Egypt. J. Anat. Vol. 27 (1) 87-100, January 2004 | ISSN 1110-2144

TRANSITIONAL PATTERNS OF THE ZYGAPOPHYSEAL JOINTS AT THE THORACOLUMBAR REGION

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INTORDUCTION

The gradual changes of morphology from one vertebra to another do not occur in all parts on the same rate. Those of the costal joint surface were found to occur in a very restricted manner **(Shinohara, 1997).** The transformations in the structural elements of vertebrae were found to be under the control of Hoxgenes **(Kostic & Capecchi, 1994).**

In the lower thoracic vertebrae (T9 to T12) multifidus takes its origin from a bony tubercle (mamillary tubercle) which is situated posterosuperiorly on the transverse process. This tubercle is situated posterolateral to the superior articular process. The mamillary tubercle of T12 is much more prominent **(Pal & Routal, 1999).** In the lumbar vertebrae multifidus takes its origin from a bony protuberance (mamillary process), which is situated on the posterior border of the superior articular process **(Chadha et al., 2003).**

In the thoracic region, the articular surfaces of vertebral superior articular processes are flat and face posterolaterally, whereas in the lumbar region they are curved and face posteromedially **(Breathnach, 1965). Williams et al. (1995)** reported that the change in the orientation of the articular process from thoracic to lumbar type usually occurs at the 11^{th} thoracic vertebrae but rarely at T12 or T10. **Davis (1955)** found that the most frequent site of transition is at the zygapophyseal joint (ZJ) between T11 &T12 vertebrae. The above references described the change as sudden, i.e. at a single joint where the inferior articular process of the upper vertebtra (T11) and the superior articular process of the lower vertebra (T12) were involved. The joint of the thoracolumbar transitional region was described by **Davis (1955)** to be neither like a typical thoracic nor like a typical lumbar joint; he named it a "mortice joint" because of its resemblance to carpenter's mortice.

Singer et al. (1988), using computed tomography, reported that the gradual transition at T11 &T12 vertebrae was more frequent than the sudden ones at single T12 vertebrae. On the other hand, **Shinohara (1997)**

found predominance of the sudden transition over the gradual ones at T12 & L1.

From the above literature it could be noticed that there is an obvious disagreement among the various authors as regard the level and rate of change (sudden or gradual) in the orientation of ZJs, from the thoracic to the lumbar type. So it was the aim of the present study to settle the controversy using dry bones and CT scans and to discuss the functional explanation for this transition from the thoracic to the lumbar types.

MATERIAL AND METHODS

In the present study 20 adult human macerated *vertebral columns* were collected from the anatomy department and Museum of Ain Shams University. The exact age and sex of individual columns was not known but all were fully ossified (adult). All these columns were free from any congenital anomaly or pathological change.

The superior articular facets of ZJs at the thoracolumbar region (T9-L1) were examined for the degree of concavity, orientation (direction), the degree of approximation from the mamillary tubercle, and the presence of bilateral asymmetry between the two facets. Any degree of deviation from the typical thoracic or lumbar facets were registered and tabulated by a diagram in correlation with its level. Also, in each vertebral column the numbers of vertebrae that show atypical (transitional) facets were recorded to assess the pattern (rate) of change in orientation at the thoracolumbar region.

In addition, Axial (Horizontal) sections of Computerized Tomography were also done on the same region of vertebral column of 20 patients proved to be negative for disc prolapse or bony pathology. Sections of 3mm thickness were aligned parallel to the vertebral endplate so as to pass with ZJs. The facets were investigated for their shape and orientation at each level.

RESULTS

Examination of the typical thoracic superior articular process showed that it projects superiorly from the junction of the pedicle and lamina. It ends in sharp margin superiorly. Its articular surface (facet) was flat facing posterolaterally (Fig. 1) and articulates with the anterior surface of the inferior articular process of the vertebra above (Fig. 2). The articulating surfaces of these processes lie on an arc of a circle whose center is in the vertebral body (Fig. 3).

The last two or three thoracic vertebrae were found to be different from the remainder in having a complete facet for the head of the corresponding rib with typical creeping toward the pedicle as we reached T12 (Fig. 4). The last two thoracic vertebrae have very small transverse process. The mamillary tubercle situated posterosuperiorly on the transverse process away from the lateral border of the superior articular process with a notch in between. A gradual enlargement of the mamillary tubercle and approximation toward the lateral border of the superior articular facet (obliteration of the notch) was noticed in the last vertebrae (Fig. 4).

