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The orientation of the articular facets of the zygapophyseal joints at the cervical and upper thoracic region

G. P. PAL, R. V. ROUTAL AND S. K. SAGGU

Department of Anatomy, M. P. Shah Medical College, Jamnagar, India

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ABSTRACT

Knowledge of the orientation of facet joints in the cervical and upper thoracic region is important for understanding the biomechanical properties and clinical conditions relevant to the neck. The study was undertaken on dry macerated bones from 30 adult male human vertebral columns. The orientation of the superior articular facets in relation to their inclination with the sagittal and transverse planes was examined between C3 and T3 vertebrae in each column. The linear dimensions of the superior articular facets and the width/height ratio were also calculated. The results show that all vertebrae at C3 level and 73% at C4 level displayed posteromedially facing superior articular facets. Similarly at T1 level (C7/T1 joint) and below, all columns showed posterolaterally facing superior articular facets. The level of change in orientation, from posteromedial to posterolateral facing superior facets, was not constant and occurred anywhere between C4 (C3/C4 joint) and T1 (C7/T1 joint). The change in orientation followed 2 different patterns, i.e. sudden or gradual. The C6 vertebra (C5/C6 joint) was the most frequent site to show the transition. The shape of the superior articular facets was circular to oval at C3, C4 and C5 levels and gradually changed to a transversely elongated surface at C7 and T1. These findings correlate well with various cervical movements and associated clinical conditions.

Key words: Spine; vertebrae; zygapophyseal joints; articular facets; cervical spondylosis.

INTRODUCTION

The zygapophyseal or facet joints are important structures in determining the biomechanical properties of the spinal column and are of clinical relevance. The pattern of orientation of facets guides and limits the excursion of the motion segments. The orientation of articular processes is also relevant in axial weight bearing (Schaik et al. 1997; Pal & Routal, 1999).

Accurate information concerning the orientation of the articular facets in the cervical region is not available in the literature. According to descriptions in textbooks of anatomy and orthopaedics the articular facets in the cervical region are oriented in the coronal plane; the articular surfaces of superior facets are stated to face upwards and backwards and the corresponding inferior facets to face downwards and forwards (Schaeffer, 1953; Bailey, 1974; Grieve, 1988; Sherk, 1989; Williams et al. 1989). Details about regional variation in the orientation of articular facets in the cervical region are not available.

The study of Panjabi et al. (1993) is probably the only one which gives the linear and angular measurements of articular facets in the cervical region. This study investigated the orientation of articular facets by measuring the angles made by facets in relation to the sagittal and transverse planes. However, a drawback of this study is that it provides information based on pooled data and no attempt was made to study the changing pattern of orientation of facets in individual columns. Although various reports are available on the orientation of facet joints at the thoracolumbar junction (Davis, 1955; Singer et al. 1988; Shinohara, 1997; Pal & Routal, 1999), such information is not available for the cervicothoracic junction.

The aim of the present study was to investigate the orientation of articular facets in the cervical and

Correspondence to Professor G. P. Pal, Department of Anatomy, Modern Dental College and Research Centre, Gandhi Nagar—Air Post Road, Indore 753112, India.

upper thoracic region. An attempt was also made to correlate the orientation of the facets with spinal movements and associated clinical conditions.

MATERIALS AND METHODS

The material consisted of 30 dry macerated human male vertebral columns from the collection of the M. P. Shah Medical College, Jamnagar, India. The articular facets of all columns were free from any congenital anomaly or degenerative changes. Although the exact age at death for individual column was not known, all were fully ossified (adult).

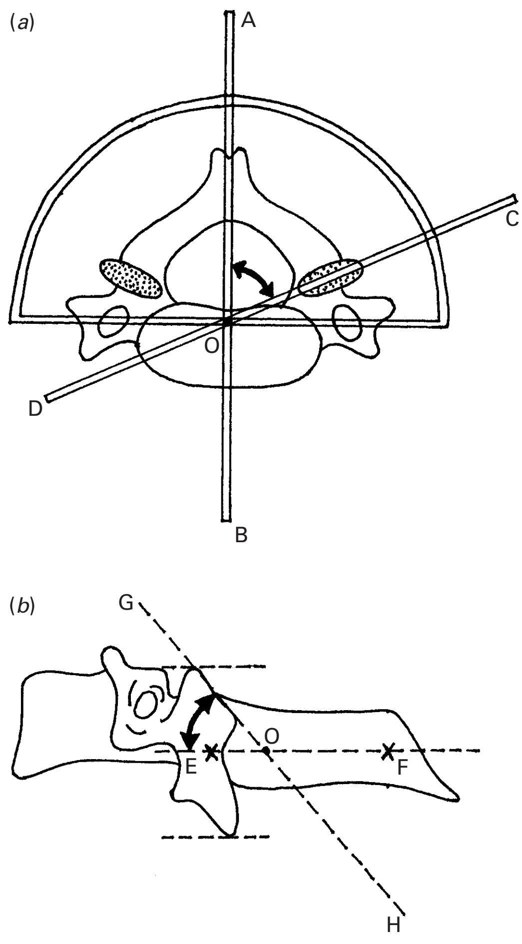

Fig. 1. (*a*) Drawing of a C3 vertebra, viewed from above with a modified protractor in place for measuring the angle of inclination of the superior articular facet in relation to the sagittal plane. AB, arm placed in midline, CD, same arm placed in relation to the inclination of facet. O, screw securing the arm to the protractor. AOC, angle measured (arrow). (*b*) Drawing of a typical cervical vertebra viewed from the lateral aspect. The line passing through the points E and F represents the transverse plane. The point E is midway between the superior and inferior articular processes and point F is midway between the superior and inferior borders of the lamina. The line GH represents the inclination of the superior articular facet in relation to the plane EF. The angle GOE (arrow) represents the angle of inclination in relation to the transverse plane, measured by a modified protractor.

