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SPONDYLOSIS DEFORMANS IN THE DOG

A Morphologic Study with Some Clinical and Experimental Observations

by

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To My Family

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PART I

Introduction and Literature Review

Introduction

Spondylosis deformans in the dog is a condition of the vertebral column familiar to veterinarians. It involves the vertebral body at the intervertebral space and is characterized by formation of spurs or complete bony bridges. These may be single or multiple in distribution and are often noticeable and impressive. The condition is frequently an incidental finding during routine radiographic examination or at necropsy. Reports of the etiology, pathogenesis, frequency, distribution, and clinical significance have been incomplete and contradictory.

The aim of the present investigation is to describe more completely this condition in the dog.

There are numerous and more extensive studies of spondylosis deformans in man, but agreement concerning the etiology, pathogenesis, and clinical significance is lacking. The condition has also been described in quadrupeds other than the dog. Comparative aspects of the condition are to be considered in a discussion of its structure, pathogenesis, and clinical significance.

Literature Review

Knowledge of anatomical details of the canine vertebral column is essential for an understanding of spondylosis deformans in the dog. Anatomical descriptions are readily available (Hansen 1952, King and Smith 1955, King 1956, Smith 1960, 1966, Hare 1961 a, b, Miller *et al.* 1964, Hoerlein 1965).

Disagreement on a specific pathogenesis of spondylosis deformans has permitted use of a varied nomenclature. The individual bony growth has been referred to as a bony spur, spondyle, or a vertebral osteophyte. The condition has been known as spondylitis deformans traumatica, spondylitis ossificans deformans (Pommer 1933), spondylarthritis (Schick 1942), anchylosing spondylitis (Boddie 1949), spondylosis deformans (Hansen 1952), spondylitis deformans, spinal osteoarthritis (Glenney 1956), morbus Bechterew (Schnitzlein and Martin 1957), ankylosing spondylitis (Archibald and Cawley 1959), syndesmitis ossificans (Martin 1959), and spondylitis (Hoerlein 1965). It is possible that some of these terms have been used to describe conditions of traumatic or infectious nature. However, similarities in morphology have been suggested by the descriptions.

Pommer (1933, 1936) reviewed earlier studies on the vertebral column of the dog and other animals and described two types of vertebral fusion based on radiographic studies. When fusion occurred at the level of the vertebral bodies, he used the term spondylitis ossificans deformans or spondylitis deformans traumatica. Fusion at the level of the articular processes was referred to as spondylarthritis ankylopoetica. Ipolyi (1939, 1941) continued to use Pommer's classification and terminology in a report on examination of 229 dogs. Pommer's classification was again used in its original form by Hoerlein (1965).

The incidence of spondylosis deformans in the dog has been related to sex, age, and breed. The condition has been described in all ages with higher incidence in old age (Pommer 1933, Ipolyi 1939, 1941, Schick 1942, Debard 1949, Hansen 1952, Fankhauser 1955, Glenney 1956, Martin 1959, Schnitzlein 1960, Morgan *et al.* 1966, Read 1966). Both number of affected dogs and degree of involvement have been shown to increase with age (Schick 1942, Morgan *et al.* 1966).

Most reports have indicated equal occurrence of spondylosis deformans in both sexes (Pommer 1933, Ipolyi 1939, Hansen 1952, Martin 1959, Read 1966). However, a higher incidence in both male (Bruder 1955, Fankhauser 1955) and female (Morgan *et al.* 1966) has been reported.

It has been proposed that there is a predisposition in the boxer (Hansen 1952, Glenney 1956, Martin 1959, Schnitzlein 1960, Zimmer and Stähli 1960, Morgan *et al.* 1966) and in the larger breeds (Pommer 1933, 1936, Ipolyi 1939, 1941, Boddie 1949, Debard 1949, Fankhauser 1955, Martin 1959, Morgan *et al.* 1966). The dachshund has been reported to have a lower incidence (Pommer 1933, 1936, Fankhauser 1955, Morgan *et al.* 1966), although others have suggested a higher incidence (Archibald and Cawley 1959).

Distribution patterns showing a higher involvement in specific areas throughout the vertebral column have been described (Pommer 1933, Hansen 1952, Bruder 1955, Glenney 1956, Martin 1959, Schnitzlein 1960, Morgan *et al.* 1966, Read 1966).

Total incidence reported has ranged from 9 to 75 per cent (Pommer 1933, Ipolyi 1939, 1941, Hansen 1952, Glenney 1956, Schnitzlein 1960, Morgan *et al.* 1966, Read 1966).

Varying suggestions of etiology and pathogenesis of spondylosis have been offered. Pommer (1933) reported that stresses on the ligaments and periosteum were significant. These stresses could be normally present in active dogs or could be due to degenerative discs, trauma, or repeated pregnancies.

Ipolyi (1939, 1941) thought that intervertebral disc softening due to trauma or muscle or ligamentous weakening must always precede vertebral changes. Resulting motion and disc herniation exerting pressure on the periosteum were important. However, he discounted the importance of the longitudinal ligament in the pathogenesis.

Schick (1942), Fankhauser (1948), and Hansen (1952) also associated disc changes with spondylosis deformans. Schick noted in a radiographic study that affected vertebral bodies were sclerotic and disc spaces narrowed. Hansen described two types of disc protrusion in the dog. Type I protrusions were caused by a total rupture of the anulus fibrosus and were massive in scope. Type II protrusions were more limited and were caused by a partial rupture of the anulus fibrosus with a bulging of the dorsal surface of the disc. He concluded that spondylosis deformans and the two types of disc protrusions were separate morphologic expressions of disc degeneration. Degeneration resulting in protrusions of type II had similarities to that associated with spondylosis deformans. Simultaneous presence of spondylosis deformans and type II protrusions in the cervical region of the dog was found rarely by Olsson and Hansen (1952). Hansen (1952) also thought that the attachments of the ventral longitudinal ligament might have played a role in the development of osteophytes, if changes in the disc were minimal.

Martin (1958, 1959) observed that intervertebral discs, associated with vertebral osteophytes, were normal in appearance. If there were changes in the discs, he interpreted them as appearing later than the osteophytes. He seemed to be influenced by descriptions of ankylosing spondylitis in man and suggested an association of changes in the dog with prostatic disease and sacro-iliac change. He introduced the name syndesmitis ossificans into veterinary literature recognizing a primary ossification of vertebral ligaments.

Schnitzlein and Martin (1957) and Schnitzlein (1960) also stressed the role of the ligaments and described the vertebral changes as morbus Bechterew. This is synonymous with spondylarthritis ankylopoetica or ankylosing spondylitis.

Archibald and Cawley (1959) considered that the condition satisfied the definition of a rheumatoid spondylitis and referred to it as ankylosing spondylitis.

Throughout the review of literature the alternate use of the terms spondy*litis* and spondy*losis* was obvious. Hansen (1952) appeared to be the first in veterinary literature to use the term spondylosis. Hoerlein (1956, 1959) returned to the use of spondylitis since he described the condition as inflammatory with complete ossification of vertebral ligaments. In 1965, he considered spondylosis deformans to be similar to specific osteomyelites of vertebrae such as those due to mycotic infection and spirocerca lupi. Glenney (1956) also defined the condition as an inflammation of the vertebra.

Clinical significance has been attributed to spondylosis deformans from the time of early works. Pommer (1933, 1936) described cases both with and without clinical signs. However, it would be difficult to determine the exact part disc herniation played in his material. In his study of calcinosis and enchondrosis intervertebralis (1937), he stated that the clinical appearance due to disc herniation was very similar to that caused by spondylitis ossificans.

Ipolyi (1939, 1941) described clinical signs in dogs progressing to paralysis but mentioned that 50 per cent of his cases with spondylosis deformans were asymptomatic. He found no relationship between degree of spur formation and symptoms.

Differential diagnosis of paraplegia or paresis in the dog has frequently included spondylosis deformans (Fankhauser 1948, 1955, Boddie 1949, Debard 1949, Hoerlein 1953, 1956, Müller 1955, Glenney 1956).

Debard (1949) described pain as a result of vertebral spurs causing tension on vertebral ligaments. He also reported pain due to pressure on spinal nerve roots.

Hoerlein (1956) briefly described vertebral osteophytes in a discussion of clinical conditions affecting the vertebral column of the dog. Later (1965), he attributed pain to resulting pressure on spinal nerves or spinal cord. Belkin (1958) also described involvement of the spinal cord or nerves as causing clinical symptoms.

Vertebral osteophytes have been described in dogs in which there were no clinical signs pointing to the vertebral column (Brook 1936, Martin 1958, 1959, Morgan *et al.* 1966).

PART II

Morphologic Studies

A. Material and General Methods

The present morphologic study included a material of 100 vertebral columns with spondylosis deformans. This material was obtained from two different groups of dogs.

The majority of cases was included in a group of 119 vertebral columns randomly selected from the Pathology Department of the Royal Veterinary College, Stockholm, Sweden. They were removed from necropsied dogs 2 years of age and older, from October 1964 until May 1965. This material was used in studying the incidence of spondylosis deformans, and allowed statistical evaluation of findings.

The second group consisted of 26 vertebral columns specifically selected because they were affected with spondylosis deformans. These dogs were either presented to the College for euthanasia or submitted for necropsy.

Information concerning age, sex, and breed was obtained in all cases except two. Necropsy reports were available for study on all dogs obtained from the Pathology Department.

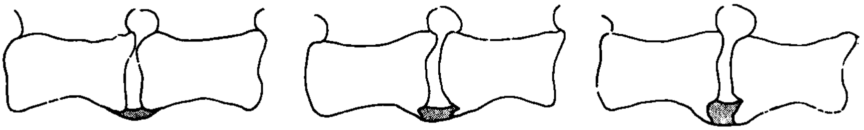
The routine method of examination for the entire material was to disarticulate vertebral columns at the atlanto-occipital and sacro-iliac articulations. If these last mentioned joints were fused, the pelvis was removed from the cadaver together with the vertebral column.

With a band-saw, ribs were cut 2 to 5 centimeters from the vertebral column. The large muscle masses were removed and an identification tag attached.

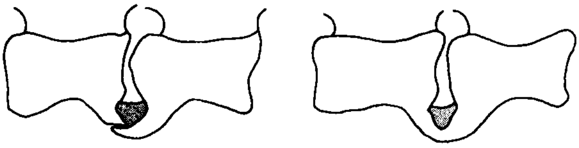
The entire specimen was then radiographed. Depending on the dog's size, a total of six to ten exposures was made in two projections on non-screen film.

The first part of the gross examination was directed toward soft tissue structures adjacent to the vertebral column.

Size and location of osteophytes on the vertebral margins were noted at gross dissection and compared with the radiographic appearance. Size was then recorded using a technique similar to the one described by Nathan (1962) (Fig. 1). Five stages of development were defined. Stage one represented earliest gross findings, which were palpable nodules not identified on the macroradiographs. The changes were located over intervertebral spaces and adjacent



Stage one Stage two Stage three



Stage four Stage five

Fig. 1. Five stages used in recording size and shape of vertebral osteophytes as determined grossly and macroradiographically. Stage one could only be identified grossly since it contained soft tissues. (The shading indicates soft tissue).

vertebral rims and were up to 5 millimeters in diameter. Stage two consisted of small osteophytes on the vertebral margins. They were the earliest changes seen radiographically. Stage three was characterized by larger bony projections with a cup shape but without extension beyond the vertebral end plate. Stage four was identified by the tip of the osteophyte extending beyond the edge of the vertebral body ventrally and/or laterally. No union between opposing osteophytes was noted. Unattached crescent-shaped or triangular-shaped radiopaque segments found within ventral anular tissue were included in this category. In stage five bony fusion had occurred between opposing osteophytes.

If more than one osteophyte was located on the margin of a vertebral end plate, only the size of the largest spur was recorded.

The position of spurs on the vertebral margin was primarily determined by gross dissection. The perimeter of the vertebral margin was divided into four sectors that were designated as dorsal, ventral, right lateral, and left lateral (Fig. 2). Some osteophytes were of such size or distribution that they were recorded in more than one sector.

The vertebral columns of 96 dogs were disarticulated and component parts individually examined. The radiographic study was available for comparison during gross examination. Clinical history and necropsy results were purposely not studied until after completion of dissection.

Examination of cervical vertebrae was accomplished by two methods. In small dogs the pedicles of the vertebrae were cut with bone-cutting forceps and

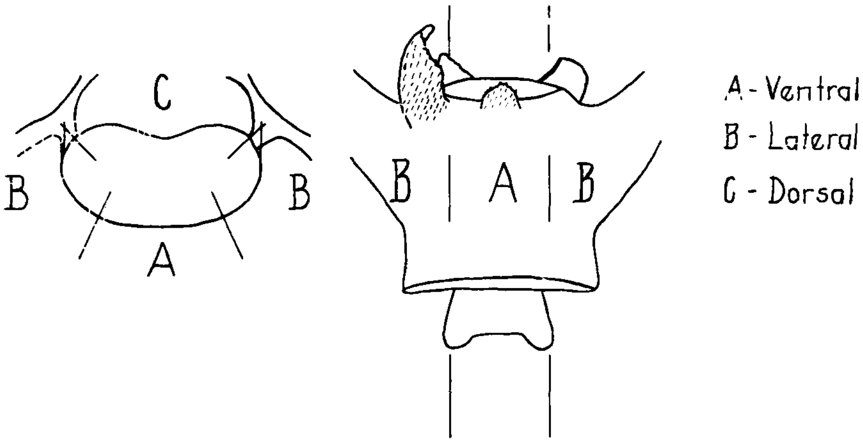


Fig. 2. Pattern used in recording location of osteophytes on the vertebral margin as determined grossly.

the arches removed intact. This permitted evaluation of the floor of the spinal canal following removal of the spinal cord. Each intervertebral disc was cut transversely to permit examination. Neural arches were separated through disarticulation of the vertebral synovial joints. In large dogs it was impossible to cut through the pedicles of vertebrae with the bone-cutting forceps which were available. Therefore, separation of the entire vertebral segment was accomplished by first cutting transversely through the intervertebral disc and then disarticulating the vertebral synovial joint.

The thoracic and lumbar portions of the vertebral columns in all dogs were examined in the following manner. The vertebral arch and spinal cord were removed following cutting of the pedicles bilaterally with bone-cutting forceps. The vertebral synovial joints were disarticulated and each rib removed. Most of the intervertebral discs were cut in a transverse plane near the disc centers. A relatively small number of discs were sectioned in a sagittal plane (page 26).

Based on earlier studies (page 7), the morphologic condition, as determined grossly, was recorded according to five stages. The first two stages were considered to represent normal maturation and formed Group A. The last three stages were considered to have definite signs of degeneration and were placed into Group B. Protruded discs were recorded separately and evaluated as one of the end results of disc degeneration.

The first of the five stages included normal maturing discs. The nucleus pulposus was mucoid, gelatinous, and glistening, and there was a sharp demarcation between nucleus and anulus fibrosus. Anular fibers were easily identified in the periphery of the disc and blended into one perinuclear band. There was no evidence of fissures, discoloration, herniations, or prolapses.

Stage two was characterized by further maturation of the disc, with most of the gross changes present in the nucleus pulposus. It was more fibroid and dull in appearance, becoming grayish or milky white in color. A distinction between anulus and nucleus was still present. The anulus had become more coarse in appearance and minimal separation between lamellae could be seen.

Stage three included all forms of nuclear calcification and applied with few exceptions to chondrodystrophoid breeds. Various degrees of intradiscal nuclear protrusion and true nuclear prolapse were noted. Generally the appearance of the anulus fibrosus was similar to that found in stage two.

Stage four included discs with marked degeneration without calcification. The nucleus appeared firm in consistency, fibrous, and sometimes lumpy. It could not easily be distinguished from the inner anular fibers. Large cavities or stellate-shaped fissures were present in the nucleus. There was further development of the coarseness in the anulus fibrosus. Yellowish discoloration was rather common in this stage and dehydration was obvious.

Stage five included discs severely degenerated with little recognizable tissue remaining. Because degeneration was extensive, it is possible that calcified material was overlooked. The tissue fragmented badly on cutting due to excessive dehydration. There were large cavities and fissures throughout the disc. Intradiscal nuclear protrusion and anular bulging was noted. Discoloration was common and varied from dark grey or brown to bright red.

The gross morphologic condition of vertebral synovial joints and costovertebral articulations was recorded. Those joints which had smooth and glistening cartilage with no discoloration or marginal osteophytes were considered normal. Joints with erosion, pitting, or discoloration of the cartilage and/or marginal osteophytes were classified as changed.

A group of 49 vertebral columns was handled in such a way that thorough dissection was not possible. This group included 9 that were boiled to remove soft tissue, 6 that were used for isotope studies to be reported in a later paper, 6 that were cut sagittally for examination and photography, 20 that had sections removed for microscopic or radiographic studies in such a way that complete dissection was not possible, 3 that were excluded because of radiographic signs of metastatic neoplasia in the vertebrae, and 5 that did not show any changes of spondylosis deformans.

Throughout the present study each intervertebral space was identified by the number of its intervertebral disc counted from the cranial to the caudal region (Hansen 1951, 1952).

Chi square (with Yates' correction) or t-tests were used for statistical evaluation. Means are given together with the standard deviations. The results of statistical analysis were recorded as not significant ($P>0.05$), almost significant ($0.05>P>0.01$), significant ($0.01>P>0.001$), and highly significant ($0.001>P$).

Certain methods were used that were specific for a particular type of investigative procedure. These will be described later.

B. Results

1. Incidence and Distribution

The occurrence of vertebral osteophytes was examined from different aspects. The incidence, irrespective of number of osteophytes per vertebral column, within the randomly selected material was considered from the standpoint of sex, age, breed, and weight of the dog. The material was also divided into groups of dogs of chondrodystrophoid and non-chondrodystrophoid breeds and the incidence determined. Distribution throughout the vertebral column, location on the vertebral margin, and the average size and number of osteophytes on each affected vertebral column were determined. The incidence was more thoroughly studied in the three most highly represented breeds from the randomly selected material.

Incidence and Causes of Incidence Variation

The incidence of spondylosis deformans in the total material was 71/116 (0.61).

Sex — The frequency of affected males was 34/53 (0.64) and of affected females was 37/63 (0.59). This difference in sex distribution was not significant ($\chi^2 = 0.16$; d.f. = 1).