The typical lumbar vertebrae have the same elements as the thoracic vertebrae, but are more massing in keeping with greater load they have to transmit. The blunt superior articular process projects upwards from the junction of each pedicle and lamina. The superior articular facet of the typical lumbar vertebra is concave (cupped) and facing posteromedially (Fig. 5). The interlocking of the articular processes effectively prevents rotational movement of the column (Fig. 3). The true lumbar transverse process is represented by the small accessory process on the dorsal surface of the transverse process at its base. The accessory process is immediately inferior to the rounded mamillary process which projects posteriorly from the superior articular process from its lateral border (Fig. 5).

Out of the present investigation three different types of transitional superior articular surfaces could be distinguished in the thoracolumbar region between T10 & L1 mainly at T 12. The superior articular surfaces possess intermediate characters between the typical thoracic and typical lumbar. The most common type of transitional articular surface was oriented coronally i.e. facing posteriorly (Fig. 6). The second type showed a double articular surface on the same facet separated by a vertical ridge; the medial surface was oriented coronally, while the lateral surface was still as the typical thoracic i.e. facing posterolaterally (Fig. 7). The third type of transitional facets was rare and if present was nearly similar to the typical lumbar but with less sagittalization (less rotated) with slight cupping and the mamillary tubercle slightly away from the lateral border (Fig. 8). The different types of transitional facets were diagrammatically presented in (Fig. 9). Noteworthy, it was found that asymmetry is a common finding 40% among the articular facets of dry bone specimens, either at T11 alone 10% (Fig. 10) or T12 alone 10% (Fig. 11) or both T11 and T12 20%.

According to the above anatomical criteria of transitional facets (ZJs), the patterns (rate) of orientations of the ZJs from typical thoracic to typical lumbar could be classified into 3 main patterns: the common gradual ones, less frequently the sudden type and rarely the more gradual type. Any of the above 3 patterns may be found in the region between T 10 &L1, i.e. this classification is not based on fixed level (Table 1)

The gradual pattern where there was only one coronally oriented transitional ZJ, i.e. the change extending over 2 successive vertebrae ether

T10,11 (Fig. 12)or T11,12 (Fig. 13). This pattern was by far the most common and was found in 30 out of 40 specimens examined (bony and radiological), i.e. in about 75%.

The more gradual pattern where there were two successive joints that included atypical facets nearly in the coronal plane between T10,11 and T11,12 and was present in 4 specimens only (bony and radiological), i.e. about 10% (Figs. 2&4).

The *sudden pattern* of orientation showed no atypical "coronal" ZJs, where the change occurred over a single vertebra, i.e. its superior facet has the thoracic criteria while its inferior facet has the lumbar criteria. It is either present at T11, i.e. ZJ between T11-12 (Fig. 14) or at T12, i.e. ZJ between T12-L1 (Fig. 15). This pattern was found in 6 specimens (bony and radiological), i.e. in 15%.

The most common patterns of transition were diagrammatically concluded in (Fig 16).

Table (1): Patterns of orientation of ZJs at thoracolumbar region

Type	Between T10,11	Between T11,12	Total
Gradual pattern			
Dry bone	4 / 20	11 / 20	15 / 20
Radiology	6 / 20	9 / 20	15 / 20
	10 / 40 (25%)	20 / 40 (50%)	30 / 40 (75%)
More gradual pattern	T10, 11 & T11, 12		
Dry bone	3 / 20		
Radiology	1 / 20		
	4 / 40 (10%)		4 / 40 (10%)
Sudden pattern			
Dry bone	1 / 20	1 / 20	2 / 20
Radiology	1 / 20	3 /20	4 / 20
	2 / 40 (5%)	4 / 40(10%)	6 / 40 (15%)

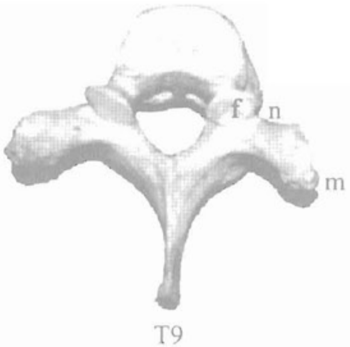


Fig (1): Posterior superior view of the thoracic vertebra (T 9) showing its superior articular facet directed posterolaterally (f), laterally situated mamillary tubercle (m) with an intervening notch inbetween (n).