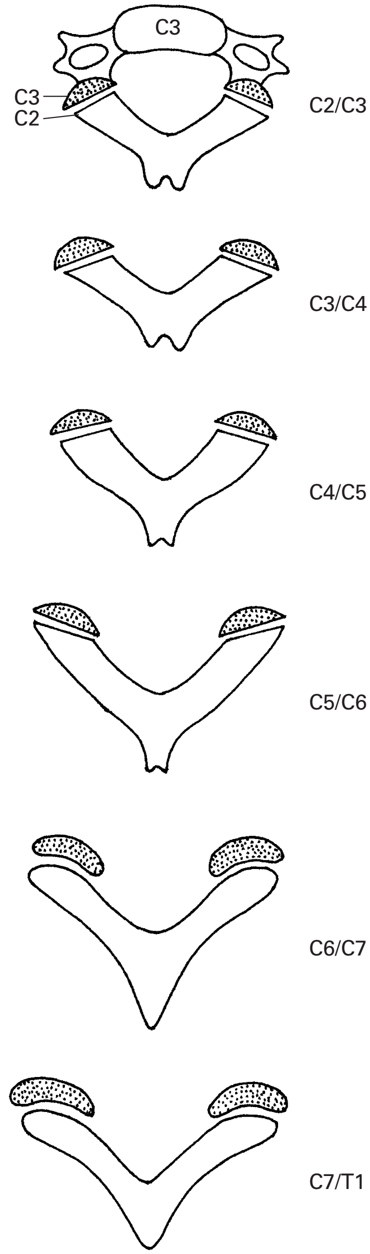

Fig. 2. Drawing showing the orientation of the superior articular surfaces (facets) from C3 (C2/C3 zygapophyseal joint) to T1 (C7/T1 joint) vertebral levels. The articular processes are drawn as seen from above. The body, transverse process, pedicle and superior articular process of C3 and inferior articular process of C2 are drawn to give the orientation of the facet joint at C2/C3. At all other levels, only the superior and inferior articular processes are drawn. The superior articular processes are shaded to differentiate them from the inferior processes. The sudden change in orientation of facets is seen at the C5/C6 facet joint.

The superior articular facets in all vertebrae from C3 to T3 were carefully studied for the following parameters.

Orientation of superior articular facets

Inclination of facets in relation to the sagittal plane. This measurement was carried out by the method of

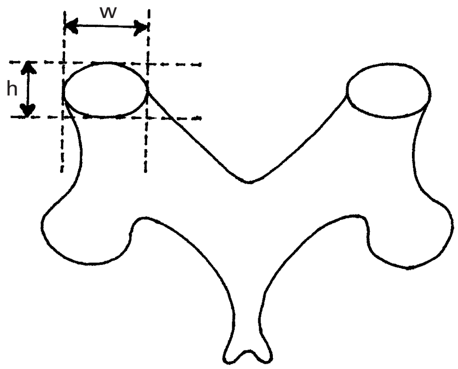

Fig. 3. Height (h) and width (w) of the superior articular facet obtained by a vernier calliper.

Tulsi & Hermanis (1993) with the help of a modified protractor (Fig. 1 *a*). The median sagittal line of the vertebra on its superior surface was determined by drawing a line through the root (base) of the spinous process and the midpoint of the body of vertebra. The midpoint of the body of the vertebra was obtained by another line running in the coronal plane through the widest portion of the body of the vertebra.

The data derived from individual columns were used to draw the orientation of superior articular facets sequentially from C3 to T3 (see below). These data were also pooled to determine the general pattern of orientation of the superior articular facets.

Inclination of facets in relation to the transverse plane. This measurement was carried out by drawing a transverse plane on the right and left surfaces of the vertebra. The transverse plane was determined by drawing a line passing midway between the superior and inferior articular processes and midway between the superior and inferior borders of the laminae (Fig. 1 *b*). The angle of inclination of the superior articular facets in relation to this transverse plane was measured with the help of a specially designed protractor.

All measurements were carried out thrice by one author (GPP) and the means recorded. Statistical analysis (*t* test) was applied to the pooled data to compare the differences in the orientation of articular facets in relation to the sagittal and transverse planes on both sides.

Sequential orientation of articular facets in individual columns. The direction of orientation of the superior articular surfaces (facets) on both sides from C3 to T3 was drawn in sequence from above downwards on paper (Fig. 2). The articular facets were drawn as seen from above and their orientation approximated to the angle that they make with the sagittal plane (see above). This helped to indicate the changing pattern of orientation of the articular surfaces and bilateral asymmetry (tropism) at a glance, within a column.

Linear dimensions of the superior articular facets

The maximum width and maximum height of the superior articular facets was measured with a vernier calliper in millimeters (Fig. 3). These measurements were taken to obtain the width/height ratio which gives a rough estimate of the shape of the articular facet, i.e. round, or vertically or transversely elongated.

