The results showed quantitatively that the kyphosis of the thoracic spine decreases during forced inspiration but increases during forced exhalation. However, an important finding of this study was that the three analyzed sectors of the thoracic spine showed a non-uniform mechanical behavior during breathing. The upper T1–T7 thoracic segment was more rigid than the T7–T10 segment. This different biomechanical behavior with increased mobility of the T7–T10 could be the underlying cause of the cranial displacement of the apex during forced exhalation.

The non-uniform sagittal ROM of the thoracic spine during deep breathing could be related to the different types of anatomic rib connections in the thoracic cage. At T1–T7 (the true ribs), the attachment of the ribs to the sternum and spine could greatly limit the mobility of the thoracic spine. A little mobility is expected, however, as the rib attaches to the cartilage before it attaches to the sternum. Ribs joined to T8–T10 (the false ribs) have longer costal cartilage, which attaches to other cartilage, resulting in more mobility in this area of the rib cage. At T11–T12 (floating ribs), the ribs have no anterior attachment, therefore, the greatest mobility of the thoracic spine can be expected in this area.

To date, some few studies have examined the impact of the rib cage on thoracic spine motion and stiffness (10–13). Using cadaveric models devoid of dynamic and stabilizing abdominal and paraspinal muscles, it has been found that the rib cage increases stiffness and decreases range of motion of the whole thoracic spine. Applying 400 N follower loads under $\pm$ 5 Nm dynamic moments to cadaveric specimens (13), the flexion/extension range of motion of the entire thoracic spine (T1–T12) was almost similar that found in the current *in-vivo* study. However, the ROM of the upper, middle, and lower segments of the thoracic spine found in specimens was different than in the current study on humans. One reason is that cadaveric specimens do not take into consideration the attachments of the upper thoracic spine to the cervical spine and scapulo-humeral joints. Similarly, at the lower thoracic spine, cadaveric specimens are usually devoid of the powerful abdominal stabilizing muscles, ileo-psoas and posterior paraspinal muscles. Although, models based on cadaveric specimens have tried to mimic the movements of the thoracic spine *in vivo*, all of them have still limitations the most important the arbitrary division of the thoracic spine in