Age — Dogs were divided into age groups and evaluated for incidence of vertebral osteophytes (Fig. 3). Approximately 50 per cent were affected by the age of 3 to 6 years. By the age of 9 years, 75 per cent had changes and the figure approached 100 per cent in dogs of still higher age. The effect of age could also be noted when the incidence of each of the five stages of osteophytes was plotted following division of the entire material into three age groups (Fig. 4).

Breed — The incidence of vertebral osteophytes could only be compared in the three breeds with greatest representation. Frequency in the German shepherds was 9/13 (0.69), dachshunds 18/24 (0.75), and boxers 18/19 (0.95). Heterogeneity between breeds was measured and the difference in frequency was determined to be not significant ($\chi^2 = 1.84$; d.f. = 2).

Constitution — Hansen's definition of chondrodystrophoid breeds (1952) was used as a criterion for division of the material. The frequency of spondylosis deformans in chondrodystrophoid breeds was 22/29 (0.76) and in non-chondrodystrophoid breeds was 49/87 (0.56). Heterogeneity between groups

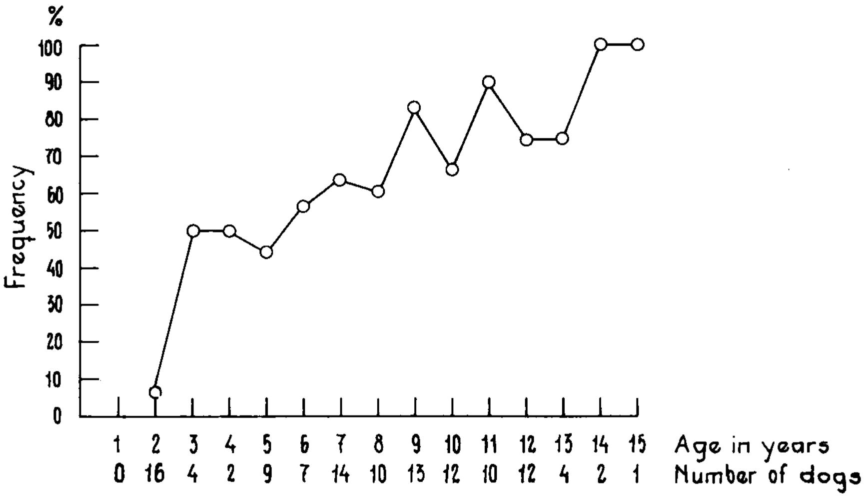


Fig. 3. Frequency distribution of spondylosis deformans as related to age in the randomly selected material.

was measured and the difference was determined to be not significant ($\chi^2 = 3.57$; d.f. = 1).

Weight — Comparison was also made following division of the randomly selected material into weight classes. Frequency in dogs weighing 10 kg or less was 18/38 (0.47), 10.1 to 20 kg was 15/27 (0.56), 20.1 to 30 kg was 23/34 (0.68), and over 30 kg was 15/17 (0.88). Heterogeneity between the different weight classes was measured and determined to be almost significant ($\chi^2 = 7.21$; d.f. = 3).

Number of Osteophytes on Each Vertebral Column

The number of osteophytes present on each vertebral column from dogs in the randomly selected group was determined. The mean frequency in those under 4 years was 3.50 (± 3.12), 4 to 10 years was 10.66 (± 8.26), and over 10 years was 12.30 (± 8.87). The difference in number of osteophytes between those under 4 years and those 4 to 10 years was highly significant (t = 3.58; d.f. = 46), the difference between those 4 to 10 years and over 10 years was without significance (t = 0.74; d.f. = 65), and the difference between those under 4 years and over 10 years of age was significant (t = 3.64; d.f. = 25).

In the total affected material, the mean frequency of number of osteophytes on each vertebral column of dogs under 4 years was 7.00 (± 4.34), from 4 to 10 years was 10.96 (± 8.81), and over 10 years was 12.49 (± 8.84). The differences between those under 4 years and those 4 to 10 years, and between those 4 to 10 years and over 10 years, were without significance (t = 1.84; d.f. = 57; t = 0.83; d.f. = 92). The difference between those under 4 years and over 10 years was almost significant (t = 2.44; d.f. = 45).

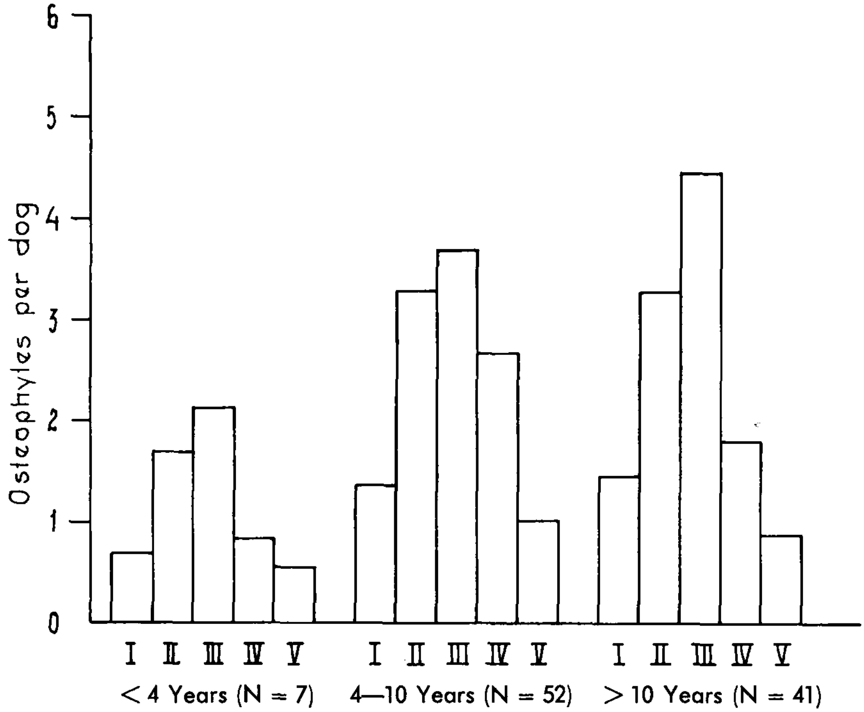


Fig. 4. Frequency of the five stages of vertebral osteophytes in 100 dogs with spondylosis deformans following division into three age groups.

The number of osteophytes present on each affected vertebral column was specifically determined for each of the dogs belonging to the three most highly represented breeds. The average numbers were 5.94 (± 5.98) in the dachshund, 11.11 (± 8.99) in the German shepherd, and 17.61 (± 8.72) in the boxer. Pairwise comparisons were made and the difference between the number of osteophytes found in the dachshunds and boxers was highly significant ($t = 4.67$; d.f. = 34). The differences found between the dachshunds and German shepherds and between the German shepherds and boxers were not significant ($t = 1.50$; d.f. = 25; $t = 1.79$; d.f. = 25).

Incidence of Stages of Osteophytes

The average incidence of each of the five stages of osteophytes per affected vertebral column was determined following division of the entire affected material into three age groups (Fig. 4).

The average incidence of each of the five stages of osteophytes found on the affected vertebral columns of dogs from the three most highly represented breeds was determined (Fig. 5).

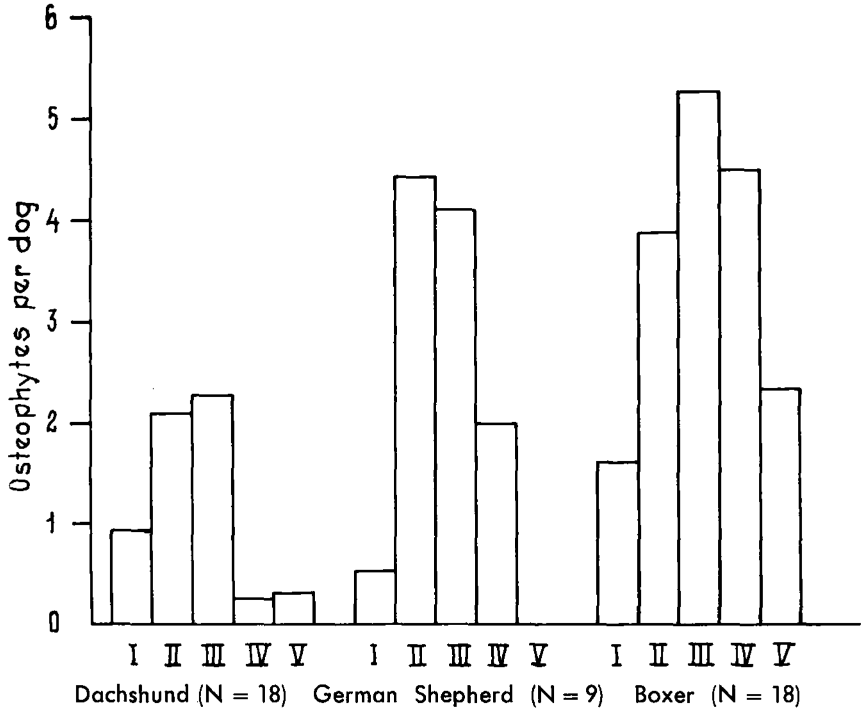


Fig. 5. Frequency of the five stages of vertebral osteophytes in affected vertebral columns in the three breeds most highly represented.

Distribution of Osteophytes within the Vertebral Column

Distribution was plotted graphically (Fig. 6). Frequency in the cervical region was low compared to the remainder of the vertebral column. No osteophytes were found involving the first cervical vertebra or the odontoid process of the second. A low frequency was also noted in the first three thoracic segments and was followed by a steady increase, with a peak at disc number 15. There followed a decline in number of osteophytes from disc number 16 through 25, and a second peak was present at disc 26.

Distribution of each of the five stages of osteophytes was recorded graphically (Fig. 6). Most in the cervical region were small, with only two belonging to stage five. The majority of spurs in the thoracic region was of stages two and three, while those of stage five were relatively rare. Most of the osteophytes in the lumbar region were of stages three and four and the number of stage five spurs was greater than in other areas of the vertebral column.

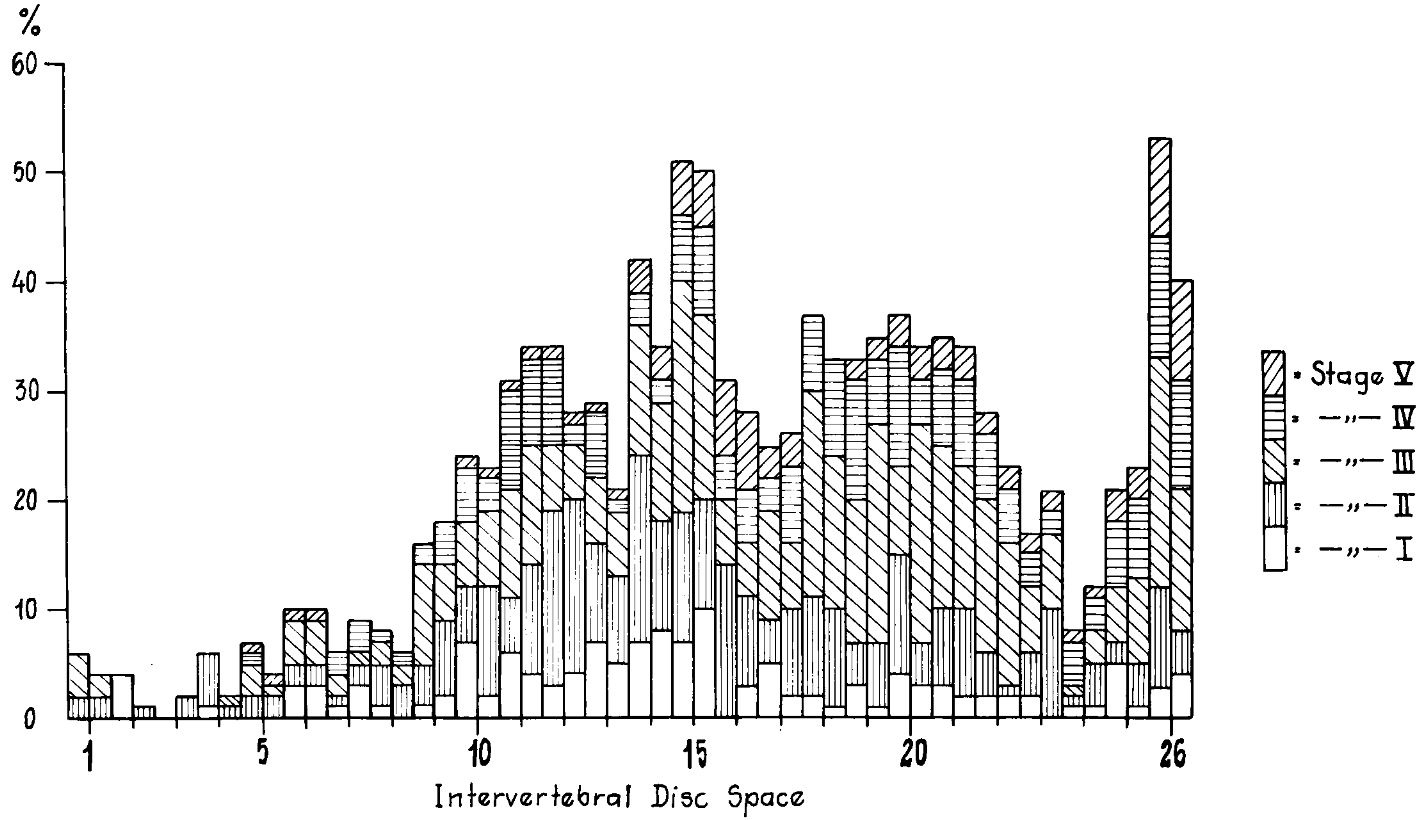


Fig. 6. Frequency distribution of each of the five stages of spondylosis deformans in 100 affected dogs as it is related to both cranial and caudal aspects of each intervertebral disc space.

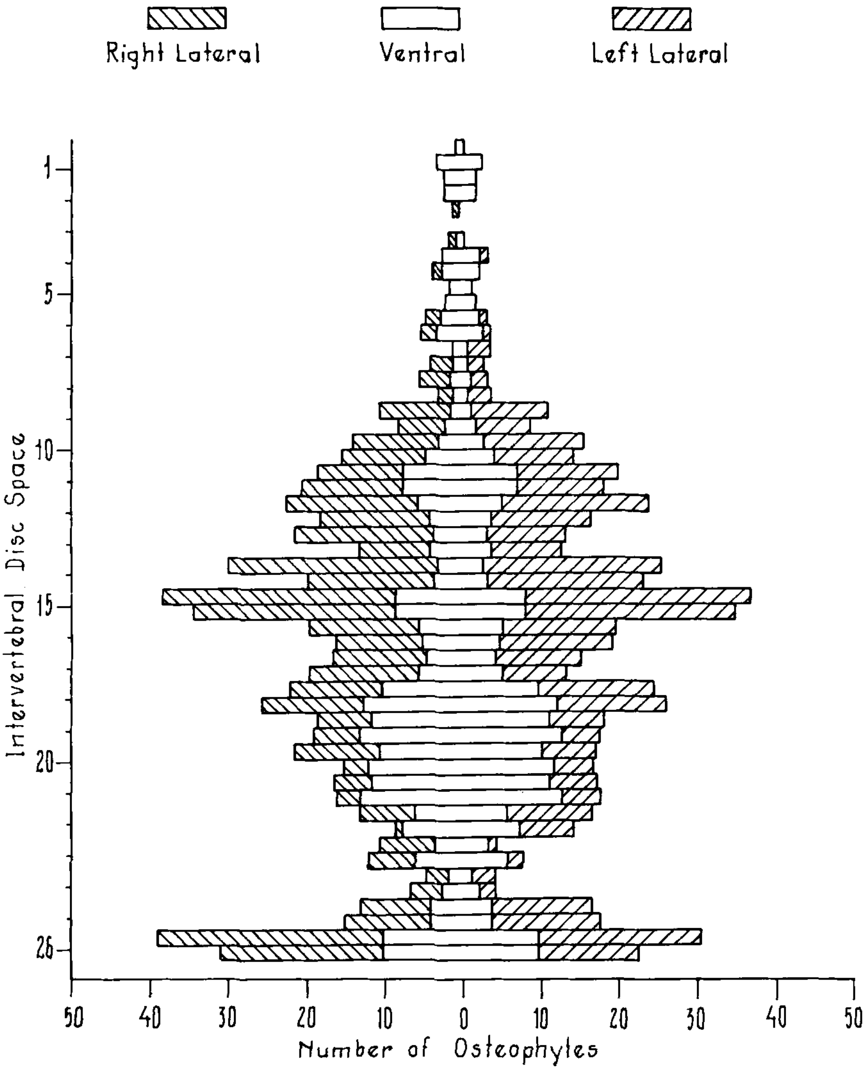


Fig. 7. Distribution of osteophytes in 100 dogs with spondylosis deformans as related to position on the vertebral margin of both cranial and caudal aspects of each intervertebral space.

Distribution of Osteophytes on the Vertebral Margin

The exact location of each osteophyte was recorded according to a previously described method (page 12, Fig. 7). The majority of spurs in the cervical region was located on the ventral midline. Usually they represented a continuation of the prominent ventral ridge as found especially on C-2, 3, 4. No osteophytes were found located dorsally or near the intervertebral foramina.

The pattern changed from disc spaces 7 through 17 with approximately two thirds of the spurs equally divided to the right and left of the midline. From spaces 18 through 23 the majority of osteophytes was again located on the midline. A shift was noted from disc space 24 caudally to the lumbo-sacral junction. Here the spurs were located to the side of the midline, but in a lower percentage than in the mid-thoracic region.

Dorso-lateral new bone growth was noted around intervertebral foramina and plotted as lateral in position (Figs. 8, 10, 14). In the thoracic region, osteophytes originated from the dorsal portion of the costal fovea and from the costal fovea of the transverse process of the vertebrae (Fig. 10). Two dorsal osteophytes near the midline were located by gross examination. These were in different vertebral columns on the cranial aspect of disc spaces number 8 and 16. Both were small and there was no gross evidence of spinal cord pressure. They were not plotted (Fig. 7).

Spurs were frequently located around coccygeal discs but location and number were not recorded. No osteophytes were noted on the ventral aspect of the midportion of the sacrum.