RESULTS

The means ± S.D. for the angle of inclination of the superior articular facets in relation to the sagittal plane are shown in Table 1. No statistically significant difference was noted on either side ($P < 0.001$). From the mean value (pooled data, Table 1) the level of transition, from posteromedial to posterolateral facing facets, corresponded to the C6 vertebral level (C5/C6 zygapophyseal joints).

The means ± S.D. for the angle of inclination of the

Table 1. *Range, mean ± S.D. of the angle of the superior articular facet orientation in relation to the sagittal plane*

	Left side angle (°)		Right side angle (°)		
Vertebra	Range	Mean ± S.D.	Range	Mean ± S.D.	*t* value
C3	62–85	70.2 ± 7.03	54–85	69.50 ± 7.7	0.60
C4	60–104	82.0 ± 10.16	68–112	81.40 ± 9.56	0.23
C5	70–118	91.0 ± 11.78	75–120	91.0 ± 10.95	0.00
C6	76–120	95.93 ± 10.06	75–118	95.56 ± 10.45	0.14
C7	72–104	93.90 ± 7.40	78–105	94.23 ± 6.64	0.18
T1	86–110	99.03 ± 5.38	85–114	99.58 ± 5.49	0.32
T2	95–115	105.20 ± 5.07	96–118	106.89 ± 6.58	1.12
T3	102–120	109.50 ± 5.22	96–118	107.42 ± 5.95	1.48

Statistically significant differences were not observed ($P < 0.001$) on either side.

Table 2. *Range, mean ± S.D. of the angle of superior articular facet orientation in relation to the transverse plane*

	Left side angle (°)		Right side angle (°)		
Vertebra	Range	Mean ± S.D.	Range	Mean ± S.D.	*t* value
C3	32–60	46.83 ± 7.65	32–65	44.80 ± 9.43	0.91
C4	35–65	51.00 ± 7.62	35–66	50.63 ± 7.96	0.21
C5	45–70	53.63 ± 7.13	40–65	51.03 ± 6.16	1.52
C6	35–70	56.36 ± 8.82	35–75	55.73 ± 8.41	0.12
C7	50–78	64.13 ± 6.37	45–75	65.26 ± 7.35	0.63
T1	55–78	67.6 ± 6.31	64–78	70.06 ± 6.42	1.50
T2	60–80	69.55 ± 6.00	58–78	71.86 ± 3.92	1.77
T3	65–82	71.51 ± 4.28	65–82	71.86 ± 4.46	0.27

Statistically significant differences were not observed ($P < 0.001$) on either side.

Table 3. *Means of width and height of the superior articular facet (in mm) and width/height ratio*

	Left side		Right side		Width/height ratio	
Vertebra	Width	Height	Width	Height	Left Side	Right Side
C3	10.70	9.63	9.86	10.40	0.97	1.05
C4	11.00	10.5	10.56	10.93	1.02	1.02
C5	11.16	9.66	11.43	9.66	1.16	1.16
C6	11.93	8.74	12.66	9.23	1.31	1.38
C7	13.90	8.16	13.20	9.00	1.56	1.71
T1	14.13	9.13	14.37	8.37	1.64	1.57
T2	10.62	10.10	10.82	10.37	1.02	1.01
T3	9.92	9.57	9.84	10.19	1.02	1.03

superior articular facets in relation to the transverse plane are shown in Table 2. No statistically significant difference was seen ($P < 0.001$) on either side. The angle gradually increased from 45 ° at C3 to 72 ° at T3.

The maximum height and maximum width of the superior articular facets and the width/height ratios are presented in Table 3. The width was more variable as compared with the height. The width/height ratio indicated that width and height were almost the same at C3, C4, T2 and T3 levels. However, width was much greater at C7 and T1 as compared with height. The shapes of facets, based on their ratios, are presented in Figure 4. The facets at C3–C6, T2 and T3 were almost flat but the facets at C7 and T1 showed a slight concavity facing posterolaterally.

Based on the analysis of sequential orientation of the superior articular facets in individual columns (Fig. 2), it was observed that at C3 level (at the C2/C3 facet joint) all columns showed posteromedially facing superior articular facets. Similarly, at T1 level (C7/T1 joint) and below, all columns showed posterolaterally facing superior articular facets. The level at which a change in orientation from posteromedial to postero-lateral facing superior articular facets occurred was not constant; it took place anywhere between C4

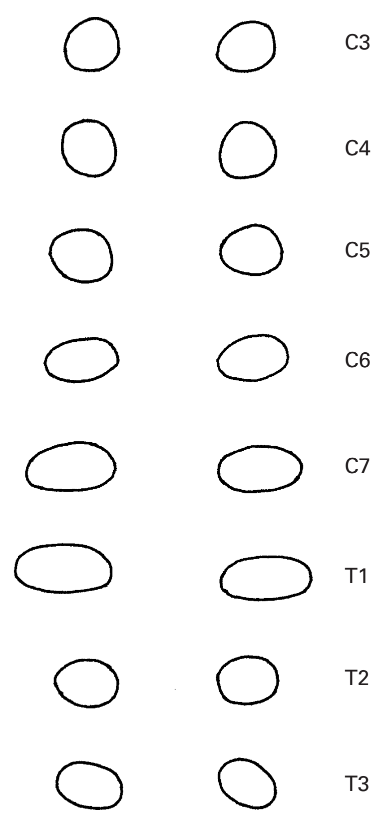

Fig. 4. Drawing to show the shape of the superior articular facets at various vertebral levels. These shapes were drawn from their mean measurements (Table 3).