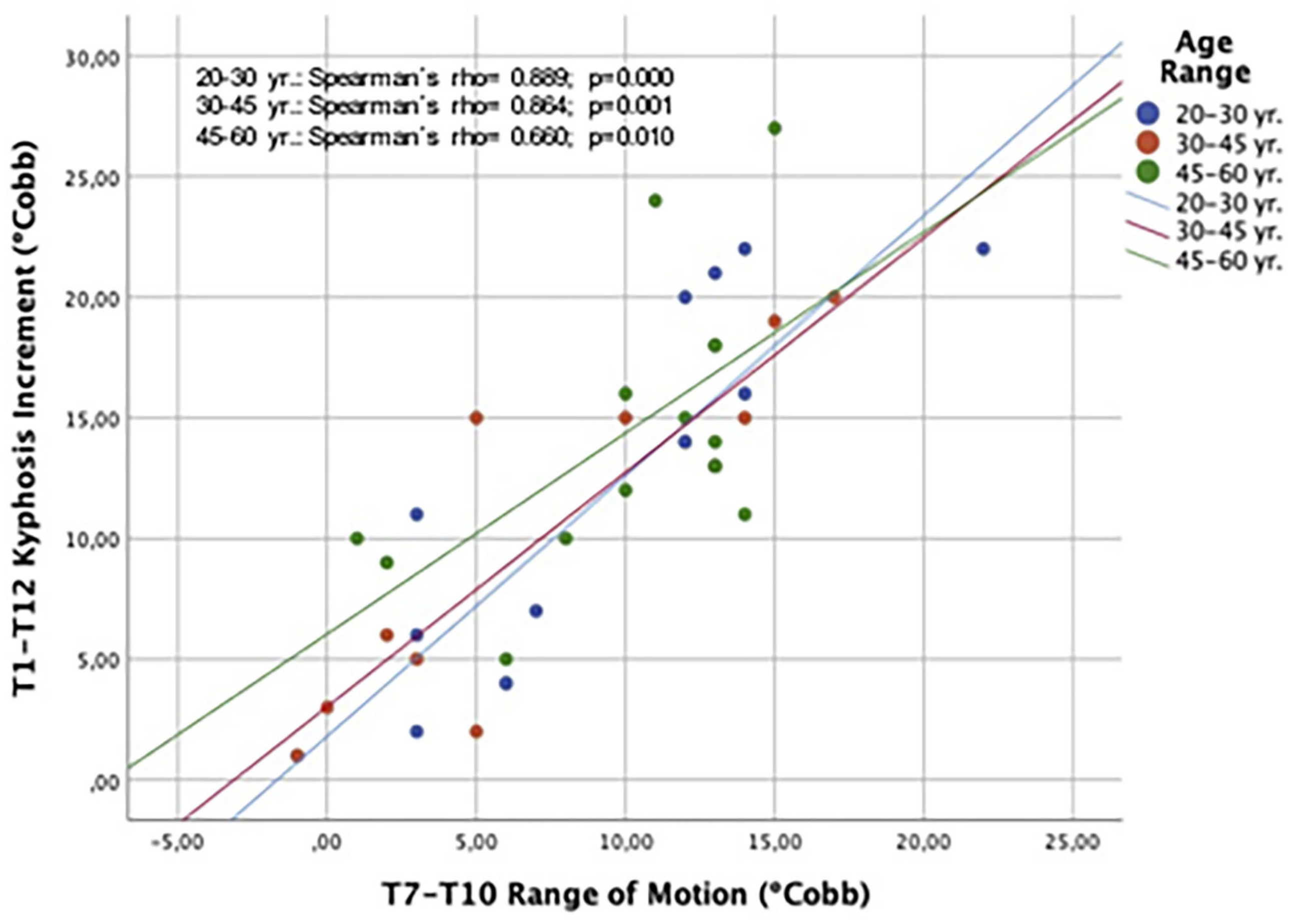

FIGURE 6 | Spearman's correlation plot showing the relationship between changes in T7–T10 ROM and the global T1–T12 kyphosis during forced respiratory movements. Results are discriminated by age ranges.

TABLE 4 | Mobility of the thoracic spine with respect to the sternum and manubrium.

	Inspiration		**Exhalation**		**Change**		**Wilcoxon signed-rank test**	
	Mean ± SD	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**	**Z**	***p***
Sternum T1–T2 angle (degrees)	42.9 ± 8.1	30–62	48.8 ± 8.4	35–69	5.8 ± 2.0	2–9	−5,429	0.000
Manubrium T1–T2 angle (degrees)	54.5 ± 7.9	40–67	58.9 ± 8.1	45–74	4.4 ± 2.1	2–8	−5,030	0.000
Distance LE sternum to T12 (mm)	181.4 ± 38.5	139.9–260.8	137.4 ± 38.5	81.2–223.5	43.8 ± 10.7	23–69	−5,373	0.000
LE sternum to T12 horizontal angle (degrees)	38.5 ± 7.5	26–55	25.3 ± 6.6	14–36	13.3 ± 5.4	0–25	−4,985	0.000
Distance UE manubrium to T1 (mm)	126.5 ± 15.5	99.5–158.5	121.2 ± 15.9	93.6–151.1	5.1 ±1.7	2–8	−5,112	0.000
UE manubrium T1 angle (degrees)	22.9 ± 6.4	11–37	41.4 ± 8.3	24–57	18.6 ± 6.4	4–32	−5,514	0.000
Distance T12 horizontal LE sternum	242.6 ± 25.5	196–284.6	196.1 ± 31.0	132.4–271.9	46.0 ± 16.8	18–80	−5,025	0.000

LE, lower edge; UE, Upper edge.

sectors that do not consider the anatomic characteristics of the thoracic spine (three types of rib attachments).

To our knowledge, there is only one study reporting normal functional ROM of the thoracic spine in alive subjects (5). A short ROM from T2–T3 to T6–T7 was found, very similar to our results. However, from T8–T9 to lower levels the ROM increased until a maximum of 4.2° at T12–L1. The discrepancy between these findings and the results of our study may be explained by the different position of the subject and the mechanical conditions applied. In our study, volunteers were standing position and only a maximal inspiration and exhalation under gravity was required for analysis of the thoracic ROM. In the previous study, participants were in supine position, and extension and flexion were forced by inserting triangular pillows below the back. The subjects were not affected by gravity, by stability of muscles, and for obese individuals, flexion and extension were more difficult. In addition, most of the participants had been diagnosed with cervical or lumbar spinal diseases although the thoracic spine was disease-free. Therefore, our results are not fully comparable and represent the ROM of the thoracic spine during breathing with more reliability.

Notably, this work demonstrates that the most mobile thoracic segment during forced deep breathing is T7–T10, the false rib region. The movement of this short segment provides enough expansion for respiratory function in cases demanding high ventilation rates. The T7–T10 inspiratory lordosis facilitates the ascension and expansion of the thoracic cage when deep breathing is required. The increase in lordosis could also facilitate the function of the intercostal muscles and diaphragm. Concerning the ROM of the discs corresponding to the T7–T10 segment, our findings are in accordance with those reported by White and Panjabi (14) estimated a representative ROM of 6 degrees for T7–T8 through T9–T10. Our measurements in the T7–T10 are similar (12 degrees). These authors also suggests that respiration utilizes most of the available ROM in this region.

The rather short ROM of the T10–T12 vertebral segment, which is almost fixed during peak respiratory movements, was unexpected, considering that this segment represents the area of greatest mobility in the thoracic spine. This segment is located in the transition zone between the rigid thoracic and mobile lumbar spine, which supports high mechanical stress. This vertebral segment is not kyphotic or lordotic on the sagittal plane.

Displacement of the thoracic spine in relation to the sternum was also evaluated in this study. The results again demonstrated the rigidity of structures located at the upper level of the respiratory bellows: the sternum, the two first ribs, and discs T1–T2. The distance from the T1 vertebra to the sternum changed minimally during maximum inspiration and exhalation, while the distance from the T12 vertebra to the sternum changed markedly.