2. *Macroscopic and Macroradiographic Studies*

New bone growth was found in numerous locations along the junction of the vertebral end plate and vertebral cortex (Fig. 8), and was found both alone or matched with equal or unequal development on the opposing vertebral body (Figs. 10, 11, 12, 13, 14, 15). The bony growths ranged in size from small, barely discernible nodules to massive ankylosing bridges (Figs. 13, 14, 15). They were single, multiple in scattered locations, or concentrated in one area of the vertebral column. Typically, the new growth extended around the intervertebral disc (Figs. 10, 11, 12, 13, 14, 15). Often, the spurs were located dorso-laterally and involved the costo-vertebral articulations (Figs. 10, 14).

The extent of development of many spurs could not be accurately determined from the cadaver because of tissue between two opposing osteophytes. Macroradiographs or boiled specimens were required to determine the extent of ossification.

Ventral and Lateral Osteophytes

The general appearance of an osteophyte was that of a ‘scoop’ with the tip extending toward the disc. It usually presented a sloping and smooth ventral or lateral surface that blended gently with the cortex of the vertebral body. (Figs. 9, 10, 11, 12, 13, 14, 15). This was best seen in osteophytes in stage three or larger. Actual ankylosis was rare and an interlocking of small finger-like projections was more common (Fig. 11). The width of the osteophyte had no relation to the extent of longitudinal development.

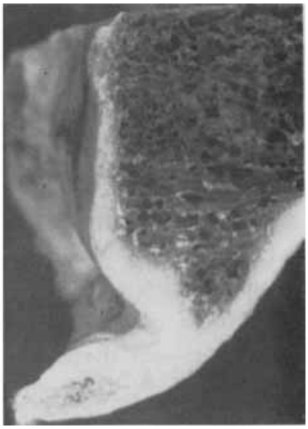



Fig. 8. Caudal surface of L6 of a boiled specimen from a German shepherd (12 yr ♀). Extensive bony growth occupies most of the periphery of the vertebral end plate. The osteophytes do not meet at the midline ventrally where the longitudinal ligament was located. The dorso-lateral spurs are within the intervertebral foramina but taper sharply as they enter the spinal canal.

Fig. 9. Lateral view of the caudal end of L5 following sagittal sectioning of the vertebral column of a boxer (8 yr ♀). The osteophyte is of stage four and located laterally and ventrally.

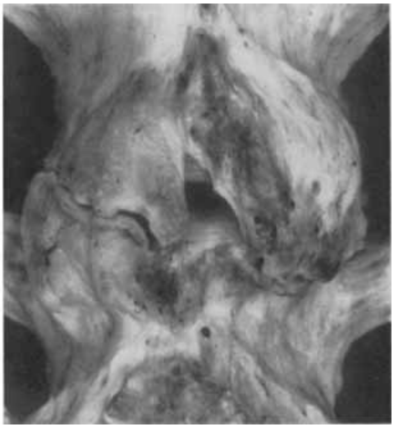



Fig. 10. Lateral view of the right side of boiled thoracic vertebrae T9—10 from a German shepherd (12 yr ♀). The costo-vertebral joint covers the intervertebral space and the ventral osteophytes blend with the periarticular osteophytes. There is encroachment upon the intervertebral foramen. The osteophyte on the right is in stage four and that on the left is in stage three.

Fig. 11. A ventral view of a boiled specimen of L6—7 from a German shepherd (12 yr ♀). The interlocking osteophytes bridge the intervertebral space without fusion. The absence of osteophytes on the ventral midline is at the location of the ventral longitudinal ligament. Longitudinal grooves are seen laterally on the osteophytes. Numerous foramina penetrate the surface of the new bone growth as well as the vertebrae.

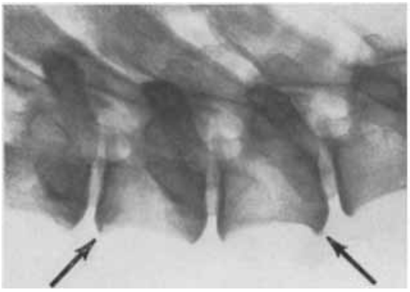
Fig. 12. The right side of T12—L2 after sagittal sectioning of the vertebral column from a boxer (9 yr ♀). The osteophytes are of stage four. There is a free segment of bone between L1 and L2 that is not in contact with adjacent vertebrae. Disc spaces are of normal width. Disc 19 (in the center of the picture) is discolored and has an intradiscal fissure.

Separate centers of ossification were frequently noted on the macroadiographs of the ventral portion of the anulus fibrosus (Fig. 16). These centers were usually in conjunction with marginal spurs, but in some cases were the only radiographic sign of osteophyte formation at the intervertebral space. These crescent-shaped bodies did not have the appearance of fracture fragments. No fracture line was identified and the bodies were widely separated from the vertebrae. The shape of these free segments was not similar to that usually taken by protruded disc material.

Frequently, osteophytes became so large that spurs from cranial and caudal corners of a vertebral body met at the midpoint of the ventral margin (Figs. 12, 14, 15). A great increase in dorso-ventral diameter of the vertebral body resulted.

Dorsal and Dorso-lateral Osteophytes

Only two dorsal osteophytes were found. Dorso-laterally located osteophytes were more common and represented a continuation of large lateral spurs (Fig. 8). In the thoracic area, osteophytes occurred associated with costovertebral articulations (Fig. 10). In this location, they usually permitted a free pathway for spinal nerve roots.



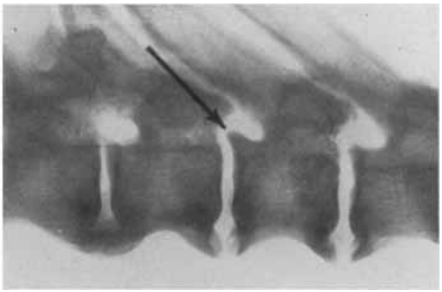
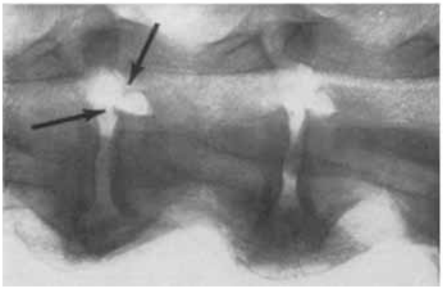


Fig. 13. Radiograph of T4—7 following removal from the cadaver of a standard poodle (10 yr ♂). The osteophytes are of stage two (arrows). Disc spaces are of normal width.

Fig. 14. Radiograph of T8—11 following removal from the cadaver of a bull mastiff (7 yr ♀). Starting from the right, the osteophytes are of stages three, four, and five. A dorso-lateral osteophyte on the caudal aspect of T9 (arrow) projects into the intervertebral foramen. Disc spaces are normal in width.



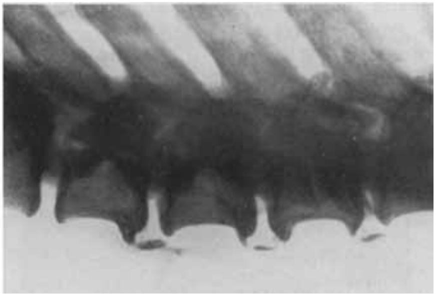


Fig. 15. Radiograph of L3—5 following removal from the cadaver of a German shepherd (6 yr ♀). The osteophytes are of stage five. There is narrowing of the intervertebral foramen at disc 23 due to dorsal extension of the dorso-lateral osteophyte and new growth from the accessory process (arrows).

Fig. 16. Radiographs of T3—7 following removal from the cadaver of a boxer (9 yr ♀). The osteophytes are of stage four and are characterized by the flat or crescent shape of the isolated piece of bone ventral to the disc. Width of the disc spaces is normal. Presence of the rib heads makes diagnosis of change in the region of the dorsal portion of the discs and the intervertebral foramina difficult.

Atypical Osteophytes

Cases were noted in which osteophytes differed from those described above. These formed at intervertebral spaces that were narrow and there was an increase in the amount of bone in the vertebral end plates. These osteophytes were more dense, and appeared as straight ventral projections from the vertebra instead of a 'scoop' of tooth-shaped spur (Fig. 17).

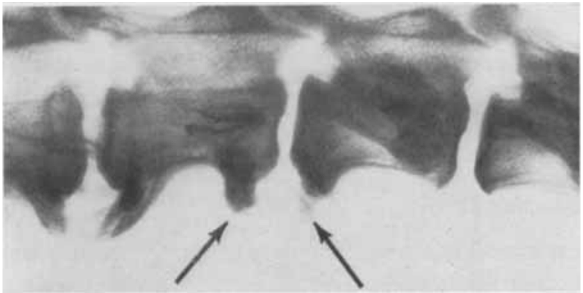


Fig. 17. Radiograph of T12—L2 following removal from the cadaver of a great Dane (2 yr ♀). Disc spaces 19 and 20 are narrowed and the stage three osteophytes (arrows) are atypical in shape and direction of growth.

Ventral Longitudinal Ligament

Macroscopic examination of the ventral longitudinal ligament revealed the following. In cadavers and boiled specimens, it was common to find a notch in an osteophyte or between two osteophytes in which the longitudinal ligament lay (Figs. 8, 11). This notch remained even though the bony growth became large, and often osteophytes encased the ligament (Fig. 19). In the cervical region, new bony growth was usually on the midline, and the ventral longitudinal ligament was elevated in a ventral direction by the osteophyte.

Other longitudinal grooves of smaller size were seen in boiled specimens (Fig. 11). These grooves apparently were due to pressure from overlying soft tissue structures. Nerves from the last two lumbar segments frequently lay in smooth and well-outlined tracks, especially at the lumbo-sacral junction. No compression of spinal nerves was noted grossly. Numerous foramina of different sizes were identified on the surface of the osteophyte (Fig. 11).

Vertebral End Plates

Vertebral end plates appeared normal on boiled specimens and were separated from osteophytes by a circumferential groove ventrally and laterally (Figs. 8, 9). In no case was an osteophyte found extending from the central portion of a vertebral end plate. Any bony bridge that formed at the intervertebral disc space was at the periphery of the end plate and followed the outer ventral or lateral contour of the disc. There was seldom any macroradiographic evidence of increased deposition of bone adjacent to the end plate.

The majority of osteophytes developed around intervertebral spaces that were of normal width (Figs. 12, 13, 14, 15, 16). Excluding chondrodystrophoid breeds, there were only a few instances of associated calcification of intervertebral discs.

3. *Microscopic Studies*

Three techniques were used for the description of microscopic morphology of vertebral osteophytes, viz; microradiography, tetracycline labelling, and conventional histology.

a. Microradiographic Studies

Following gross examination, sections were cut for processing as undecalcified specimens. Sagittal sections were taken at or near the median plane and included both vertebrae and intervening disc. They were taken from 61 dogs at most interspaces of the vertebral column to include regions representative of the five stages of growth of vertebral osteophytes and normal vertebral bodies. A small number of sections in other planes was also made. The bone was fixed and dehydrated in successive baths of absolute alcohol, and was then imbedded in a monomer of methyl-methacrylate. When this had hardened, it provided support for the section during cutting, grinding, and polishing. The procedure used was a combination and modification of earlier techniques. It has been described by Olsson and Rietz (1966).

The 100 μ section of undecalcified bone was then microradiographed. The photographic plate was processed and the resulting microradiograph was viewed through a microscope. For basic information about microradiography, the reader is referred to the review by Eriksson (1965).

Normal Mature Vertebrae

The description of the microradiographic appearance of mature vertebrae was primarily based on sagittal sections. The vertebral end plate was made of compact bone but appeared to be different from the compact bone forming the cortex of the vertebral body. The end plate was repeatedly crossed by vascular channels from the marrow-containing portion of the vertebral body to the surface of the end plate. In addition, there were numerous small cavities on the surface that created a 'pitted' appearance. Both of these findings were more obvious in the center of the plate, adjacent to the location of the nucleus pulposus. The peripheral portion of the end plate was thicker ventrally, while the center was noticeably thinner (Fig. 18).

On sagittal sections, the concave surfaces of both cranial and caudal vertebral end plates were identified, and were more pronounced if the sections were taken near the median plane. The concavity occupied approximately one third of the dorso-ventral diameter and was slightly dorsal in location. It corresponded to the position of the nucleus pulposus (Fig. 18).

The end plate turned away from the intervertebral space at the ventral border of the vertebral body. However, more of a sharp 'corner' was formed

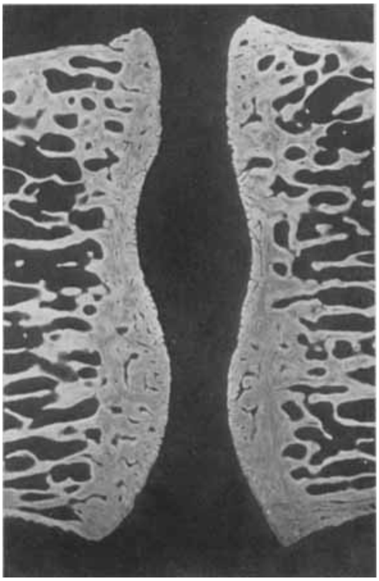


Fig. 18. Microradiograph of a sagittal section of L6—7 from a boxer (8 yr ♂). Thickness and contour of the vertebral end plate and width of the interspace are normal. (× 4).

where the end plate met the cortex dorsally. There was still a smooth transition between end plate and vertebral cortex both dorsally and ventrally (Fig. 18).

The trabecular pattern of the vertebral body was oriented in a longitudinal direction with interweaving of the trabeculae (Figs. 18, 20). On transverse sections, the trabecular pattern through the body was found to be in the form of 'tubes' with appearance of a honeycomb (Fig. 19).

Different stages in growth and maturity of Haversian systems were seen in both transverse and sagittal sections. Most osteons were aligned in a craniocaudal direction and thus better seen on transverse sections.

Forming Osteophytes

The first evidence of development of osteophytes appeared to be at or near the ventral margin of the vertebral end plate. Earliest changes consisted of a small mound with a calcified cartilage surface. Some small osteophytes had a core of rather mature-appearing bone trabeculae. These corresponded to a stage two osteophyte (Figs. 20, 21).

Regardless of the stage of the developing osteophyte, the same pattern was seen on the surface. A deposition of mineral within the matrix around the chondrocytes was noted within and just outside the zone of calcifying cartilage

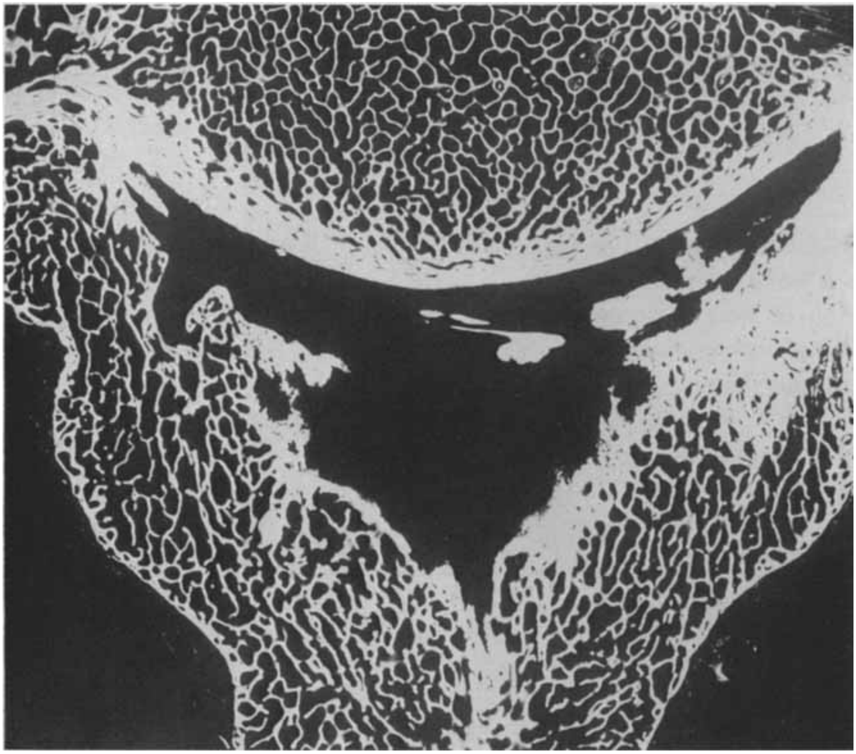


Fig. 19. Microradiograph of a transverse section of an osteophyte and the ventral portion of L3 taken from a German shepherd (6 yr ♀). The vertebral body has a normal trabecular pattern with many 'tubules' extending cranio-caudally. A tendency to form the same tubular pattern is noted in the osteophyte. The form of the osteophyte suggests early formation laterally and subsequent joining on the ventral midline. (× 7).

(Fig. 22). The zone of calcified cartilage contained cavities with an irregular border. These were adjacent to smaller cavities with a smoother border. A varying amount of bone was seen around the smaller cavities creating osteon-like structures (Fig. 23). With an increase in amount of bone, the size of the cavities decreased. Small foci of calcified cartilage were identified between the bony islands (Fig. 23).

With formation of stages three and four, the osteophytes lengthened the area of their attachment with the vertebral cortex in a direction away from the disc (Fig. 20). Calcified cartilage was only found on the surface of the osteophyte directed toward the disc, and on the ventral portion of the distal tip. The calcified cartilage was equally distributed or was concentrated more at the tip of the spur (Fig. 20).