Table 4. *Orientation of superior articular facets at various vertebral levels in 30 vertebral columns*

Vertebra	Orientation of superior articular facets		
	Posteromedial	Posterolateral	Transitional
C3	30 (100%)	—	—
C4	22 (73%)	03 (10%)	05 (17%)
C5	10 (33%)	09 (30%)	11 (37%)
C6	02 (07%)	18 (60%)	10 (33%)
C7	01 (03%)	23 (77%)	06 (20%)
T1	—	30 (100%)	—
T2	—	30 (100%)	—
T3	—	30 (100%)	—

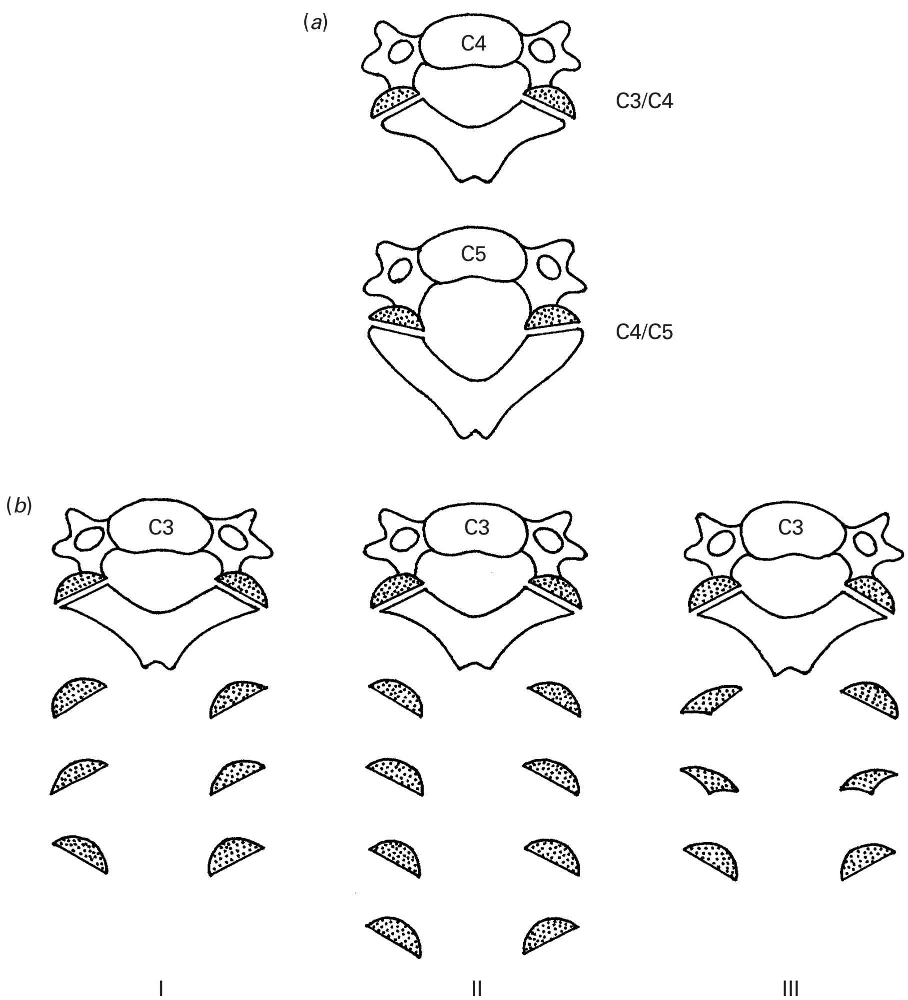

Fig. 5. (*a*) Drawing showing the sudden change from superomedial facing facets at C4 to superolateral facing superior articular facets at C5 vertebral level (at the C4/C5 zygapophyseal joint). (*b*) Drawing showing various patterns of gradual changes, i.e. both the superior articular facets of the transitional vertebrae facing posteriorly and to the right (I), posteriorly and to the left (II) and facets showing double articular areas (III). In each pattern, the C2/C3 facet joints are shown on the top. At the subsequent lower levels, only superior articular processes are drawn.

(C3/C4 joint) and T1 (C7/T1 joint). The C6 vertebra (the C5/C6 facet joint) was the most frequent site for the transition (Table 4).

The change in orientation followed 2 different patterns, i.e. sudden and gradual.

Sudden change

This change occurred at a single vertebra. A vertebra was considered as showing a sudden transition when both its superior articular facets faced posteromedially and both inferior facets faced anteromedially (Fig. 5*a*). Sudden change was observed in 11 out of 30 columns (37%). This change occurred at C3 level (at C3/C4 facet joints) in 3 columns; at C4 (C4/C5 joints) in 4 columns, at C5 (C5/C6 joints) in 2 columns and at C6 & C7 levels in 1 column.

Gradual change

The gradual transition from posteromedial to posterolateral facing superior articular facets extended over 2 to 5 successive vertebrae. This was due to the fact that of the 2 superior facets only 1 changed its direction from posteromedial to posterolateral. The other facet became posterolateral only after a few (successive) vertebrae (Fig. 5*b*). A gradual change occurred in 19 out of 30 columns (63%). The transition extended over 2 successive zygapophyseal joints in 11; over 3 successive joints in 5; over 4 in 1 and over 5 in 2 columns out of 19.