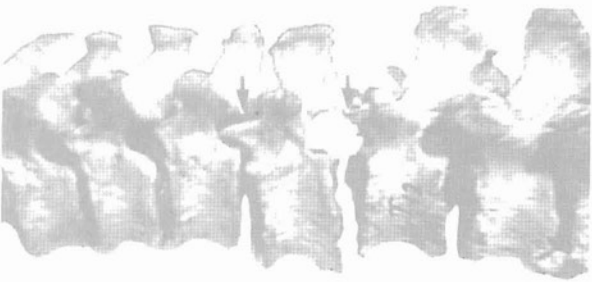


Fig (2): Lateral view of the vertebral column at the thoracolumbar region showing the articulation between sup. and inf. articular processes of the 2 successive vertebrae. Notice the gradual pattern with 2 coronally oriented ZJ (↑) between T10&11 and T11&12 i.e. changes over 3 successive vertebrae.

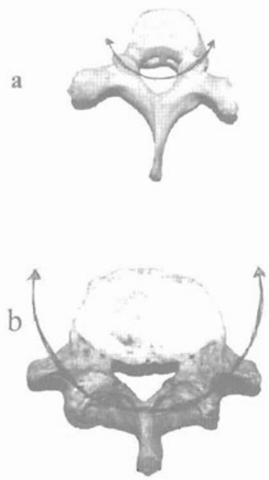
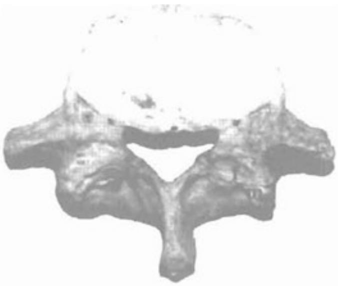


Fig (3): Photograph showing typical thoracic vertebra (a) & typical lumbar vertebra (b). The orientation of facets is designed so as if an arc of a circle with its center at the center of the body passes through the articular facets. In the thoracic region the arc is parallel to the articular surface of the facets permitting free rotation at this region, while in the lumbar region the arc is perpendicular to the facet.



L2

T12

Fig (4): Lateral view of the last 3 thoracic vertebrae, showing the typical gradual creeping of the body facet toward the pedicle as we reached the T12 thoracic vertebra. Note the gradual enlargement and approximation of the mamillary tubercle (3) toward the superior articular facet (1) with gradual obliteration of the notch (2), and the lumbar orientation of the inferior Articular facet at T12 (→).

Fig (5): Posterior superior view of a typical lumbar vertebra (L2) showing the concave superior articular facet (f) directed posteromedially with the mamillary process (m) at its lateral border.

T12

Fig (6): Dorsal view of the 12th thoracic vertebra showing the symmetric oval and rounded coronally oriented transitional superior articular facets (1). Note the laterally situated and prominent upward mamillary tubercle (3) with a notch inbetween (2).

Fig (7): Posterior superior view of 12th thoracic vertebra showing asymmetric superior articular facet. The left facet (L) is typically thoracic (facing posterolaterally) while the right one (R) is divided into 2 halves by a vertical ridge with the medial half coronally oriented but the lateral half facing posterolaterally.

Fig (8): Posterior superior view of 12th thoracic vertebra showing the slight concave with slight sagittally oriented superior articular facet (f).

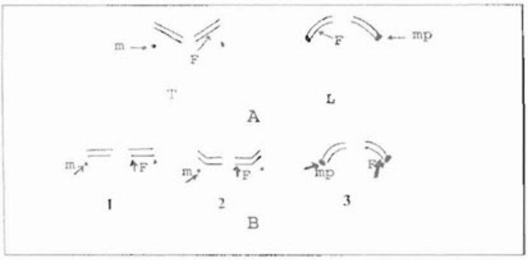


Fig (9): Diagrams showing the typical facets: (A) with thoracic in the left side and lumbar to the right side. (B) Shows the 3 transitional types of articular facets detected. The 1st one to the left (1) is coronally oriented, the middle (2) is the divided while that on the right (3) is that with slight concavity & mild sagittalization. Note the mamillary tubercle (m), superior articular facet (F) and the mamillary process (mp).