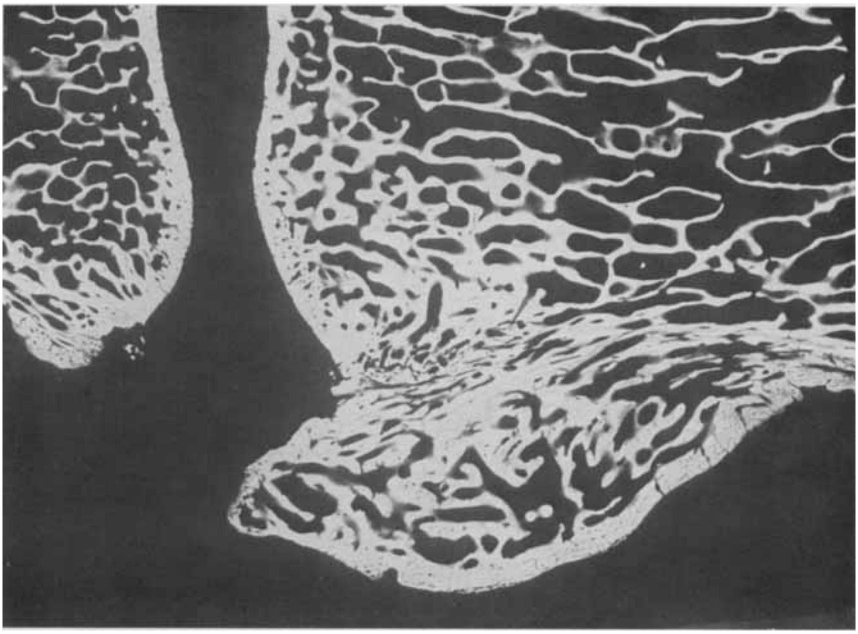


Fig. 20. Microradiograph of sagittal section of T9—10 from a German shepherd (6 yr ♀). The osteophyte on the left is of stage two. Dorsal to the osteophyte is an indentation with irregular contour and sharp margins. Outside this 'notch' are small dense fragments. The osteophyte on the other vertebra is of stage three. It has a wide base of attachment and the interposed ventral vertebral cortex has been almost removed. Trabeculae of the osteophyte blend with the trabeculae of the vertebra. The groove is evident and small dense fragments are seen adjacent to this area. The ventral cortex of the osteophyte consists of compressed lamellar bone. (× 6).

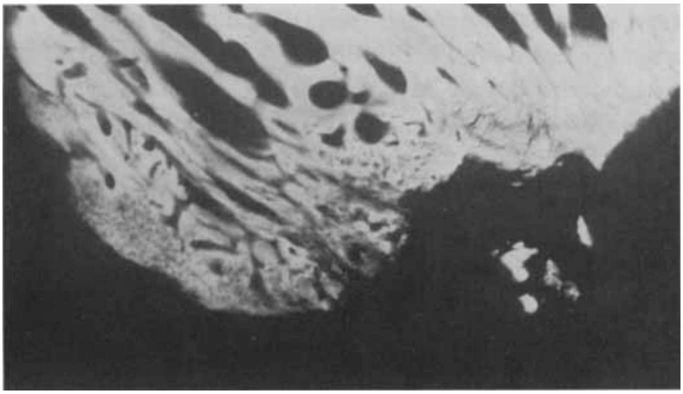
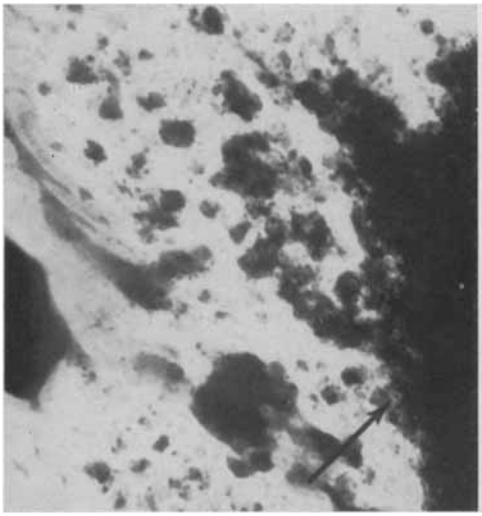


Fig. 21. Detail of the osteophyte on the left in fig. 20. The appearance of the indentation and fragmentation is suggestive of an avulsion. This is the site of attachment of the outer anular lamellae. The outer part of the osteophyte consists of calcified cartilage. (× 30).



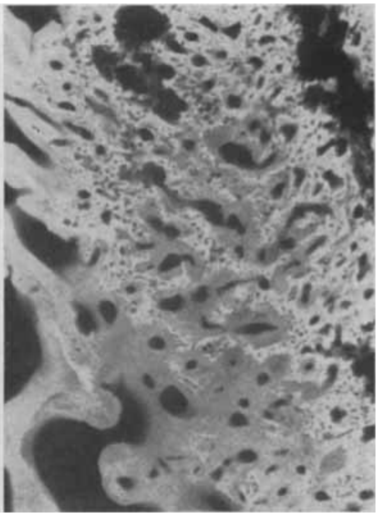
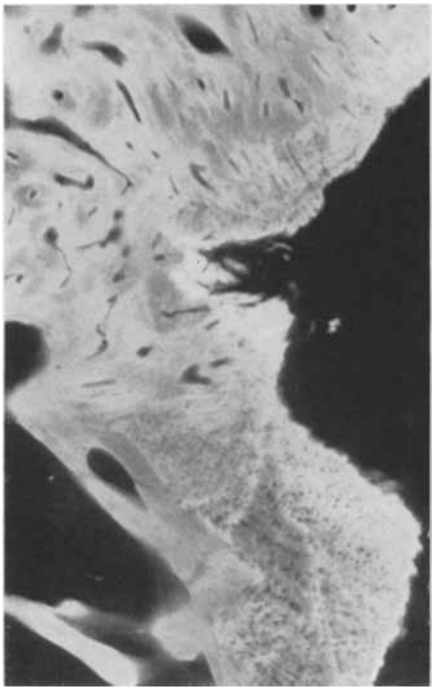


Fig. 22. Microradiograph of the surface of an osteophyte located on L3 of a German shepherd (6 yr ♀). The wide zone of calcified cartilage is adjacent to mature bone on top and to the left of the picture. Chondrocytes (arrow) are seen in stages of calcification of their matrix. (× 150).

Fig. 23. Microradiograph showing the surface of an osteophyte located on L5 of a German shepherd (6 yr ♀). The surface of calcified cartilage has interspersed bony trabeculae and small osteon-like appearing bone formations. Mature bone is at the lower left corner of the picture. At the top center of the picture is a large cavity with an irregular border of calcified cartilage. (× 75).

As the osteophytes increased in size, mature-appearing trabeculae were noted within the osteophyte. The trabeculae were thicker and the number of developing Haversian systems was greater than noted in the host vertebrae. The ventral and/or lateral cortex of the osteophyte had the appearance of compressed lamellar bone with frequent formation of Haversian systems (Fig. 20).

The previously described circumferential groove at the periphery of the vertebral end plate was noted in all but the earliest stages of development of osteophytes (Fig. 20). At the bottom of the groove was a ‘notch’ within the vertebral end plate. Usually the ‘notch’ was filled with calcified cartilage. This cartilage appeared more dense radiographically than the calcified cartilage on the surface of the osteophyte (Fig. 24, 25). In some cases the ‘notch’ appeared empty and there were small, dense fragments adjacent to it. Bone islands were not common within the cartilage in the ‘notch’. The groove narrowed as the spur developed into stages three, four, and five. However, it still retained a discernible amount of calcified cartilage. There was little relation between the appearance of the groove and the ‘notch’, and the stage of the osteophyte.



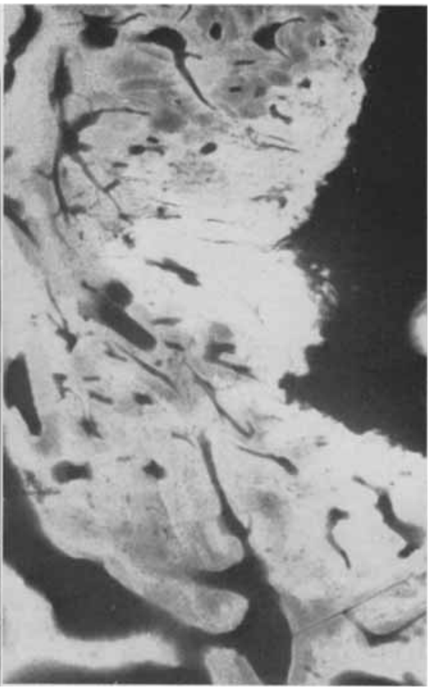


Fig. 24. Microradiograph of the 'notch' of a stage four osteophyte located on the caudal aspect of T11. The defect in the vertebral end plate is probably due to an avulsion of the bone and loss of the calcified debris during preparation of the specimen. Tiny fragments of dense tissue are adjacent to the empty 'notch'. The cartilage bordering the defect is dense and has a different appearance to that on the surface of the osteophyte. The disc space is to the right of the picture. (× 50).

Fig. 25. Microradiograph of the 'notch' of a stage four osteophyte located at disc 7 of a German shepherd (6 yr ♀). The 'notch' contains packed calcified debris with free small fragments of dense tissue near the surface. The disc space is to the right of the picture. (× 50).

Calcified cartilage was not evident on the ventral and/or lateral cortical surface of the osteophyte in any stage of development (Fig. 20). There was no line of demarcation between the cortex of the osteophyte and the vertebral body (Fig. 20).

The vertebral cortex at the area of origin of the osteophyte became less distinct with growth of the osteophyte to stages three, four, and five (Fig. 20). In some sections the cortex could not be identified, and the trabeculae of the vertebrae and osteophyte were interwoven. Even with disappearance of the interposed cortex, the previously described groove often remained.

Dorsal osteophytes were found more commonly on the microradiographs

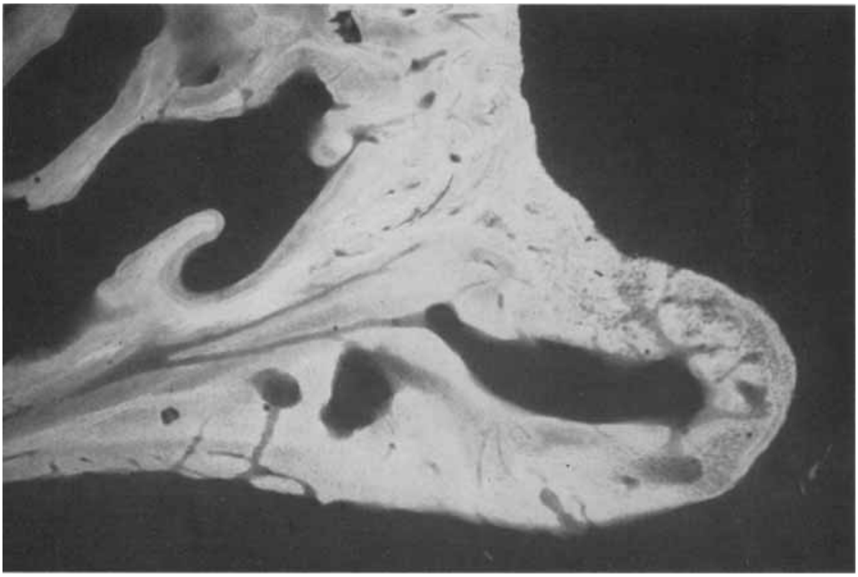


Fig. 26. Microradiograph of a sagittal section of the ventral corner of the cranial end of T5 from a standard poodle (10 yr ♂). The osteophyte is of stage two. The groove is filled with calcified cartilage and the entire contour of the osteophyte is smooth. The surface of the osteophyte toward the disc and the tip are covered with calcified cartilage. (×40).

than on gross dissection. They were composed of both calcified cartilage and more mature-appearing bone, and were formed on the corner of the vertebral end plate and dorsal cortex. In these cases there was no formation of a circumferential groove.

Union of two spurs was indicated by the presence of a wide band of calcified cartilage joining the two surfaces. Small, bony islands were identified within the calcified cartilage. The same pattern of change was seen as on the surface of the growing osteophyte except that the calcified cartilage covered a wider space and appeared to have less organization.

Mature Osteophytes

Many spurs appeared to have ceased active growth. This was determined by formation of mature-appearing trabecular bone, with a cortical bone completely covering the osteophyte. In other spurs the calcified cartilage surface was still present, but neither additional calcification within the matrix nor formation of bony islands was seen. In either case, the groove was smaller and appeared to be in the stage of closure (Fig. 26). This apparent cessation of activity of growth of the osteophyte occurred at stages two, three, or four. Osteophytes in stage five had achieved complete bridging ventrally and/or laterally to the intervertebral space.

Cases were seen frequently in which new bone growth extended the entire length of the vertebral body between osteophytes on both cranial and caudal borders. This was usually associated with osteophytes in stages four or five but often occurred with stage three. In these cases, the old ventral cortex of the vertebral body was gone and the ventral cortex of the osteophyte became the new vertebral cortex. The width of the cortex and trabeculae of the osteophyte was the same as in the vertebra.

Growth of osteophytes as determined by the presence of incompletely calcified cartilaginous surfaces appeared to be an individual characteristic. This was not a consistent finding on osteophytes throughout one vertebral column. However, there seemed to be a tendency for growth to be more nearly equal on both sides of the same intervertebral space.

Free Bony Segments

Microradiographs often demonstrated calcified cartilage and/or bony segments lying free in the ventral anular area. Changes of this type were classified within stage four. Macroradiographs and gross dissection showed the segments to have no attachment to adjacent vertebral bodies.

The segments were generally composed of calcified cartilage with bony islands, but as they enlarged they developed a trabecular pattern similar to that found in the vertebral body. In some cases, cartilage on the entire circumference of the free segment and advancing tips of adjacent osteophytes had different degrees of calcification. The growth pattern of these free segments was identical to that seen on the surfaces of osteophytes attached to vertebrae (Fig. 27). Joining of a free segment to a vertebral spur, or to another free segment, was characterized by a wide connecting band of calcified cartilage with the earlier described characteristics.

In other discs, part or all of the free segment was composed of mature lamellar bone and little sign of activity was noted.

Changes Associated with Osteophytes

Amorphous mineral debris was present in the ventral anulus of discs both with and without associated osteophyte formation. In some cases debris was close to, and in others, unassociated with active or inactive spurs. In more rare cases, debris was noted in various stages of incorporation into free bony segments or attached osteophytes (Fig. 27).

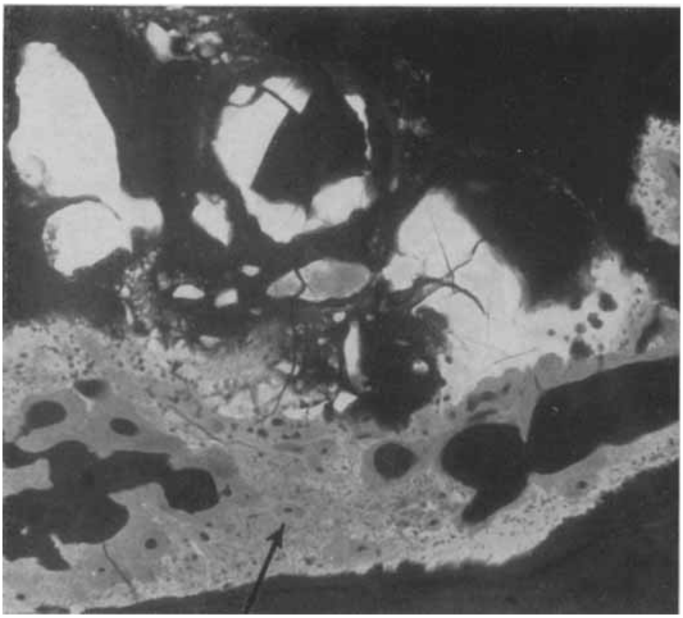


Fig. 27. Microradiograph of a free bony segment within the ventral portion of disc 17 of a German shepherd (6 yr ♀). Large amorphous dense masses lie within the soft tissue and are being incorporated into the segment. The majority of the free segment is composed of calcified cartilage with small bone islands around small cavities (arrow). Other larger cavities are also lined with bone tissue (×40). (This is the same disc space as seen in fig. 22).

Width of disc spaces and density of vertebral end plates were usually normal (Fig. 20). However, several sections had marked narrowing of disc spaces and increased width of vertebral end plates. In these, the surface of the end plate had lost its 'pitted' appearance and appeared worn (Fig. 28). The pattern of osteophytes in these cases was similar, but lacked the seemingly purposeful manner of development characterizing those described earlier. Origin of the spurs took place at a greater distance from the corner of the vertebral body. Direction of growth was more frequently ventral or away from the vertebral body, and there seemed less effort to bridge the intervertebral space. The width and number of trabeculae and the thickness of cortex was greater in these spurs when compared with the host bone.

Vertebrae were noted with severe destruction of the vertebral end plate, in which marrow spaces of the vertebral body reached the cartilage plate. This change occurred in older dogs, and was limited to the thinner central portion of the vertebral end plate. No correlation with changes in width of the disc space, or with the presence of osteophytes, was noted.

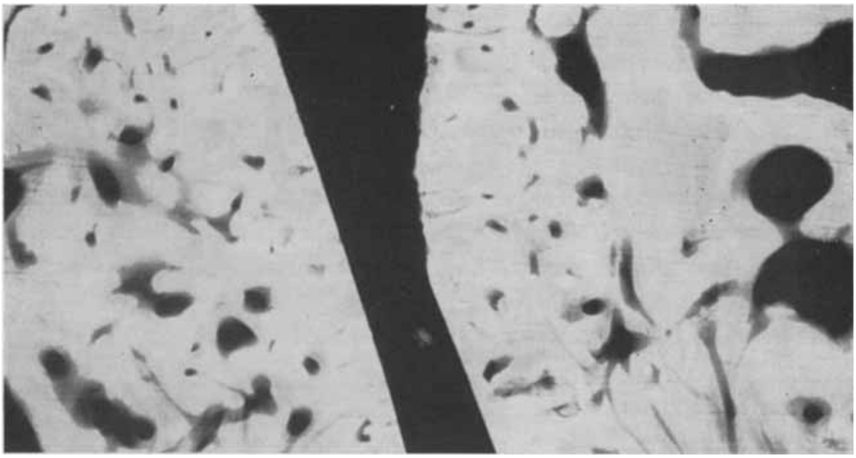


Fig. 28. Microradiograph of a sagittal section of the vertebral end plates at disc 15 of a standard poodle (10 yr ♂). The vertebral end plates are smooth and the disc space is markedly narrowed. Thickness of the compact bone forming the end plate is greater than normal. (× 40).

b. Tetracycline Labelling Studies

Tetracycline antibiotics administered in vivo are preferentially incorporated at the site of mineralization of bone matrix or in cartilage when undergoing calcification (Urist and Ibsen 1963). This relatively non-toxic, non-radioactive, easily administered, intravital, bone-seeking fluorogen can be studied in properly prepared undecalcified sections. The sections display a characteristic fluorescence of the tetracycline when viewed through transmittant ultraviolet light.