Three different types of gradual changes were observed (Fig. 5*b*). In type I columns both superior articular facets of successive transitional vertebrae faced posteriorly and to the right (7 out of 19 columns) and in type II columns they faced posteriorly and to left (9 out of 19 columns). In the third type of gradual transition (type III), the articular surface showed double areas (3 out of 19 columns). In a vertebra where an articular facet showed double areas, the medial region of the facet faced posteromedially (similar to the superior articular surface of C3) and the lateral region faced posterolaterally (similar to the superior articular surface of a thoracic vertebra). Both these areas were separated by a vertical ridge (Fig. 5*b*). For the measurement of angles, the larger surface area was considered.

An important observation was that, once the transition from posteromedial to posterolateral orientation had occurred unilaterally or bilaterally, reversal of this pattern was never observed in subsequent lower vertebrae (Fig. 5*a*, *b*).

DISCUSSION

Facet orientation

The textbook description that the cervical articular facets are oriented in a coronal plane is in marked contrast to the present findings. In the present study, it was observed that the superior articular facets face posteromedially in all columns at C3 level and in 73% at C4 levels; they faced posterolaterally at C6 and C7 and at C5, were almost oriented in coronal plane (Table 1). Tulsi (1968) studied the orientation at C3 vertebra and observed that the superior articular facets were always oriented posteromedially.

Panjabi et al. (1993) studied the orientation of superior articular facets by 2 different methods, i.e. the 'angle of inclination of the facet in relation to the sagittal plane' and by the 'card angle' method. They observed that the superior articular facets between C3 to T3 are all oriented in only one direction, i.e. facing posterolaterally in relation to the sagittal plane. This is not in accordance with the findings of the present study or that of Tulsi (1968) which indicated that C3 superior facets always face posteromedially. However, their findings with the 'card angle' method are different. According to this method, they observed that the superior articular facets at C3 and C4 face posteromedially and at C5 and below face posterolaterally. It is quite surprising that the same material of Panjabi et al. (1993) indicated 2 different orientations by 2 different methods for C3 and C4 vertebral levels.

A detailed study of the sequential orientation of articular facets from above downwards in individual columns (Fig. 2, Table 4) indicated that the pooled data of the present study (Table 1) and that of Panjabi et al. (1993) conceal important information and are thus misleading. First, the pooled data indicated a level of change in orientation at C5 (facet joints between C4/C5). Secondly, no information regarding various patterns of change in orientation can be deduced from these pooled data (Table 1). Thus the study of sequential orientation of facets in individual columns was helpful in providing the pattern and level of change in orientation.

In contrast to the change in orientation of articular facets at the thoracolumbar junction, the change in orientation was not confined to the cervicothoracic junction. In the cervical region, the change in orientation occurred anywhere between C4 and T1 vertebral levels (facet joints between C3/C4 and C7/T1). Posterolaterally facing superior articular facets were seen in only 10% of vertebrae at C4 level. This increased to 60% at C6 and 76% at C7 and all

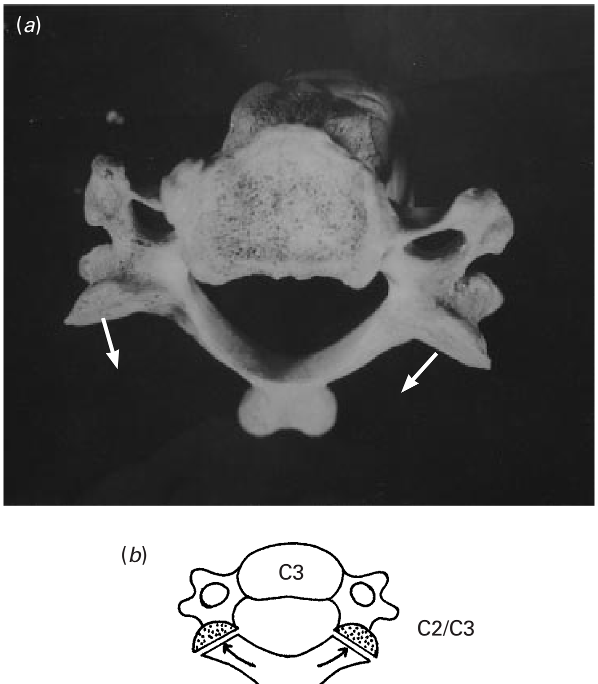

Fig. 6. (*a*) Photograph of C3 vertebra showing posteromedially facing superior articular facets. (*b*) Figure showing the C2/C3 zygapophyseal joints where both the superior articular facets face posteromedially. The superior articular facets of C3 prevent the rotational movement between C2/C3 joints, thus keeping the C2 vertebra in a fixed position.

vertebrae were oriented posterolaterally at T1 level (Table 4).

Kinematics of the cervical and upper thoracic vertebral column when the change in orientation of the superior articular facets is sudden

On the basis of the present study, an attempt is now made to speculate on the probable motions at facet joints. This assumption is based on the findings of the angle of inclination of the facets in relation to the sagittal (Table 1) and transverse planes (Table 2) and on the shape of articular facets (Table 3, Fig. 4).