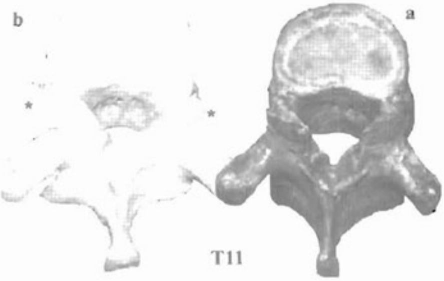


Fig (10): Posterior superior view of 2 specimens of T11 showing a) typical symmetry between right and left facets, b) asymmetry between right and left facets "facet tropism"(*).

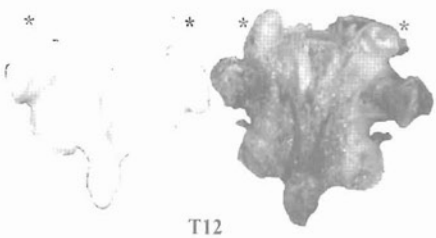


Fig (11): Posterior view of 2 specimens of T12 showing the facet tropism (asymmetry) between the Rt & Lt superior articular facets (*).

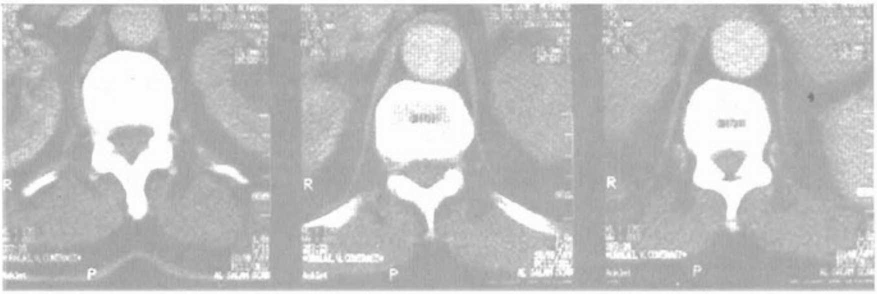


Fig (12): Axial (horizontal) computerized tomography (CT) at the transitional zone showing the gradual pattern where the ZJ between T10,11'to the right' is coronally oriented and that between T11,12 'in the middle' is sagittally oriented and facing posteromedially.

Fig (13): Posterior superior view of T11& 12 showing gradual pattern of the ZJ between them. As the superior articular facet of T11 (f) is typical thoracic and of T12 (F) is coronally oriented.

Fig (14): posterior superior view of T11& 12 showing the sudden pattern of transition. Note the typical thoracic orientation of superior articular facet at T11 (f) and the typical lumbar orientation of superior articular facet at T12 (F).

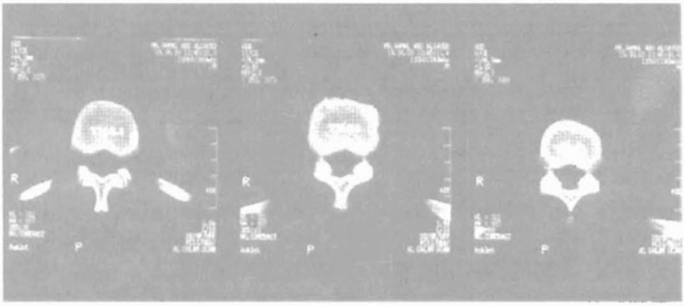


Fig (15): Axial (horizontal) computerized tomography (CT) at the transitional zone showing the sudden pattern. The joint between T11,12 is typically thoracic, while that between T12,L1 is typically lumbar. Note that there where no ZJ in the coronal plane.

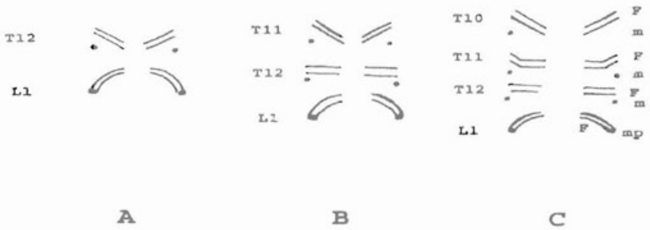


Fig (16): Diagrammatic representation of the common patterns of orientation of the articular surface at the transitional thoracolumbar region. The sudden type (A) with no transitional facets, (B) gradual pattern with one ZJ having transitional facets, (C) very gradual pattern with two ZJs having transitional facets. Note the mamillary tubercle (m), superior articular facet (F), mamillary process (mp).