Of the 100 dogs with spondylosis deformans, 15 were given tetracyclines prior to death. In addition, 7 normal control dogs were labelled. Most of the affected dogs were terminal clinical cases in which tetracyclines were administered therapeutically. In those labelled for the purpose of this investigation, the dose of antibiotic ranged from 30 to 66 mg/kg bodyweight, and it was given intravenously. Chlortetracycline hydrochloride was the drug most commonly used. The time period between administration of the drug and death of the dog ranged from 15 hours to 12 days.

If labelled with tetracycline antibiotics, the 100 μ thick, undecalcified sections used in preparation of microradiographs were examined with a microscope equipped with a mercury vapor lamp as the source of ultraviolet light. The techniques employed in the present study were those used by Olsson and Rietz (1966).

Normal Mature Vertebrae

The normal mature vertebrae had a rather uniform pattern of labelling. On sagittal sections there was scattered fluorescent labelling on the surface of both dorsal and ventral cortices and on the surface of trabeculae. In compact bone only a few labelled osteons were seen.

Deposition of tetracycline was uniformly distributed on the trabecular bone. However, only a low percentage of the surfaces were labelled. There were no areas within the vertebral body with a consistently higher percentage of labelled surfaces, nor were there any areas totally lacking fluorescence. Surfaces of the vertebral end plates were not labelled in any sections.

Forming Osteophytes

Actual growth of the spurs could be demonstrated as well as bone formation within them. The latter was considered a sign of active remodelling. The small amounts of calcified cartilage that constituted an early sign of osteophyte formation were labelled diffusely. The manner of labelling changed with formation of a trabecular pattern. Regardless of the stage of development of the osteophyte, calcifying cartilage on the tip and surface toward the disc was highly fluorescent (Fig. 29). The only fluorescence seen in the newly forming cortex on ventral or lateral surfaces was a well-defined periosteal line (Fig. 30). The 'notch' between osteophyte and vertebral body was almost without exceptions labelled to a high degree, independent of the tetracycline uptake elsewhere.

Free bony segments within the ventral anulus usually possessed many labelled areas. The labelling was more extensive when there was calcified cartilage on the periphery. Labelling of trabeculae within the center of these islands resembled that of adjacent vertebrae.

The greatest level of activity occurred when two osteophytes, or an osteophyte and a free fragment, were in the process of joining (Fig. 30). The interspace was partially filled with diffusely labelled zones of calcifying cartilage. There was active formation of bone on the surface of the bone trabeculae within the osteophyte as it continued to grow. This was usually at a rate similar to that noted within the host bone. However, on several occasions, there were more labelled surfaces on the trabeculae of the osteophyte than of the vertebra.

Calcifying cartilage within small growing osteophytes on the dorsal aspects of vertebrae was labelled diffusely. These osteophytes were precisely on the dorsal corner, and projected only a short distance.

Mature Osteophytes

As osteophytes neared a mature stage, intense labelling on the surface toward the disc disappeared with formation of a more mature-appearing cortex.

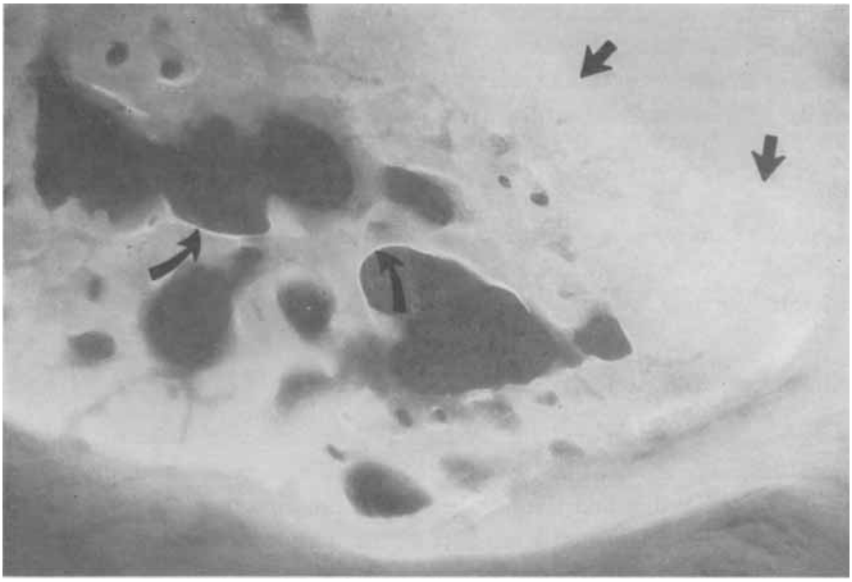


Fig. 29. Sagittal section of an osteophyte on the ventral corner of the cranial end of L7 from a German shepherd (8 yr ♀). The undecalcified bone section was labelled with tetracycline and viewed in transmittant ultra-violet light. The calcified cartilage surface of the osteophyte is directed toward the disc space at the upper right corner of the picture (straight arrows). The cartilage shows a marked diffuse pattern of fluorescence. There are also distinct lines of fluorescence on the surfaces of bone trabeculae within the osteophyte (curved arrows). There is no tetracycline label on the ventral cortex of the osteophyte at the bottom of the picture. (× 75).

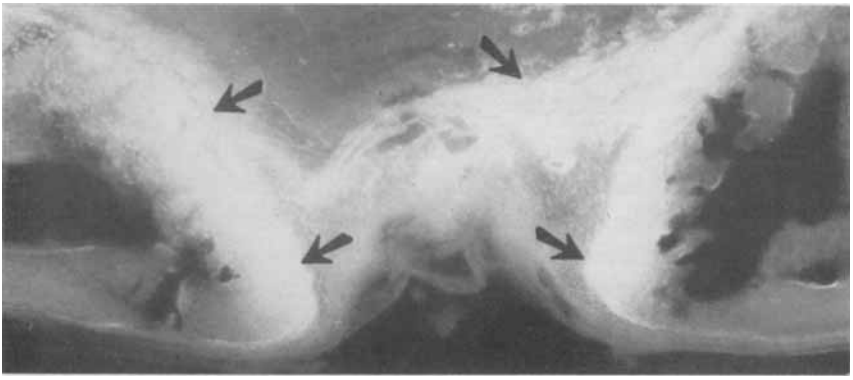


Fig. 30. A sagittal section of the tips of two adjacent osteophytes at disc 14 from a German shepherd (6 yr ♀). The undecalcified bone section was labelled with tetracycline and viewed in transmittant ultra-violet light. The calcifying cartilage on the surface and that extending between the tips of the osteophytes has a marked fluorescence (arrows). The loose ligamentous tissue covering the ventral surface of the osteophytes is wrinkled. There is a thin but distinct fluorescent line on the ventral aspect of both osteophytes indicating some appositional bone growth. (× 75).

The last area to possess fluorescence was within the 'notch'. Marked labelling at this point could be seen when all other parts of the osteophyte appeared mature. The degree of fluorescence on trabecular surfaces and cortices was similar to the host bone at this stage.

Debris

Amorphous mineral deposits were identified in the ventral anular area. These possessed a diffuse pattern of fluorescence. These foci were identified on microradiographs and had the appearance of amorphous calcified masses.

c. Conventional Histologic Studies

Bone adjacent to that used for undecalcified sections was taken for conventional histologic examination. Usually the sagittal sections included the ends of two vertebral bodies and the disc between them. However, the large size of some specimens necessitated removal of the dorsal portion of the vertebral bodies and of the disc. In these sections, only the ventral parts were examined.

Specimens were fixed in 10 per cent solution of aqueous neutral formalin. They were decalcified through use of 5 per cent nitric acid and embedded in paraffin. Staining on 6 μ sections included hematoxylin and eosin, van Gieson's picrofuchsin-hematoxylin, and Toluidine blue.

Transverse sections of intervertebral discs were made from 11 dogs, using the method described by Hansen (1952). This technique maintained shape of the disc and resulted in least damage to the histologic preparations. All regions of the vertebral column and all stages of growth of vertebral osteophytes were included.

Development of Vertebral Osteophytes

The following description was based mainly on the sagittal sections. Earliest changes observed were multiple small foci of fibrocartilage between the outer lamellae and the longitudinal ligament. These foci occurred either adjacent to, or slightly away from, the vertebral corner. However, most commonly they occurred at the point where the vertebral body, outermost anular fibers, and ventral longitudinal ligament came together. If foci were not adjacent to the vertebrae, stages of increasing size were noted until contact was made with the bone. Small blood vessels were seen within the newly formed fibrocartilage (Fig. 31). Bone was formed around these vessels by osteoblasts apparently in direct contact with the walls of the vessels. Additional formation of bone occurred at the margin of cavities that were seen to connect with marrow spaces of the osteophyte (Fig. 32). Many of the smaller cavities became filled with bone and the appearance was similar to that of an osteon. The larger

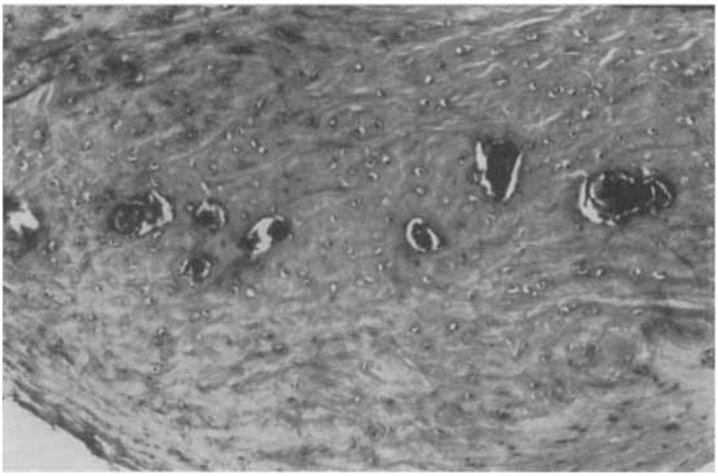
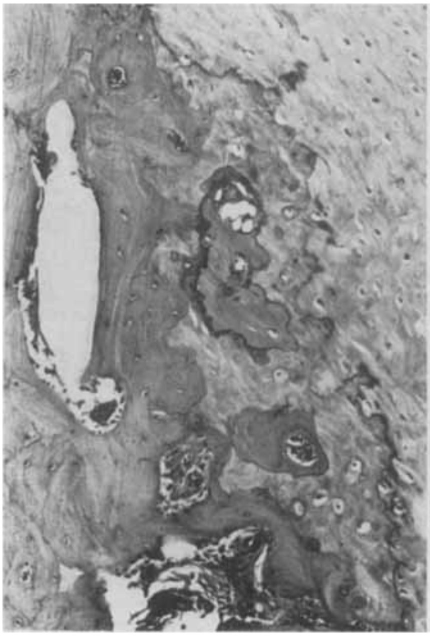


Fig. 31. Area of fibrocartilage adjacent to the forming osteophyte within disc 13 of a German shepherd (12 yr ♀). Vascular spaces have small amounts of bone around them. H & E (× 100).



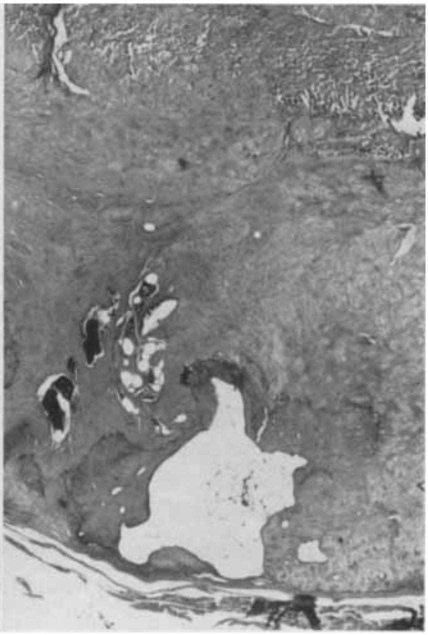


Fig. 32. Edge of an osteophyte at disc 26 of a mongrel (10 yr ♀). The layer of fibrocartilage is at the upper right of the picture. Next is a layer of calcified cartilage with small bony islands. To the left of the picture is more mature-appearing bone. H & E (× 100).

Fig. 33. Free segment of bone within the collagenous tissue ventral to the anulus of disc 6 in a German shepherd (6 yr ♀). The segment contains a large cavity and numerous smaller ones. To the left of the bony segment are vascular spaces. At the top of the picture are the outer anular lamellae. At the bottom of the picture is the longitudinal ligament. H & E (× 20).

cavities which were connected with marrow spaces developed thicker zones of bone but still retained a rather large central cavity. The osteophyte increased in size toward the disc through continuous formation of cartilage and subsequent bone formation. The newly formed bone appeared mature. Immature bone was not noted (Fig. 32).

The ventral longitudinal ligament was displaced in a ventral direction by the growing osteophytes. A tissue rich in collagen fibers filled the space between the outermost lamellae of the anulus fibrosus and the ventral longitudinal ligament. In some cases collagenous tissue created a massive bridge between two opposing osteophytes (Figs. 33, 34 A, 35, 36). When there was only one osteophyte at an intervertebral space, the collagenous mass had a more irregular shape. The size of this collagenous mass increased in direct relationship to the increase in size of the osteophytes. In contrast to the normal anulus fibrosus, the newly formed tissue between anular fibers and ventral longitudinal ligament contained blood vessels in small numbers (Fig. 33).

An identical pattern of bone formation, as described above, was noted in isolated areas between the anulus and longitudinal ligament. Cavities appeared within cartilaginous foci, and formation of bone followed in many of these 'islands' (Fig. 33).

Frequently, large masses of calcified debris were seen in the newly added collagenous tissue. They were either isolated or partially incorporated in the developing segments or osteophytes (Fig. 36).

Formation of bone on the ventral and lateral surfaces of the osteophyte did not occur in the manner just described. Bone was formed from the cambium layer of the periosteum covering these surfaces.

The earlier-described 'notch' around the periphery of the vertebral end plate was found in almost all sections. It was usually filled with fragments of bone, necrotic cartilage, and anular fibers (Figs. 34, 35, 36).

Active growth of the osteophyte, as well as signs of inactivity, were noted in sections taken from dogs of all ages. In apparently non-growing osteophytes, there was no further formation of bone at the junction between the fibrocartilage and osteophyte. The fibers from the newly added collagenous tissue attached to the osteophyte in a manner not unlike that seen between the anulus and the vertebral end plate. The groove was seen in various stages of repair and finally achieved complete healing and became smooth.

Changes in the Anulus Fibrosus

The normal anulus fibrosus was basophilic, with strongest stainability close to the nucleus pulposus and to the cartilaginous plate or vertebral end plate. The degree of basophilia diminished toward the outer parts of the disc. The lamellae had a fish-bone pattern and were separated by a small amount of basophilic-staining material with granular appearance.

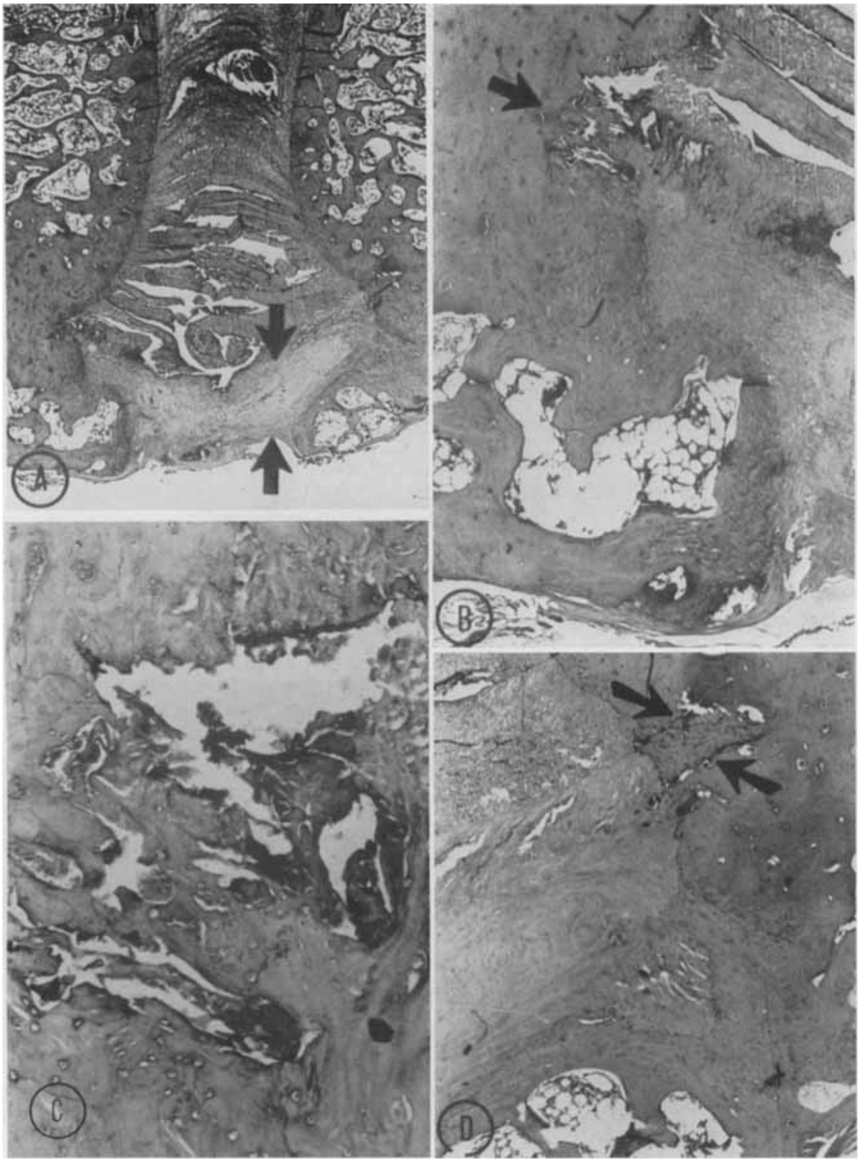


Fig. 34. A. Sagittal section of ventral portion of disc 9 and adjacent vertebrae of a mongrel (11 yr ♀). Stage three osteophytes are on both vertebrae. The layer of additional collagenous tissue (between arrows) is seen ventral to the ruptured and separated anular lamellae. H & E (× 7).

B. Detail of osteophyte on left side of A. A 'notch' is present (arrow) and separation of anular lamellae is marked. A zone of fibrocartilage is to the right of the advancing surface of the osteophyte. Ligamentous tissue is ventral to the forming osteophyte. H & E (× 20).

C. Detail of the 'notch' seen in B. Bone is on the left of the picture and anulus to the right. Necrotic tissue partially fills the 'notch'. H & E (× 100).