Assuming that the change in the orientation of the superior articular facets occurs at C5 vertebral level (at C4/C5 facet joint), the cervical and upper thoracic column can be divided functionally into 4 different zones: (1) occipital condyle/C1 and C1/C2 joints; (2) C2/C3 and C3/C4 facet joints; (3) C4/C5 and C5/C6 facet joints; (4) C6/C7 to T1/T2 facet joints. The joint between the occipital condyles and C1 vertebra and C1/C2 (atlanto-axial joint) joints have independent nodding and side-to-side rotational movements respectively.

The posteromedial orientation of the superior articular facets (Fig. 6*a*) at C3 and C4 vertebral levels

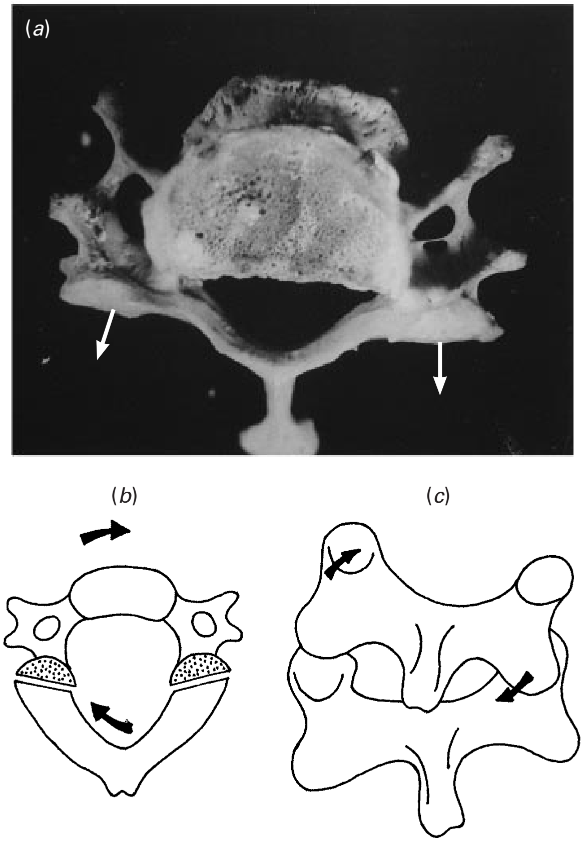

Fig. 7. (*a*) Photograph of C6 vertebra showing posterolaterally facing superior articular facets. (*b*) Drawing showing the posterolateral facing superior facets. These, facilitate rotational motion. (*c*) Diagram showing that rotation is accompanied by lateral flexion (Modified and redrawn from Grieve, 1988).

which resist the rotational motion has the following biomechanical significance. The side-to-side rotational movement occurs at the atlanto-axial joint. In this movement the skull along with C1 vertebra moves on the superior articular surfaces of the C2 vertebra. This can only be achieved if the C2 vertebra during this rotational movement remains immobile (fixed). The posteromedially facing superior articular facets of C3 vertebra at the C2/C3 zygapophyseal joint do not allow C2 vertebra to rotate on C3 and thus keep C2 vertebra fixed during rotational movement at the atlanto-axial joint (Fig. 6*b*). Thus posteromedially facing superior articular facets of all C3 vertebrae and most C4 vertebrae facilitate the rotational movement at C1/C2 joint by fixing the C2 vertebra. A posterolaterally facing superior articular facet of C3 vertebra would not facilitate the side-to-side movement at the C1/C2 joint as the C2 vertebra would not remain stable during rotational motion.

As the superior articular facets of C5 and C6 face posterolaterally in relation to the sagittal plane, these facets are inclined forwards in relation to the transverse plane (Table 2) and are oval or circular in

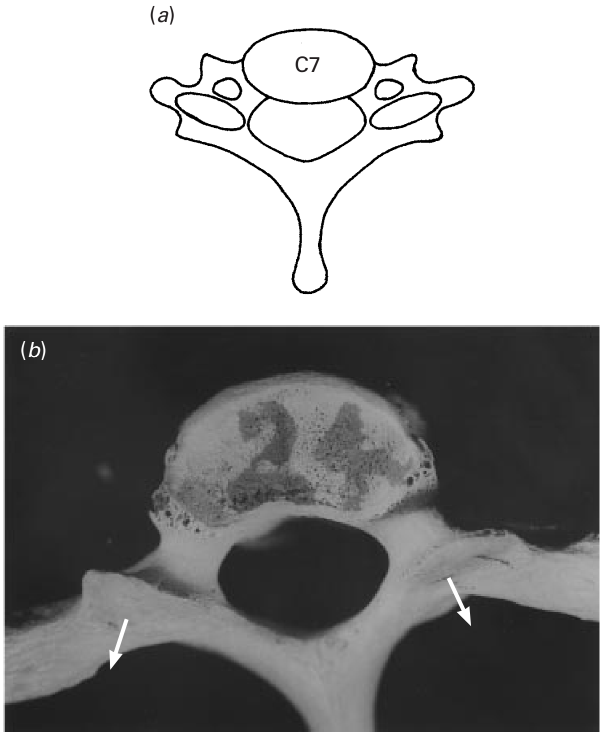

Fig. 8. (*a*) Diagram of a superior view of C7 vertebra showing transversely elongated posterolateral facing superior articular facets which extend from the laminae to the transverse processes. (*b*) Superior view of T1 vertebra showing the orientation of the superior articular facets at a right angle to the pedicles.