DISCUSSION

The patterns of orientation at ZJs found in the present study (the gradual pattern 75% and the sudden pattern 15%) are in accordance with those of **Pal and Routal (1999)**, who observed a majority of gradual transition in 93% and a minority of sudden pattern in only 7%. On the contrary, **Shinohara (1997)** found the transition to be more sudden (66%), than gradual (34%). Similarly, **Singer et al. (1988)** found the sudden and gradual transition almost in equal population

In the present study the change was found to extend up to 3 successive vertebrae, which lead to 3 types; gradual, more gradual, and sudden type, while both **Singer et al. (1988) and Shinohara (1997)** observed the gradual change extending over only 2 successive vertebrae. **Davis (1955)** described the change as abrupt (occurring at one vertebral level).

In order to understand why and how the posterolaterally facing flat articular surface in the thoracic region change to the posteromedially facing curved surfaces in the lumbar region, we have to know the mechanisms of load transmission in the thoracic and lumbar regions of the vertebral column. In this respect two facts would help to explain this mechanism. First, it is a general rule that the forces act at right angle to the plane of any articular surface. Secondly, the line of gravity passes anterior to the vertebral bodies in the thoracic region and posterior to the lumbar region, crossing the column at T11 and T12 vertebrae **(Yang and King, 1984).** As the thoracic region is concave anteriorly and the line of gravity passes anterior to the vertebral bodies, there is tendency for accentuation of load on the vertebral bodies. Hence the weight acting at the zygapophyseal Joints is also slightly transmitted towards the bodies through the pedicles. In the lumbar region the line of gravity passes posterior to the vertebral column, so the weight is mainly transmitted through the joints vertical to surface in the direction of the pedicles **(Pal and Routal, 1999).**

The above mechanism of load transmission by the lumbar facet joints is also supported by the findings of **Cihak (1970),** according to whom the lumbar zygapophyseal joints at birth are all oriented in the coronal plane. However, during postnatal growth their orientation starts to rotate from the coronal towards the sagittal plane. This process of sagittalization begins at the 6^{th} and completed by 18 month of postnatal life. **Pal and Routal (1999)** mentioned that the above period corresponds to the development of the lumbar curvature, which is associated with the child learning to stand erect and walk. Thus the process of sagittalization of the articular processes in the thoracolumbar region is associated with the increase of load on the joints.

On the other hand **Pal (1989)** attributed the rotation of the lumbar ZJs to the action of multifidas muscle by pulling on the mamillary process. It swings the lateral extremity of the superior articular process to a more dorsal position (sagittalization).

Tawackoli et al. (2003) speculated that the gradual transition might help to protect the spine from fracture at the theoracolumbar region resulting from sudden vertical impact i.e. fall from a height. This is because the gradual transition would enable to absorb forces gradually during their shift from anterior to posterior components of vertebrae, i.e. from bodies in thoracic region to neural arches in the lumbar region. However, where the transition is sudden, the single transitional vertebra would bear the impact of forces, thus making it more liable to low back pain and more predisposed to fracture. Similarly, **Pal & Routal (1999)** found that a vertebra showing sudden transition is also more susceptible to torsional injuries, as torsional stress is resisted by sagittally oriented facet joint.

The findings in this study indicated that there is asymmetry in the left and right thoracic facets. Most of the right facets were higher superior inferiorly than the left. On the contrary, **Ishihara et al. (1997)** found that most left thoracic facets are longer and higher superior inferiorly than the right facets. Facet asymmetry can be related to biomechanical malfunction and vertebral degenerative changes in the human spine **(Boden et al. 1996)**. **Karacan et al. (2003)** revealed a positive correlation between lumbar disc herniation and both asymmetry and sagittalization of facet joints. They reported that facet asymmetry was observed at the lumbar disc herniation level in 70.5% of the patients; while in 46% of patients there were asymmetry at adjacent level of herniation. **Sanders et al., (2003)** suggested some theories related to facet asymmetry; a) asymmetrical articular facets might promote normal spinal scoliosis, b) facet asymmetry could promote an automatic rotation of the spine, c) asymmetric facets could lead to asymmetric loading on the spine, which in turn may cause asymmetric growth of the spine and development of spinal deformities. In support with the above it could be assumed that these patterns of normal variation of ZJs at the thoracolumbar region may be related to the incidence of low back pain or disc prolapse.