Together, these data provide novel implications for the role of the thoracic spine in respiratory mechanics. To date, the literature has attributed only a passive role to the thoracic spine in respiratory function. The respiratory motor is mainly believed to be the diaphragm, the intercostals and other accessory muscles (2, 15). These primary respiratory muscles have never included the thoracic spine erector muscles. However, breathing dynamics is highly dependent on the movements of the thoracic spine in extension that is attributable to the contraction of the paraspinal extensor muscles. These muscles have a definite relevant role in respiratory function particularly when maximal breathing is required.

The thoracic spine erector muscles are responsible for the lordotic movements of the T7–T10 segment, which triggers chest elevation and increases the respiratory exchange surface on all planes. Thus, the inspiratory lordotic and the expiratory kyphotic effect occurs in the most elastic segment of the thoracic spine at the base of the thorax, where the range of motion of the lever arm in relation to the sternum is greater, which maximizes the effects of spinal lordosis and kyphosis on the breathing response.

The thoracic spine not only has the ability to maintain chest height but also seems to be the primary respiratory longitudinal engine for forced inspiration. In addition, the thoracic spine preserves respiratory collapse during exhalation to the flexion limit and enables lung expansion during forced inspiration. The thoracic spine not only behaves in these situations as a facilitator of costal and diaphragmatic breathing but also directly increases the respiratory exchange surface during forced inspiration. The inspiratory spinal lordosis observed in our study enables chest expansion, horizontalization of the arch ribs, and expansion of the more elastic base of the thoracic cage. All of these mechanisms subsequently increase the respiratory exchange surface. The ascent of the upper rigid segment (the sternum, the first ribs, and the T1–T2 vertebral segment) induced by the inspiratory lordotic attitude of the thoracic spine also facilitates the expansion of the base of the chest by posteriorly displacing the T10–T12 segment. Furthermore, rib inspiratory expansion is predisposed to a more effective expiratory intercostal contraction, hence, decreasing the exchange surface at that time (11, 16).

For all of these functions, the spine also requires strong stability, ensured by the isometric coactivation of the paraspinal muscles, including the erector spinae (17, 18). At the same time, these muscles all contract rhythmically to actively assist ventilation during forced breathing (19). The close relationship between ventilation and spine erector muscle activation has been demonstrated previously by a number of studies; however, its function has been limited only to stabilizing the spine and not contributing to active inspiration (20–22).

The engine system that represents the mid-lower thoracic spine (T7–T10) is certainly the mechanism implied in forced respiratory function, beyond tidal ventilation. In addition, the lordotic displacement of the thoracic spine facilitates the respiratory function of the diaphragm, relieving abdominal pressure and expanding the thoracic basement to facilitate muscle contractility.

Considering that situations of high respiratory demand are frequent during normal active life, and although the respiratory functional reserve must be very large, vertebral movement can be triggered by submaximal efforts, which are very common during everyday activities. Apparently, the thoracic spine is needed for maximum respiratory requirements but is not triggered by tidal ventilation in healthy subjects. In conditions of respiratory restriction, the thoracic spine mechanism could also be solicited at rest. The limited flexion-extension range of motion of the

T7–T10 segment that is presumed to occur in spinal deformities, such as thoracic idiopathic scoliosis frequently showing the apex located within this segment, could be an additional factor implicated in the restricted respiratory function of these patients. Additionally, the abolition of T7–T10 motion in the sagittal plane conditioned by the current techniques for surgical management of the spinal deformities requiring segmental fusion could have severe implications on the respiratory function of such patients.

The present study might be influenced by certain methodological limitations. First, the forced respiratory maneuvers were voluntary and followed detailed instructions to the participating individuals. However, the maximal strength of the paraspinal muscles during inspiration was never controlled. Standardization of maximal exhalation was also challenging, and both extension and flexion of the thoracic spine were especially difficult in the most obese individuals. Another limitation is that the findings may not generalize to older adults or, obviously, to those with spine conditions. In addition, pulmonary functional tests were not performed to the participants. Retrospectively, a correlation of thoracic ROM during breathing with baseline ventilation data would be worthy. Considering these limitations, we observed the same pattern of thoracic and sterno-thoracic displacement in all individuals independently of gender and age. In addition, this is the first study to address the ROM of the thoracic spine during respiratory mechanisms.

In conclusion, this study provides new insights into the dynamic behavior of the thoracic spine during respiratory function. Until now, the thoracic spine has been considered rather stable due to its restriction by the rib cage. However, the results of this study demonstrate that the thoracic spine plays a primary role during respiratory function, being the longitudinal driving force in the chest in situations requiring maximal breathing. The key issue is that maximal inspiration is highly dependent on the angular movement of the T7–T10 segment, corresponding to the floating ribs. The sternum, the first shorter ribs, and the first intervertebral discs are less elastic and can be considered passive elements. These findings are important when considering the clinical implications that thoracic fusion might have for patients with spinal deformities requiring surgery.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary files, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board of the Hospital Ramón y Cajal (Madrid, Spain) with protocol number: V1-08/05/2016. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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