shape (Table 3, Fig. 4). Thus it is expected that all the above features would facilitate various movements such as flexion, extension, rotation and lateral bending to its maximum range. This assumption is supported by White & Panjabi (1978) who found the maximum range of movements at these cervical levels. The C5/C6 level is the most common site of facet orientation transition (Table 4). As the facets face posterolaterally (Fig. 7*a*), rotatory movements are easy (Fig. 7*b*). High mobility of the neck at this level is needed in man because of the erect posture and frontally directed eyes. However, it is also expected that because of the unique orientation of the superior articular facets in relation to the sagittal and transverse planes, rotational movement might not be absolutely pure. This is supported by Grieve (1988) who claimed that rotation is invariably accompained by lateral flexion to same side. In rotation, the facets overlap on the side to which rotation is occurring and glide apart on the opposite side (Fig. 7*c*). This is due to the forward inclination of the facets in relation to the transverse plane.

At the cervicothoracic junction, the shape of the superior articular facets changes from oval to transversly elongated (elliptical) (Fig. 4). The width of the facets is much greater than their height (Table 3), extending from the lateral end of the lamina to the medial end of the transverse process (Fig. 8*a*, *b*). Similarly, the articular facets are more vertical in relation to the transverse plane (Table 2). All these features of the facet indicate the restricted mobility of facet joints at these levels. This assumption is well supported by the findings of White & Panjabi (1978) and Grieve (1988) who observed that all ranges of movements quickly diminish at C6/C7, C7/T1 and T1/T2 joints. The restricted mobility at the cervicothoracic junction is assumed to provide stability to the junctional zone and transfer load from the zygapophyseal joints towards the bodies of the vertebrae (see below).

Kinematics of the cervical and upper thoracic vertebral column where the change in orientation of the superior articular facets is gradual

In columns showing gradual transition, both superior articular facets of transitional vertebrae face posteriorly and to the right, or posteriorly and to the left (Fig. 5*b*). It is expected that in this zone of columns showing gradual transition, the rotation and lateral bending would be restricted to one side. Assuming that in a transitional zone both superior articular facets face posteriorly and to the left (Fig. 9*a*), rotation and lateral flexion to the right would be expected to be unrestricted (Fig. 9*b*). However, an attempt at rotation towards the left in this column would be restricted by the posteromedially facing right superior articular facets (Fig. 9*c*).

The presence of a double articular area in a facet (Fig. 5*b*, III) represents a gradual attempt to change the orientation from a posteromedially-facing articular facet to a posterolaterally-facing facet. This assumption is supported by the fact that the lateral part of the articular surface was always facing posterolaterally and the medial part posteromedially (Fig. 5*b*).

Transmission of load through zygapophyseal joints in the cervical and upper thoracic region

It is well known that the zygapophyseal joints are highly loaded elements (Pal & Routal, 1986; Pal & Sherk, 1988). The articular process from C3 to C6 (between C2/C3 and C5/C6 joints) are in the form of bar-like structures and their successive articulations form the pillar. Thus the vertical compressive force, passing through the zygapophyseal joints between C3 and C6, is expected to remain confined to these articular pillars. Hence the load received at the

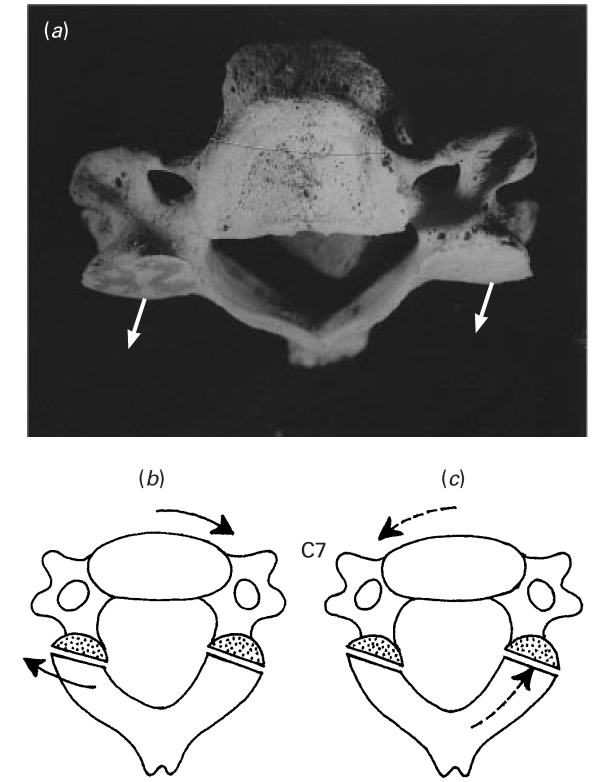

Fig. 9. (*a*) Superior view of a typical cervical vertebra showing both superior articular facets facing posteriorly and to the left. (*b*) Diagram showing that when both superior articular facets face posteriorly and to the left the rotation of the neck (and face) to the right is an unrestricted movement. (*c*) Rotation of the neck (and face) to the left will be a restricted movement as the right facet faces posteromedially.

superior articular facets will pass directly downwards to the inferior articular facets irrespective of whether they face posteromedially or posterolaterally. Thus it is expected that the direction of orientation of facets between C2/C3 and C5/C6 joints mainly determines the direction and range of movement.