Acknowledgment:

Many thanks to Dr Hesham Said lecturer of radiology Cairo University and Dr Fouad Yehia Ahmed Prof. of Anatomy Ain Shams University for their kind cooperation and supervision

SUMMARY

In the present study the superior articular facets of zygapophyseal joints (ZJs) at the thoracolumbar region were investigated for any deviation from the typical thoracic or lumbar criteria. The study included 20 macerated vertebral columns and axial CT sections on 20 patients. Out of the present results three main types of transitional facets could be differentiated: coronally oriented, divided facets with the medial surface coronally oriented while the lateral surface was facing posterolaterally and lumbar like with less sagittalization and less concavity. Bilateral asymmetry was found to be a common feature in this region. According to the number of ZJs that include atypical facets, three main patterns of orientation changes could be elucidated at the transitional thoracolumbar region. Firstly, the gradual pattern, which is by far the most common (75%) where there was one coronally oriented ZJ i.e. atypical facets in 2 successive vertebrae. Secondly, the more gradual type with 2 successive atypical ZJs (in 10%). Thirdly, the sudden pattern (15%) where there was no atypical facet at all; and the transition occurred over one vertebra where its superior facet was thoracic and the inferior facet was lumbar in type. The process of transition of orientation was found to occur between T10-L1 but most commonly between T11,12. It could be assumed that these patterns of normal variations may be related to predisposition to the low back pain or even disc prolapse.

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الملخص العربى

النمط الانتقالي للمفاصل الزلالية بين فقرات المنطقة الصدرية والقطنية للعمود الفقري

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تمت دراسة السطح المفصلي العلوي لمفصل الفقرات في المنطقة الانتقالية بين الفقرات الصدرية والقطنية ، وذلك للبحث عن وجود أي صفات مختلفة عن الفقرات الصدرية أو القطنية المثالية . وقد استخدم في الدراسة (٢٠) عمود فقري بشري و (٢٠) صورة للأشعة المقطعية لـ(٢٠) فرد مختلف . وأظهرت الدراسة إن هناك (٣) أنواع من المفاصل المختلفة عن الفقرات الصدرية والقطنية المثالية :

أولاً : السطح المفصلي متجه إلى المستوى الإكليلي .

ثانياً : السطح المفصلي منقسم إلى جزئين والجزء الأيسر متجه إلى المستوى الإكليلي .

ثالثاً : السطح المفصلي متماثل لاتجاه الفقرات القطنية المثالية ولكنه أقل تقعراً وأقل اتجاهاً إلى المستوى الأوسط وقد وجد أن الاختلاف بين اتجاهات السطح المفصلي الأيمن والأيسر لنفس الفقرة شائع في الفقرات الانتقالية . وتبعاً إلى اتجاه السطح المفصلي فيمكن تقسيم المفاصل الغير مثالية بين الفقرات الانتقالية إلى ثلاثة أنواع :

١. النوع المتدرج : وجد في ٧٥ % من العينات حيث انه وجد مفصل واحد في الاتجاه الإكليلي أي بين سطح مفصلي سفلي وعلوي لفقرتين متتاليتين .

٢. النوع شديد التدرج : وجد في ١٠ % من العينات حيث وجد مفصلين متتالين في الاتجاه الإكليلي .

النوع الفجائي: وجد في ١٥ % من العينات حيث لا يوجد مفصل غير مثالي حيث وجد انه التغير في فقرة واحدة حيث أن السطح المفصلي العلوي يكون متماثل للفقرات الصدرية والسطح المفصلي السفلي متماثل للفقرات القطنية .

وقد لوحظ أن الفقرات الانتقالية حدثت من الفقرة الصدرية العاشرة والفقرة القطنية الأولى وأنها أكثر شيوعاً بين الفقرة الحادية عشر والثانية عشر .

ومن ذلك يمكن الافتراض بأن الاختلافات بين أنواع المفاصل الانتقالية له علاقة بالإصابة بآلام الظهر أو الانزلاق الغضروفي.