D. Detail of the osteophyte on the right side of A. The 'notch' is filled with bone that has been partially avulsed (arrows). Large spaces resembling marrow cavities within osteophyte. H & E (× 20).

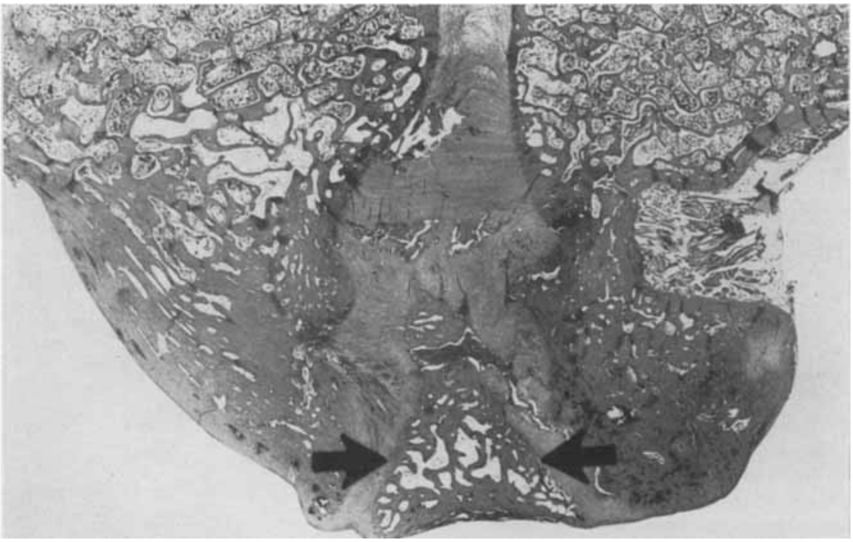


Fig. 35. Sagittal section of disc 7 of a German shepherd (6 yr ♀) and osteophytes on both associated vertebrae and a free lying segment of bone (arrows) within the added collagenous tissue ventral to the anulus fibrosus. H & E (× 6).

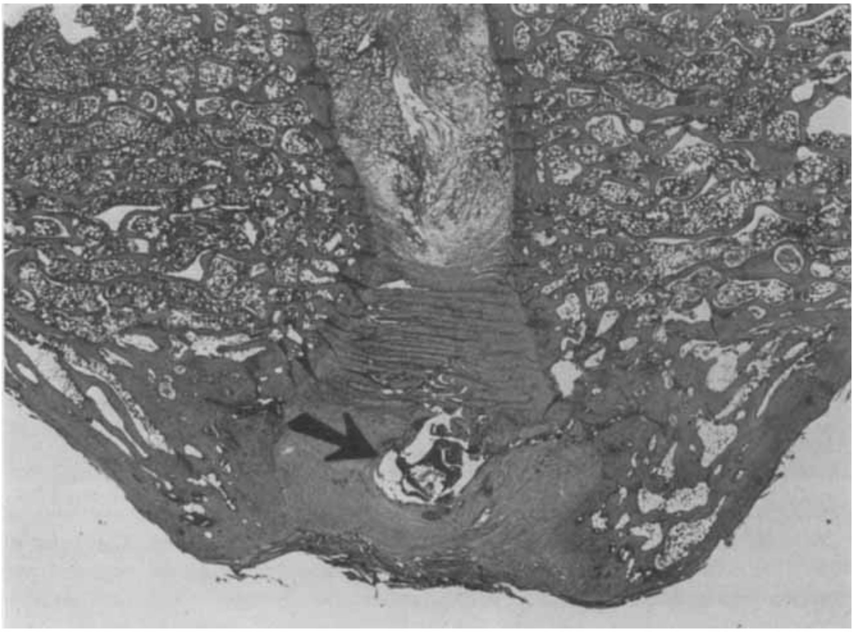


Fig. 36. Sagittal section of disc 19 of an Irish setter (13 yr ♀). There are stage three osteophytes on both vertebrae. There is a large necrotic focus in the center of the added collagenous tissue (arrow). Ruptures of the anular lamellae are present. H & E (× 6).

The first noticeable change appeared predominantly in the ventral anulus fibrosus. The normal fibrous structure became more homogeneous and failed to take the stain as well as before (Fig. 37 D). These changes were haphazardly distributed and of varying extent. Within the same sections strongly basophilic foci appeared both within and between the lamellae (Fig. 37 A, B). In several cases similar-appearing foci stained strongly acidophilic. The foci were usually well delineated and consisted of debris. In addition to these discrete foci, many lamellae had diffuse areas with more basophilic-staining properties.

The three types of change just described did not regularly appear together. Often the discretely appearing foci were noted within lamellae that were normal in appearance. Affected lamellae were usually located ventrally, but were also found dorsally in the disc.

Another obvious change that appeared early was a separation of lamellae by a basophilic granular material (Fig. 37 D). This filled the interlamellar space at first, but wider separation resulted in formation of spaces that appeared empty on the slides (Fig. 38).

A proliferation of cartilage cells was seen both within and between the lamellae (Fig. 38). These cells were isolated or in groups. Vacuoles of unknown genesis, which appeared empty on the slides, were noted within the lamellae.

Ruptures of individual anular lamellae were often seen. These ruptures were located within or near the necrotic foci or could occur in lamellae with more diffuse changes (Figs. 34 A, 37 D, 38). Broken ends of the lamellae tapered and were curved. They presented the appearance of a taut line that had snapped with ends recoiled backwards. The majority of ruptures were near the center of the lamellae and not at the attachment to the vertebral body. There were some obvious exceptions in which the breaks took place just at the attachment or only a short distance from the vertebrae. In more severely altered discs, ruptures in several lamellae together formed fissures of various lengths through the anulus. These sometimes became large enough to extend from the nucleus to the outer few lamellar fibers (Fig. 38). It was obvious that these outer rings were less affected by degenerative changes than the inner ones. Frequently, the intradiscal fissures extended just to the outer lamellar fibers. No bulging of the anulus was noted in these cases.

Origin of the necrotic debris within and between the lamellae could not be positively determined. In some sections, the basophilic acellular masses appeared to be a part of the degenerated lamellae (Fig. 37 A, B, C). Serial sections often indicated that these masses were not a part of a winding track that led from the nucleus.

Metaplasia of fibrocytes into chondrocytes within the anulus occurred within the anular lamellae adjacent to the vertebral end plate. In more extensive cases piles of chondrocytes extended well into the disc (Fig. 39).

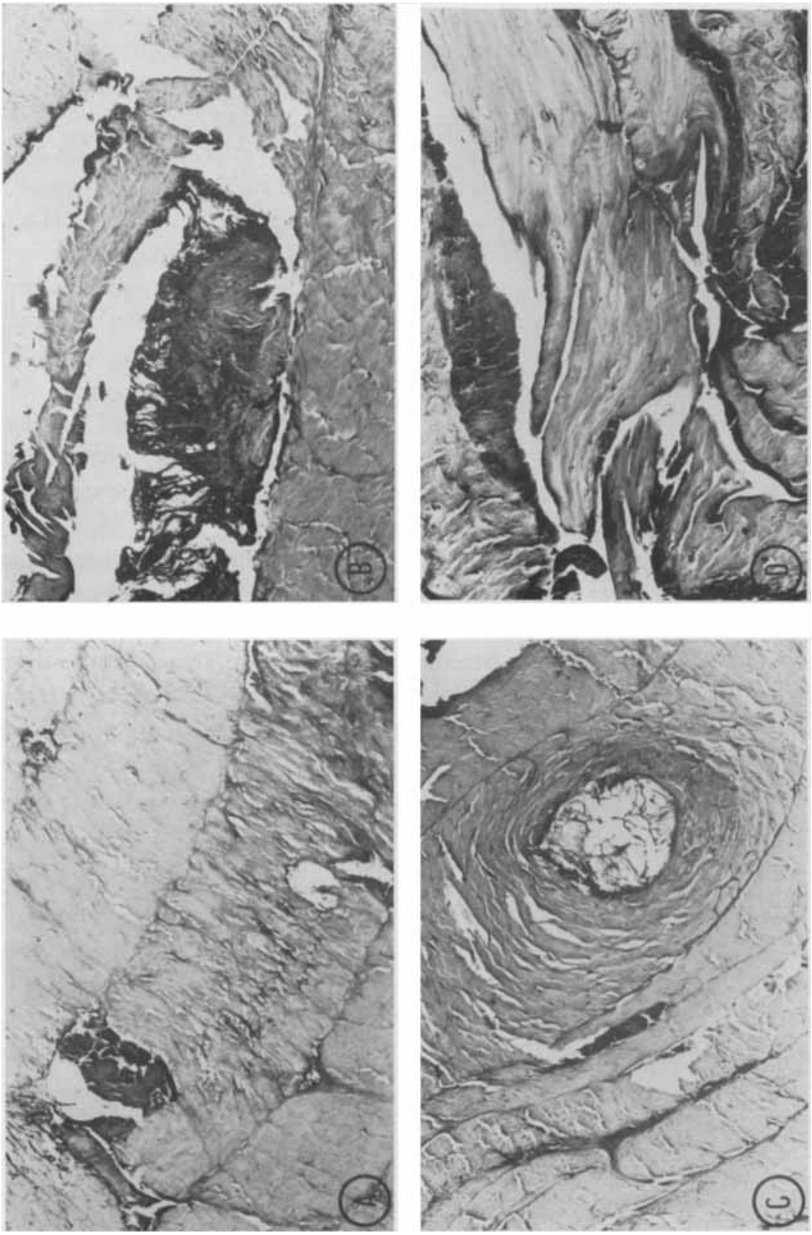


Fig. 37. A, B, C, D. Typical changes within the anulus fibrosus. H & E (× 80).

In advanced cases, the remaining intact anular lamellae were bent inward toward the nucleus rather than curving normally toward the outside of the disc.

A most advanced degree of degeneration appeared to be the result of a grinding that took place between two adjacent vertebral bodies. Direction and

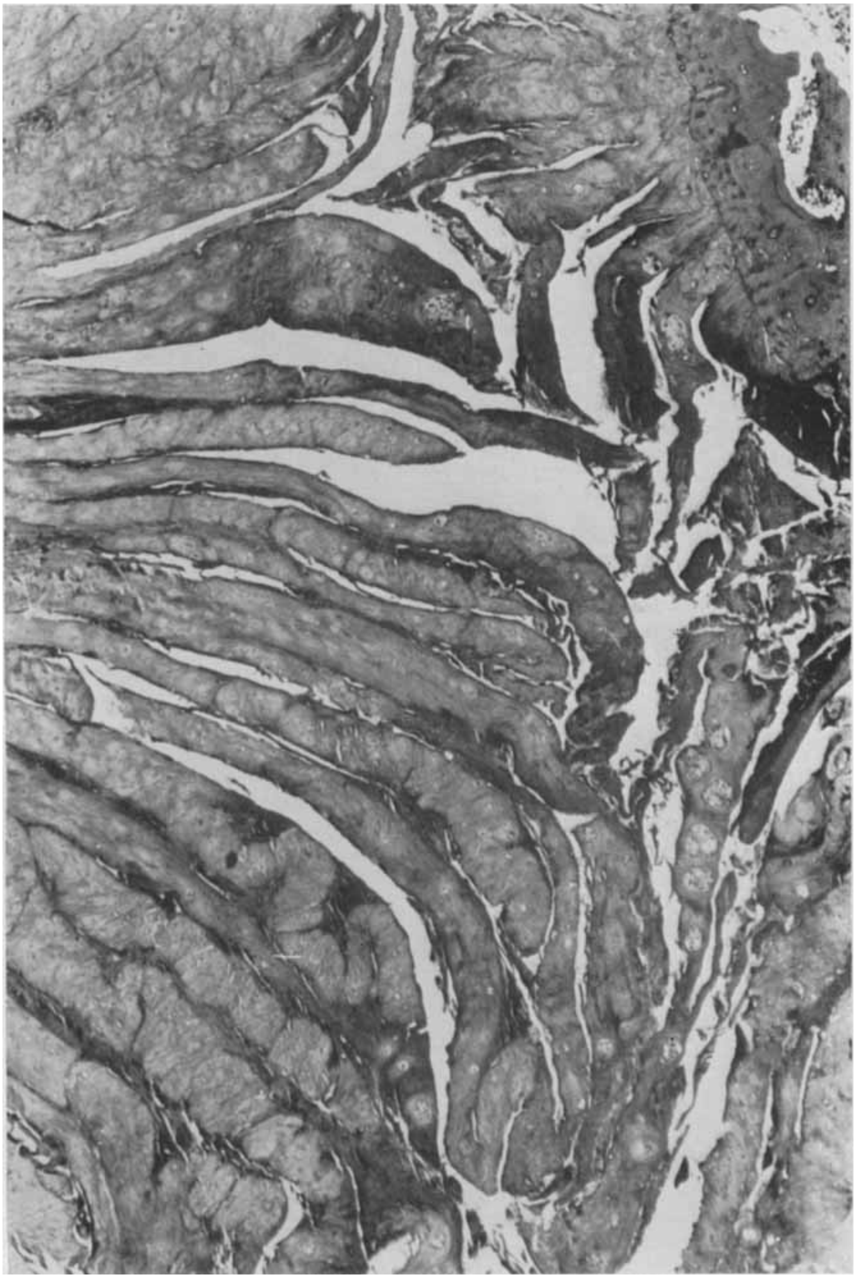


Fig. 38. Section of badly damaged anulus fibrosus with fissure formation from disc 17 of a dachshund (12 yr ♀). H & E (×25).

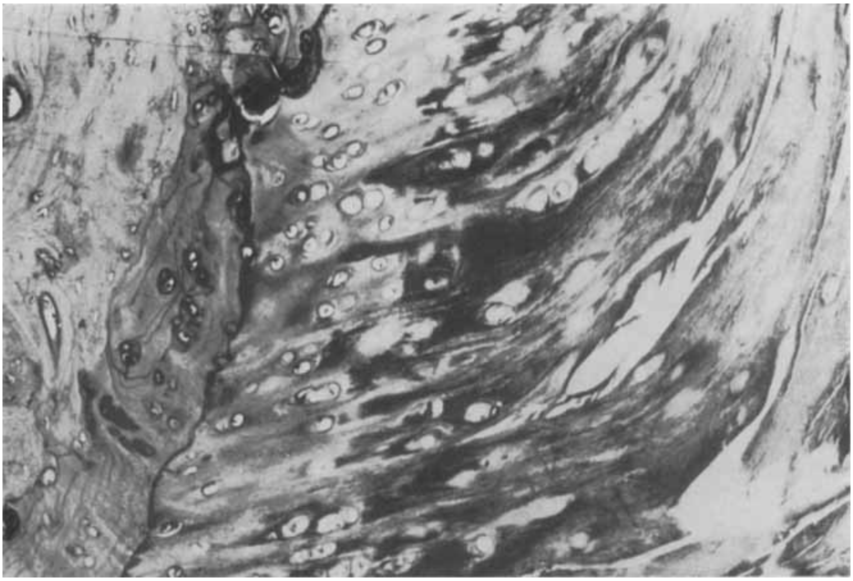


Fig. 39. Section of the attachment of the anular lamellae to the vertebral end plate of disc 11 from a mongrel (15 yr ♀). There is an increase in number of chondrocytes within the anulus. H & E (× 100).

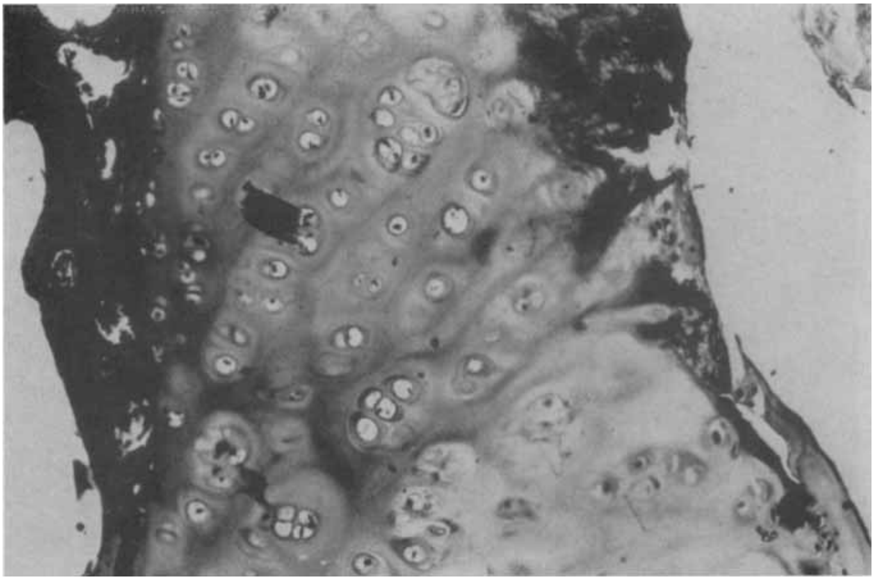


Fig. 40. Section of cartilage plate from disc 15 from a standard poodle (10 yr ♂). The cartilage plate is thickened and the chondrocytes appear in columns. The vertebral end plate is on the left of the picture and the cavity formation on the right is associated with the nucleus. H & E (× 100).

pattern of the lamellae became so disoriented that little recognizable tissue was present. In some discs the direction of the ruptured lamellae was parallel to the vertebral end plate instead of perpendicular to it (Fig. 38).

Changes in the Nucleus Pulposus

The nucleus pulposus in dogs of the non-chondrodystrophoid breeds had cells with a vesicular appearing cytoplasm. Intracellular substance was sparse with few collagen fibers. Loose fibrosus tissue separated groups of cells into lobules. This formation was more noticable in the periphery of the nucleus. Cells within the lobules became more densely basophilic. As the dog aged, the cytoplasm in the cells diminished in quantity. However, the amount of collagen-rich fibrous tissue between the lobules increased greatly. In some sections, formation of cells similar to fibrocartilage cells was noted at the periphery of the nucleus pulposus.

In dogs of the chondrodystrophoid breeds, formation of a chondroid tissue was widespread and usually occupied the entire nucleus. In some sections peripheral portions of the nucleus appeared to have undergone more change than the central portion. Parts of the nucleus pulposus became necrotic and calcification of the chondroid tissue was common. The perinuclear portion of the anulus fibrosus also had cellular changes that were similar to those found within the nucleus. This made distinction between the two major parts of the disc difficult. In some cases, nucleus pulposus underwent complete calcification and/or necrosis.