In the absence of bar-like articular process at C7 (and in some columns also at C6 the load, while transmitting from the superior articular facets to the inferior articular facets, diffuses onto the laminae (Pal & Routal, 1996). As the morphology of the articular facets at T1 and T2 is similar to that at C7, the same mechanism of diffusion of load onto their laminae is expected.

As there is a change in the morphology of facets at the cervicothoracic junction (Table 3, Fig. 4), change in direction of forces acting on facet joints, is also expected. A considerable proportion of the load acting on the zygapophyseal joints is expected to go towards the body of the vertebra through its pedicles at C7, T1 and T2 levels. This assumption is supported by the following facts. (1) There is a change in curvature at the cervicothoracic junction; (2) the line of gravity changes its direction at this junction; (3) the C7, T1 and T2 vertebrae are inclined forwards and downwards; (4) the superior articular surfaces of C7, T1 and T2 are transversly elongated and are oriented at a right angle to the direction of the pedicle (Fig. 8*c*).

The superior articular facets of C7 and T1 are quite large and wide (Table 3, Fig. 4). These facets are much more vertically oriented as compared with C3 to C6 levels (Table 2). Their surfaces are not smooth but mostly show uneven surfaces with a slight concavity facing posteriorly. Similar to the observation of Davis & Rowland (1965), we also observed the presence of 'butting facets' or 'shelves' on the T1 and sometime on T2 inferior boundaries of the superior articular facets. On these butting facets the lower margin of the inferior articular facets of the vertebra above abut during strong compression. All the above morphological features seem to be a special adaptation to prevent forward slip of C7 on T1 and that of T1 on T2.

Clinical relevance

On the basis of the findings of the present study, an attempt will be made to explain the mechanisms for facet dislocation, cervical spondylosis, spondylolisthesis and neck movements.

Bilateral facet dislocation is a flexion injury where there is a major anterior displacement, whereas unilateral facet dislocation is an exaggerated axial rotation that is coupled with lateral bending (Fig. 7*c*). Sherk (1989) and Ramani (1996) reported that dislocations are most common at C5 and C6 levels. The present study provides an explanation for this observation. The C5 and C6 vertebral levels are the most mobile segments of the neck because of posterolaterally facing superior articular facets. These offer the least resistance to flexion forces, leading to bilateral dislocation. This is facilitated by the forward inclination of the superior articular facets in relation to the transverse plane (Table 2). This kind of facet orientation also facilitates unilateral facet dislocation due to the exaggerated amount of axial rotation coupled with lateral bending. Unilateral dislocation is also expected to occur at transitional vertebrae showing tropism (Fig. 9*b*). This dislocation will occur only towards the side showing a posterolaterally facing facet. The posteromedially facing facet will resist rotational movement (Fig. 9*c*).

According to Grieve (1988) and Ramani (1996), the C5/C6 intervertebral joint is the one most commonly affected in cervical spondylosis. This may be due to the fact that the C5/C6 joint is the most mobile segment and it is expected that it would thus be subjected to maximum wear and tear, making this segment the most common site for spondylosis. Asymmetry of facet joint orientation has been considered a causative factor in disc degeneration (Farfan & Sullivan, 1967; Hagg & Wallner, 1990). Thus it is tempting to speculate that the transitional zone of the cervical vertebral column, which shows asymmetry in the orientation of its articular facets (Fig. 5*b*) would be predisposed to disc injury or herniation.

It has been reported that spondylolisthesis mostly occurs at C6 (Sherk, 1989; Black et al. 1991; Herrera & Puchades-Orts, 1998). On the basis of the present study, an explanation for spondylolisthesis at this level can be provided. The bar-like articular pillar which extends between the superior and inferior articular processes at C3, C4 and C5 is usually absent at C6. The superior articular process of C6 forms the lower end of the articular pillar which extends between the C2/C3 and C5/C6 joints. In the absence of an articular pillar at C6, the load diffuses onto its lamina while passing from the superior to the inferior articular processes. The C6 vertebra is inclined forwards and thus has a tendency to slip downwards and forwards on C7. This is resisted by the large and wide superior articular facets of C7. The superior articular facets of C6 receive a considerable compressive load vertically, while its inferior facets have to bear the resistance offered by the C7 facets in the transverse direction to prevent forward slip. This change in direction of forces generates excessive stress at the interarticular area (the area of the lamina between the superior and inferior articular facets). This may eventually lead to a break at the interarticular area and thus spondylolisthesis. This mechanism also explains the presence of an incisura at the C6 level (Herrera & Puchades-Orts, 1998) which may be a forerunner of spondylosis.

Various movements of the human cervical spine (flexion, extension, lateral bending and rotation) have been studied by many investigators (Bhalla, 1968; Penning, 1968; Lysell, 1969; White & Panjabi, 1978; Stoddard, 1981; Ramani, 1996). However, their findings are contradictory as far as the range and mean values of different movements at different cervical levels are concerned. This might be due to the fact that in different regions of the cervical vertebral column the direction of orientation of articular facets differs, i.e. at C3 and C4 the superior facets face posteromedially while at lower levels (C7, T1) they face posterolaterally. The change in orientation of facets follows different patterns (sudden or gradual) at midcervical levels. Tropism of facets is seen in transitional vertebrae. The level of change in orientation of facets also varies from person to person (Table 4). As the orientation of articular facets in the cervical region is higher variable, a general pattern cannot be formulated as far as cervical movements are concerned. Therefore, the joints of individual patients should speak for themselves.

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