Portions of the nucleus appeared to have protruded either partially or completely through the anulus.

In contrast to the changes in the anulus fibrosus, changes in the nucleus pulposus showed a definite pattern in their development. Still, the degree of change within the nuclei in discs of the same dog was not identical.

Changes in the Cartilage Plate

The degenerative changes seen in the cartilage plate were minimal when compared with the other portions of the disc. Changes in the thickness of the plate were rare. In some discs the border between the cartilage plate and anulus fibrosus was made diffuse by greatly increased production of chondrocytes and matrix. The matrix often stained darkly, indicating calcification. Streams of large vacuolated cells in columns perpendicular to the cartilage plate extended into the disc (Fig. 40). These cells sometimes formed large foci and contained up to 10 or 12 distended chondrocytes with pyknotic nuclei. This cartilage tissue met with cartilage cells in the nucleus. The resulting mass fused with the vertebral end plate and calcified in some discs. This sequence of events took place more commonly in the chondrodystrophoid breeds.

Fissures in the cartilage plate or intraspongeous herniation were not noted. In rare cases there was a wedge-shaped indentation of the cartilage plate with no evidence of associated bone formation. This did not appear as the so-called 'ossification gap', but only as a depression in otherwise normal vertebral end plates.

Changes in the Longitudinal Ligament

Necrotic areas were also observed within the ventral longitudinal ligament. These were usually small and resembled the homogeneous areas in the anulus fibrosus described above. They were not common and were not located in a specific region of the ligament. There was no subsequent formation of bone seen at these locations.

4. Correlation Between Changes Within the Intervertebral Articulation

It is well known that spondylosis deformans is not the only condition associated with the articulations between two contiguous vertebrae. Disc degeneration, disc protrusion, and arthrosis of the costo-vertebral and vertebral synovial joints were repeatedly found during dissection. Pathogenesis and significance of spondylosis deformans might be better understood if it were known how these changes were related to each other and to the vertebral osteophytes. Changes found in the intervertebral disc, costo-vertebral and vertebral synovial joints, and the presence of spondylosis deformans were recorded in the 96 dogs thoroughly dissected.

Morphologic appearance of the intervertebral discs was classified as normal maturation (Group A) or as having signs of degeneration (Group B) (Page 13). Protruded discs were recorded separately, and their incidence was evaluated as one of the end results of disc degeneration.

Costo-vertebral and vertebral synovial joints were evaluated as normal or degenerated (Page 14). Neither stage of degeneration nor number of degenerated articular surfaces at the intervertebral space was considered.

One osteophyte at the intervertebral space was considered a sign of involvement regardless of stage of development.

The material was not separated into breeds because of low representation within most breeds. However, a division into chondrodystrophoid and non-chondrodystrophoid breeds was made using Hansen's (1952) classification. These breed groups were divided according to sex. This resulted in formation of the following groups:

non-chondrodystrophoid — female
non-chondrodystrophoid — male
non-chondrodystrophoid — total

chondrodystrophoid — female
chondrodystrophoid — male
chondrodystrophoid — total
female — total
male — total

The following major relationships were studied on an intrasegmental basis, within each individual group and within the total material.

vertebral osteophytes — arthrosis of vertebral synovial joints
vertebral osteophytes — arthrosis of costo-vertebral joints
vertebral osteophytes — intervertebral disc degeneration
vertebral osteophytes — disc protrusion (Type I)
vertebral osteophytes — disc protrusion (Type II)
arthrosis of vertebral synovial joints — arthrosis of costo-vertebral joints
arthrosis of vertebral synovial joints — intervertebral disc degeneration
arthrosis of costo-vertebral joints — intervertebral disc degeneration

The interrelationships between vertebral osteophytes, changes in vertebral synovial joints, and changes in intervertebral discs were also studied for the three major divisions of the vertebral column.

Results

The results of the intrasegmental comparisons were recorded as 'Pos' (positive) or 'No' (no correlation) (Table 1). There were no instances of negative correlation. If the correlation was positive, the level of significance was recorded in the table. Statistical evaluation could not be performed in all regions because of low frequency or absence of change.

C. Discussion

Materials

Statistical evaluation was performed on the material that was randomly selected from the Pathology Department of the Royal Veterinary College. The breed distribution was compared with the breed distribution within the Stockholm dog population in 1961 (Bäckgren and Henricson 1964). It was shown that the boxer was over-represented to a highly significant degree ($\chi^2 = 13.92$; d.f. $= 1$). The poodles were evaluated as a composite group, and were under-represented in the selected material to an almost significant degree ($\chi^2 = 4.30$; d.f. $= 1$). There was no other significant difference in breed distribution between the dog population and the necropsy material. Bäckgren and Henricson showed that the distribution of breeds within a clinical material was

Table 1. Intrasegmental Correlation of Changes within the Intervertebral Articulations.

Changes	Chondrodystrophoid Breeds			Non-chondrodystrophoid Breeds			Total	Total	Total
	Female	Male	Total	Female	Male	Total	Female	Male	
Vertebral Osteophytes + Vertebral Synovial Joint Arthrosis	Pos$_1$	No	No	Pos$_3$	Pos$_3$	Pos$_3$	Pos$_3$	Pos$_3$	Pos$_3$
Vertebral Osteophytes + Costo-vertebral Joint Arthrosis	No	—	Pos$_1$	Pos$_3$	Pos$_3$	Pos$_3$	Pos$_3$	Pos$_3$	Pos$_3$
Vertebral Synovial Joint Arthrosis + Costo-vertebral Joint Arthrosis	No	—	No	Pos$_3$	No	Pos$_3$	Pos$_3$	Pos$_1$	Pos$_3$
Vertebral Osteophytes + Disc Degeneration	No	Pos$_1$	No	Pos$_3$	Pos$_3$	Pos$_3$	Pos$_1$	Pos$_3$	Pos$_3$
Vertebral Synovial Joint Arthrosis + Disc Degeneration	—	No	No	Pos$_3$	Pos$_1$	Pos$_3$	Pos$_2$	No	Pos$_2$
Costo-vertebral Joint Arthrosis + Disc Degeneration	No	—	No	Pos$_3$	Pos$_2$	Pos$_3$	Pos$_3$	No	Pos$_3$
Disc Protrusion (Type I) + Vertebral Osteophytes	No	Pos$_3$	Pos$_1$	No	No	No	No	Pos$_2$	No
Disc Protrusion (Type II) + Vertebral Osteophytes	No	No	No	Pos$_3$	Pos$_3$	Pos$_3$	Pos$_3$	Pos$_3$	Pos$_3$
	n=468	n=286	n=754	n=936	n=806	n=1,742	n=1,404	n=1,092	n=2,496

	Chondrodystrophoid Breeds				Non-chondrodystrophoid Breeds				Total	Total	Total	Total
	Cervical	Thoracic	Lumbar	Total	Cervical	Thoracic	Lumbar	Total	Cervical	Thoracic	Lumbar	
Vertebral Osteophytes + Vertebral Synovial Joint Arthrosis	—	No	No	No	—	Pos$_3$	Pos$_2$	Pos$_3$	—	Pos$_3$	Pos$_3$	Pos$_3$
Vertebral Osteophytes + Disc Degeneration	No	No	No	No	No	Pos$_3$	Pos$_3$	Pos$_3$	No	No	Pos$_3$	Pos$_3$
Vertebral Synovial Joint Arthrosis + Disc Degeneration	No	No	No	No	No	Pos$_3$	Pos$_2$	Pos$_3$	No	No	No	Pos$_2$
Disc Protrusions (I + II) + Vertebral Osteophytes	—	No	No	No	—	No	Pos$_3$	Pos$_3$	—	Pos$_3$	Pos$_3$	Pos$_3$
	n=145	n=377	n=232	n=754	n=335	n=871	n=536	n=1,742	n=480	n=1,248	n=768	n=2,496

Pos = Positive correlation
No = No correlation

1 = Level of significance $0.05>P>0.01$
2 = Level of significance $0.01>P>0.001$
3 = Level of significance $0.001>P$

representative of the normal population within the immediate area of the respective clinic. The over-representation of boxers was probably due to a selection of cases from the clinical material. The reason for this selection could not be explained. The slight difference in distribution of the poodle breeds might not have been a real difference, since the three poodle breeds were taken together as a composite group.

All dogs examined were mature and they were older than the general population. Sex distribution of the dog population in Stockholm for 1953 and 1956 has been studied (Krook 1956). The difference in sex distribution between the randomly selected material and the general dog population was not significant ($\chi^2 = 1.99$; d.f. $= 1$).

No cases of osteomyelitis, primary bone tumor, severe congenital or development anomaly, or post-traumatic change within the vertebrae were identified. Three dogs with radiographic evidence of metastatic spread of neoplasia to vertebrae were excluded.

Methods

Macroradiographic and gross examinations were of value in determining frequency, location, and gross morphologic appearance of vertebral osteophytes. The addition of microradiographic, tetracycline labelling, and conventional histologic techniques enabled a more detailed study of the structure and pathogenesis.

Classification of osteophytes into stages, for purpose of recording, was subjective but provided a workable method for recording their size and shape. The stages did not represent a quantitation of the osteophytes. That is, stage four did not represent an osteophyte two times as large as stage two. Also, osteophytes of the same stage had masses that varied widely.

The objective recording of stages of degeneration of the intervertebral disc, as determined grossly, was not always substantiated by histologic examination. It was seen that relatively normal-appearing discs often had rather severe microscopic changes.

Incidence and Causes of Its Variation

The incidence of spondylosis deformans reported in the present study was 61.2 per cent. In earlier reports, the incidence has ranged from 9 to 75 per cent. It is obvious that many factors influence this incidence.

In the present study, the incidence of spondylosis was reported as it related to age, sex, and breed. In order to evaluate the interplay of these factors, it has been necessary to make further statistical calculations that are discussed in this section.

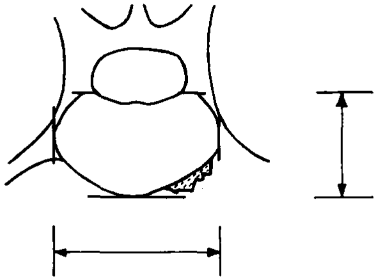


Fig. 41. Illustration demonstrating that two radiographic projections of the vertebral body will not demonstrate an osteophyte positioned on the ventro-lateral aspect of the vertebral body.

Methods of Investigation

The method of investigation affects the incidence greatly.

Some reports have not included examination of the entire vertebral column (Morgan *et al.* 1966). Other studies utilized radiographic examinations of the intact dog by routine lateral and dorso-ventral projections (Pommer 1933).

In the present study, it was noted repeatedly that small osteophytes located on the ventro-lateral margin of the vertebral body were not projected on macroradiographs. The reason for this was obvious when the vertebra was examined (Fig. 41). Also, a small osteophyte could escape detection on the macroradiograph even though it was located on the ventral midline. In the cat, Beadman *et al.* (1964) thought that 15 per cent of the osteophytes found in post mortem examinations were not visible on routine lateral radiographs. The present study suggested that a higher percentage may be unnoticed in the dog.

An examination of necropsy material will also result in changes passing unnoticed unless ventral musculature is thoroughly removed from the vertebral column. Failure to do this may result in a sizable error in determination of the number of osteophytes in the cervical, cranial and caudal thoracic, and cranial lumbar regions. This was probably the reason why Hansen (1952) reported a distribution and frequency of osteophytes that differed from that reported in the present study.

Age

The present study gave evidence that the incidence of spondylosis deformans in dogs increases with age. This fact has been reported earlier (Pommer 1933, Ipolyi 1939, 1941, Schick 1942, Debard 1949, Fankhauser 1955, Morgan *et al.* 1966, Read 1966).

This increase in incidence of spondylosis deformans with age did not necessarily mean that there were more or larger osteophytes in older dogs. The average number of the osteophytes per vertebral column was almost the same in the group 4 to 10 years of age as in the group over 10 years of age. Also, the size of the osteophytes did not increase markedly in older dogs.

From these data it would seem that most of the formation of the osteophytes took place during what might be considered 'middle age' of the dog. Also, some osteophytes progressed with age to stages four and five at the same time other new osteophytes were forming. The 'average' size of the osteophytes thus remained constant.

Exceptions to this pattern were recognized. A few older dogs had no osteophytes; conversely, others had widespread changes within the first years of life.

Sex

The observed equal sex distribution was in agreement with earlier studies in the dog (Pommer 1933, Ipolyi 1939, 1941, Hansen 1952, Martin 1959, Read 1966), but contrary to those who have reported the male to be more susceptible (Fankhauser 1955, Martin 1958), or the female to be the more susceptible (Morgan *et al.* 1966).

The average age of the sex groups is known to greatly affect incidence. This seems to have been overlooked in most earlier reports. It was discussed by Morgan *et al.* (1966) and ruled out as a cause of higher incidence in the female. The mean age in years in the present study was 7.45 (±3.78) for the males and 8.40 (±3.10) for the females. The difference between the ages was not significant ($t = 1.46$; d.f. = 114). Therefore, age did not influence the finding of an equal sex frequency.

Breed

The incidence of spondylosis deformans within the three breeds most highly represented was evaluated without reference to number of osteophytes per vertebral column. There was no significant difference in incidence between these three breeds.

The mean age of the three groups was determined to be 7.15 (±3.67) years for the German shepherds, 8.26 (±2.45) years for the boxers, and 9.75 (±3.23) years for the dachshunds. There were no significant differences between the ages of the groups of boxers and German shepherds and between the ages of the groups of boxers and dachshunds ($t = 0.96$; d.f. = 30; $t = 1.73$; d.f. = 41). There was slight significance between the age of the groups of German shepherds and the dachshunds ($t = 2.13$; d.f. = 35).

When the incidence of spondylosis and the mean age of the groups were compared, it was seen that the dachshunds were significantly older and had a slightly greater incidence of spondylosis deformans. Therefore, the higher age in the dachshund group probably caused the slightly greater incidence of spondylosis deformans as compared to the group of German shepherds.

There was an almost significantly higher frequency in the heavier dogs following division of the material by weight. Each weight class was divided into age groups to evaluate the affect of age. When comparison was made between the frequency of spondylosis deformans within four weight classes in each age group, no significant differences were found (χ^2 = 0.37, 4.88, 2.17; d.f. = 3). When comparison was made between the three age groups in each weight class, there was significance within the <10 kg class (χ^2 = 9.05; d.f. = 2), an almost significant difference within the 20.1 to 30 kg class (χ^2 = 7.70; d.f. = 2), and no significant differences in the other two classes (χ^2 = 2.30, 3.93; d.f. = 2). Thus, the significance noted following division into weight classes probably was due to unequal distribution based on age.

Hansen's definition of chondrodystrophoid breeds was used as a basis for division of the material. This included "the group of dogs that have . . . shown themselves to be particularly exposed to disc degeneration". The common denominator for these breeds was then discovered to be a pattern of endochondral ossification similar to that found in chondrodystrophy in man. In the present material, the dachshund, French bulldog, and pekingese breeds represented the chondrodystrophoid group.

No significant difference in incidence was found between the chondrodystrophoid and non-chondrodystrophoid breeds. The mean ages of the two groups were determined to be 9.83 (±1.83) for the chondrodystrophoid group and 7.75 (±3.34) for non-chondrodystrophoid breeds. This difference was highly significant (t = 4.20; d.f. = 114). The frequency of spondylosis was the same in two breed groups, one of which was significantly older. If the two groups were composed of dogs of equal ages, the chondrodystrophoid breeds might have had a lower frequency.

Hansen (1952) found that disc degeneration in chondrodystrophoid breeds usually led to type I protrusions without associated spondylosis deformans. Degeneration in discs of dogs of non-chondrodystrophoid breeds, as well as in discs of old dogs of chondrodystrophoid breeds, resulted in protrusions of type II and/or spondylosis deformans. The average age of the material in the present study was older than that in Hansen's study and this may make the result of direct comparison unreliable. However, the findings in the present study do not contradict Hansen's results.

The severity of spondylosis within breeds was also evaluated on the basis of number of osteophytes per vertebral column and the size of the osteophytes. This was only done in the three most highly represented breeds; boxer, German shepherd, and dachshund.

Within the boxer breed, the dogs had significantly greater numbers of osteophytes per vertebral column. Also, there was a higher frequency of the stages of larger osteophytes. No significant difference in age between the boxer and other two breeds was noted.

The German shepherd breed had dogs with more and larger osteophytes than the dachshunds, and yet the dachshunds were older to a significant degree.

The dachshunds had the fewest and smallest spurs and had the highest mean age of the three groups. This was in agreement with Hansen's findings that chondrodystrophoid breeds were less prone to spondylosis than were non-chondrodystrophoid breeds.

The present study indicated that if the size and number of osteophytes were considered, there would be a difference in breed predisposition to spondylosis deformans. This was in agreement with the reports describing a high incidence of spondylosis deformans in the boxer (Glenney 1956, Schnitzlein and Martin 1957, Martin 1958, Schnitzlein 1960, Zimmer and Stähli 1960, Morgan *et al.* 1966).

Distribution of Osteophytes

In the present study, the pattern of distribution throughout the vertebral column was slightly different from that noted in earlier investigations. Read (1966) reported the only study in the dog showing the incidence of osteophytes in the caudal thoracic region to be as high as the commonly reported peak at the lumbo-sacral junction. Read included in her definition of osteophytes bony changes that were not recorded as osteophytes in the present study.

The ventro-lateral location of most bony spurs in the caudal thoracic region was the probable cause of the low recorded incidence of osteophytes there. Also, the presence of overlying ribs made radiographic detection of small osteophytes difficult. Osteophytes in the lumbar region were generally midventral and were therefore more easily identified.

The incidence and size of osteophytes relative to the cranial and caudal aspects of the vertebrae of the dog was studied and no consistent pattern was noted.

The location of osteophytes on the ventral and lateral vertebral margins in the present study was in a bilaterally symmetrical pattern.

Examination of the distribution of vertebral osteophytes suggested that they were not randomly positioned. Specific patterns were obvious throughout the vertebral column and on each individual vertebral margin.

Dorsal osteophytes were rare in the present material. The presence of dorso-lateral spurs related to costal facets, transverse processes of thoracic vertebral bodies, or large lateral osteophytes was more common. The absence of dorsal osteophytes was striking in cases with extensive new bone growth present in all other areas around the vertebral margin. No cases were found in which osteophytes had encroached on the spinal canal to an appreciable extent.

Dorsal osteophytes have previously been reported in the dog. Many of these osteophytes were identified on a lateral radiograph and were not verified surgically or during necropsy. It is quite possible that dorso-lateral osteophytes, calcified disc protrusions, or ossification of the dura mater have been erroneously diagnosed as dorsal osteophytes.

Relation of Vertebral Osteophytes to Disc Degeneration

Anulus fibrosus

Changes within the anulus fibrosus appeared to play a major role in the development of vertebral osteophytes. In many discs, earliest changes were focal lesions in the anulus and these progressed to major intradiscal fissures. These changes were noted more commonly in the ventral aspect of the disc and were an almost constant finding in discs with associated osteophytes. However, the changes were also found in discs without osteophytes and, dorsally, in discs with osteophytes. The size and shape of the osteophyte did not always correspond to the extent and degree of change within the disc.

The more severe disc changes consisted of further damage to already ruptured anular lamellae and a noticeable increase in the amount of debris within the disc. In advanced cases, the disc tissue had almost disappeared and naked bone of adjacent vertebrae was ground and appeared almost 'polished'. This narrowing of the disc space appeared to have followed, rather than preceded, the early formation of osteophytes.

Hansen (1952) described changes in the anulus fibrosus that were related to dorsal disc protrusions. These changes were similar to the ones reported in the present study. However, intradiscal fissures within the ventral lamellae appear not to have been described in relation to spondylosis deformans in the dog.

The outer anular fibers consistently appeared to have been affected to a lesser degree than the remaining portions of the anulus. The reason for this is unknown.

Nucleus pulposus

The nucleus pulposus did not seem to play an important role in the pathogenesis of spondylosis deformans. Changes in the nucleus pulposus similar to those described by Hansen (1952) were noted. They consisted of chondroid and fibroid metaplasia within the chondrodystrophoid and non-chondrodystrophoid breeds respectively.

Contrary to the findings of Hansen, a slight positive correlation was observed in the intrasegmental relationships between type I protrusions and vertebral osteophytes in chondrodystrophoid breeds. Again, this may have reflected the effect of age in the present material. Further examination of intrasegmental pairs within the chondrodystrophoid breed group indicated almost no correlation between degeneration and calcification of the nucleus and vertebral osteophytes. The degeneration of the nucleus pulposus in the chondrodystrophoid breeds occurs at a younger age preceding the damage to the anulus. This lack of correlation suggests that degeneration of the nucleus in the form of calcification does not appear to stimulate the formation of vertebral osteophytes.

Hansen (1952) thought that spondylosis deformans was a morphologic expression of more advanced disc degeneration. There have been others who have also considered the pathogenesis of spondylosis deformans to be directly related to disc degeneration (Ipolyi 1939, 1941, Schick 1942, Fankhauser 1948). However, Martin (1959) described early spondylosis in the dog associated with discs that were normal in gross and microscopic appearance.

The findings of the present study strongly suggested that changes in the anulus fibrosus were far more important in the pathogenesis of spondylosis deformans than changes in the nucleus pulposus. Hansen (1959) suggested that changes in the nucleus pulposus were primary causes of all pathologic changes in the intervertebral space. Whether the anular changes described in the present study were preceded by nuclear changes or not was difficult to determine.

Cartilage Plate

The cartilage plate was less degenerated than other parts of the disc and showed no change in some discs. However, this structure seemed to play a part in compensating for a loss of nuclear material and a great increase in the width of the cartilage plate was often noted. This could account for the observation made from radiographs that narrowing of a disc space associated with disc protrusion is not permanent. After some time, normal or almost normal width is again noted (Olsson 1966).

Correlation of Changes within the Intervertebral Articulation

The possibility that vertebral osteophytes were correlated to other changes in the intervertebral articulation was considered. The intrasegmental correlations for the total material were positive for all but one pair. The same pattern held for the totals of the non-chondrodystrophoid breeds. The opposite pattern was found within the chondrodystrophoid breeds, where positive correlations were rare.

The pairs of changes with no correlation in the total breeds and non-chondrodystrophoid breeds involved type I protrusions. These were extremely rare in the non-chondrodystrophoid breeds and lack of correlation was probably due to this low number of protrusions.

The correlations that were strongly positive may have indicated an inter-relationship between the various changes within the intervertebral articulations. However, it was also possible that changes were related independently to a third factor such as increasing age. The material was not sufficiently homogeneous to permit formation of age groups to examine whether any change occurred independently of and earlier than the others.

Changes could also be correlated to disorders in another organ or system of the body. Necropsy reports on all dogs were thoroughly examined and there was no single condition that could be related to changes in the intervertebral articulation. However, there was no comparable control material with which to compare statistically the necropsy results of the investigated material.

The two positive correlations found in the totals of the chondrodystrophoid group were at a low level of significance. Disc degeneration in the two breed groups was of a different type. Therefore, it would appear that nuclear calcification, which comprised most of the disc degeneration in the chondrodystrophoid breeds, does not have a direct relationship with other changes in the intervertebral articulation. The lack of positive correlation between changes other than disc degeneration cannot be explained.

The material was divided by sexes and major regions of the vertebral column within the two large breed groups. The results of these subdivisions were generally the same as the totals for the chondrodystrophoid or non-chondrodystrophoid breed groups. The few differences in correlation followed no particular pattern. The lack of correlation within the cervical region was probably because of the low frequency of all changes these.

The results of the present correlative study were based on macroscopic observations that were only qualitative in nature. If a microscopic study were conducted in which the degrees of changes were compared, the result might be different.

Mechanism of Formation of Osteophytes

A 'notch' was consistently noted at the area of attachment of the outer anular lamellae to the vertebral end plate. Within the 'notch' were fragmented bone, calcified cartilage, and calcified debris. The cartilage and debris were regularly labelled with tetracycline. The impression gained was that of an avulsion of the attachment of the anular lamellae with progressive necrotic changes. Concomitant with the maturing of the osteophyte, the 'notch' became smoother as the tissue was replaced by bone.

Why the avulsion occurred almost exclusively at the attachment of the outer lamellae is not fully understood. As described in the present study, intradiscal fissures frequently extended to the level of the outermost lamellae. Under these circumstances the outer lamellae were the only intact fibers remaining that could transmit a stress from the nucleus to the vertebral end plate. However, even when most lamellae were intact, the avulsion and subsequent necrosis occurred regularly at the attachment of the outer lamellae. It is thought possible that non-ruptured lamellae with extensive change would be unable to effectively transmit normal stresses from the nucleus. Therefore, even though no lamellae were broken, the outer lamellae would still represent the only physiologically intact fibers through which stress could be transmitted. In either event, the traction exerted upon the attachment of the outer lamellae on the vertebral end plate would be greater than normal.

The vertebral end plate seemed to play no active role in formation of the osteophytes. Usually no increase in the amount of bone tissue within the vertebral end plate was observed. When an increase was present, there were usually severe changes within the intervertebral disc. This was contrary to earlier reports (Schick 1942, Hansen 1959). They stated that the sclerosis of the vertebral end plate was an end point of the pathogenesis of spondylosis deformans.

In the present study, thinning of the vertebral end plate more commonly was found in older dogs. This also was unrelated to spondylosis deformans.

Origin and Growth of Osteophytes

The exact location of the origin of the osteophytes varied slightly, but was usually located adjacent to the corner of the vertebral body. Multiple foci of fibrocartilage which were subsequently calcified, formed and united with the vertebrae at an early stage.

Ingrowth of blood vessels was followed by a destruction of calcified cartilage and a formation of a mature-appearing trabecular bone. This slow, orderly growth led to a final stage of continuous blending of the trabecular patterns and marrow spaces between the vertebra and osteophyte.

The mass of connective tissue formed between osteophytes continually provided the network on which bone tissue was formed. This collagenous tissue appeared as an extension of the outer anular fibers. It was definitely not disc tissue that was bulging or had been squeezed out.

The multiple foci of fibrocartilage and calcified cartilage often remained unattached within the collagenous tissue that formed outside the anulus fibrosus. Bone was formed within these foci. Many of these bony segments reached considerable size with a mature appearance but still remained unattached to the vertebrae. Others joined advancing osteophytes. The macroscopic studies did not completely rule out the possibility that the bony segments were fracture fragments. However, the histologic study made it possible to show the manner in which these segments were formed and excluded the possibility that they were a result of fractures.

The development of vertebral osteophytes was shown to have no association with possible remnants of the epiphyseal growth plate.

Formation of the osteophytes was similar in both chondro- and non-chondrodystrophoid breeds.

Microscopic studies showed which osteophytes and specifically which parts of an osteophyte were in the process of growing. The pattern of tetracycline labelling was not equal in multiple osteophytes in the same dog. Also, the presence of calcified cartilage as seen microradiographically was not always associated with high levels of tetracycline uptake. This indicated that growth of the osteophytes was not always continuous. Signs of maturity included the blending of trabecular pattern and disappearance of calcified cartilage on the surface of the osteophytes. Maturity could occur at any stage suggesting that formation and growth of an osteophyte was governed by some functional requirement. When sufficient size was reached to provide the reinforcement required, growth apparently ceased. Whether or not new stimuli could initiate renewal of growth is not known, but this seems probable.

The Role of the Ventral Longitudinal Ligament

The passive role played by the ventral longitudinal ligament in initiation or pathogenesis of osteophytes was obvious in the present study. The location of the osteophyte's origin in relation to the ventral midline determined whether the ligament would be stretched over the osteophyte, cause a groove in the osteophyte, or become surrounded by new bone. The crescent form of the osteophyte indicated that there had been ventral and/or lateral pressure. The longitudinal ligament and its thinner continuations laterally seemed to provide a restraining force on the osteophyte.

It was observed in the present study that both ventral and dorsal longitudinal ligaments were fused to the anulus of the intervertebral disc. This is in agreement with earlier studies (King and Smith 1955, King 1956, Smith 1960). The dorsal longitudinal ligament is much heavier than the ventral counterpart and extends from the axis to the coccygeal region. It forms a part of the floor of the spinal canal and displays a characteristic widening as it passes over each interspace. The longitudinal ligament attaches to a greater segment of the periphery of the vertebrae dorsally because of this marked widening.

In the present study the method and degree of attachment of the longitudinal ligaments to the vertebrae appeared similar both dorsally and ventrally. However, the fibers entered the bone dorsally at a sharper angle. This point of

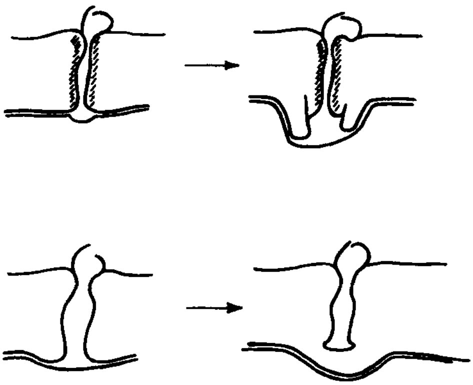


Fig. 42. Diagram explaining the possible influence the longitudinal ligament may exert on the development of spondylosis deformans. If the disc space is collapsed (above) the ligament will be more loosely fitting and exert less effect on the direction of growth of the new bone. If the disc space is of normal width (below) the ligament fits more tightly and exerts pressure influencing the shape of the bony spur.

attachment did not appear to play any part in the initiation of development of osteophytes. No evidence of cellular activity at the attachments of the longitudinal ligaments to the vertebrae was noted in these studies. The ventral or lateral growth of the osteophyte was uniform and from the cambium layer of the cortex, and not greater at the exact point of ligamentous attachment.

A thinner lateral continuation of the ventral longitudinal ligaments provided a covering for a part of the vertebral body.

Osteophytes at a narrowed interspace had a different appearance. The narrowing apparently resulted in a loosening of the ventral longitudinal ligament, which was then unable to exert as great an influence on the shape of the osteophyte (Fig. 42).

Ossification of the vertebral ligaments has been reported in the dog and the name "ankylosing spondylitis" used (Schnitzlein and Martin 1957, Martin 1958, 1959, Schnitzlein 1960). The changes observed within the longitudinal ligaments in this study were minimal and resembled those found in the anulus fibrosus. Ossification within the ligaments was not a part of the condition described in the present study. The ventral longitudinal ligament was influential only in determining the characteristic shape of the vertebral osteophytes; it did not initiate formation of them.

The present morphologic study gave ample evidence that the pathogenesis of vertebral osteophytes is as follows. Changes that are assumed to be degenerative, occur within the ventral anulus fibrosus. Stresses on the nonruptured outer anular lamellae seem to cause avulsions of their attachments.

Formation of the osteophyte occurs in a fibrous tissue formed outside the anulus fibrosus. Development resembles that found in normal growth of bone referred to as endochondral bone formation. Changes in nucleus pulposus, cartilage plate, and vertebral end plate seem to be of minor importance. The ventral longitudinal ligament is influential only in giving the osteophyte its typical curved shape. The formation of vertebral osteophytes was shown repeatedly to be a slowly occurring, non-inflammatory, reparative process.

The findings of the present study provide ample evidence to justify the use of the term spondylosis deformans to describe this condition. The common use of the term spondylitis in veterinary medicine is without justification since inflammation has no role in the pathogenesis. Other terms have been suggested that indicate a degenerative character. However, spondylosis deformans is the most commonly used term in human medicine and has been partially accepted in veterinary medicine. Therefore, spondylosis deformans seems to be the term of choice for naming this condition in the dog.

PART III

Radiological and Clinical Observations

A. Growth of Vertebral Osteophytes

1. Methods and Materials

Repeated radiographic examination of living dogs was the method used for studying growth of vertebral osteophytes. For this reason, 25 owners of dogs with radiographically diagnosed spondylosis deformans were asked to return their dogs for re-examination. Of those contacted, 22 agreed to participate in the study. Only the previously radiographed portions of the vertebral columns were re-examined. The intervals between the two examinations ranged from 11 to 27 months.

2. Results

The dogs were described and the findings were tabulated (Table 2).

3. Discussion

Examination of the total vertebral columns could not be made. Therefore, the discussion must be limited to the appearance of new osteophytes and growth of older osteophytes on the predetermined regions of the vertebral columns. Macroradiographic techniques have been shown to have limitations in diagnosis of spondylosis deformans. Nevertheless, several conclusive observations were possible.

Growth of osteophytes which were present on the first examination and/or formation of new osteophytes were seen in 15/22 (0.68) dogs. These represented many breeds, both sexes, and ages ranging from 4 to 14 years. Formation of new osteophytes during the interval between the examinations was seen in 9/22 (0.41) dogs. No new osteophytes were identified in 13/22 (0.59) dogs, irrespective of the appearance of the older spurs. No difference in size or number of osteophytes had occurred during the interval of time between the radiographic examinations of 7/22 (0.32) dogs. These were from five breeds and both sexes, and their ages ranged from 2 to 9 years.

4. Conclusions

The present study showed that two thirds of a group of dogs of widely varying ages and breeds, and of both sexes, had an increase in number or size of

Table 2. *Observations on Growth of Osteophytes as Determined by Comparative Radiographic Studies.*

Breed	Age at last study in years	Sex	Period between studies in months	Stage of development of osteophyte								Comment
				First study				Second study				
				II	III	IV	V	II	III	IV	V	
Non-chondrodystrophoid												
Airedale terrier	2	F	12		4				4			unchanged
Fox terrier	4	M	17	2					2	2		
Boxer	5	M	16	1	4	4			3	4	2	
Boxer	5	F	18	4				3	1	1		
Dalmatian	6	M	20		1				1			unchanged
Bloodhound	7	M	21	1	6	2		2	11	3		
Boxer	7	F	27	2	5	8	11	1	3	6	16	
Boxer	7	M	18		1					1		
Boxer	7	M	18	1				1	1			
Boxer	9	M	11		1	3			1	3		unchanged
Boxer	9	F	12	2	1	2		4	1	2		
Drever	9	F	13		2				2			unchanged
Standard poodle	9	M	20	1		2		1	2	1	2	
German shepherd	11	F	18	1	6	2	2	1	8	4	2	
Shetland sheepdog	11	F	19		1	1				2		
Standard poodle	12	F	16		2					2		
Labrador retriever	12	F	14		5	1		1	2	3	2	
Cocker spaniel	14	F	19		2				1	1		
Chondrodystrophoid												
French bulldog	4	M	18		2				2			unchanged
Dachshund	5	F	13		1			1	1			
Dachshund	6	F	15		2	1			2	1		unchanged
Dachshund	8	M	15				2				2	unchanged
			Totals	15	46	26	15 = 102	15	48	36	26 = 125	

osteophytes. During the interval of time between examinations, one third of the dogs had only quiescent-appearing osteophytes in various stages.

B. Clinical Significance of Vertebral Osteophytes

1. Methods and Materials

A questionnaire was sent to 86 owners of dogs that were obtained by random selection through the Pathology Department (Group A). Dogs with and without spondylosis deformans were included. Remaining owners were not contacted because of failure to obtain complete names or addresses.

The following information was requested: (1) Had the dog ever shown pain in the vertebral column or weakness in the hind quarters? In case of such pain, describe signs, treatment, and recovery. (2) Had the dog previously had any injuries to the vertebral column or hind legs? (3) What had been the general condition of the dog, especially as related to running, climbing, and jumping? (4) How long had the owner owned the dog?

The cases were divided into three groups for purposes of statistical analysis. One group was considered to have a 'negative' history relative to the vertebral column. It included all cases with negative histories and those with positive histories in which the description of pain or disability could not possibly be attributed to chronic change within the vertebral column. The second group was classified 'doubtful'. It included dogs with positive medical histories in which the cause of lameness or pain could have originated from the vertebral column. However, the medical history or necropsy offered other explanations for the disability. The third group was classified 'possible'. The positive medical histories suggested that pain or disability originated from the vertebral column. The necropsy reports rarely confirmed this possibility, but offered no other explanation for the clinical signs observed.

The 22 owners of dogs that were re-examined radiographically completed the same questionnaire (Group B). A description of this material was presented earlier (Table 2). Because of the bias in selection of material, no statistical evaluation was performed. The questionnaires were evaluated in the same manner.

2. Results

A total of 84 owners of dogs in Group A responded. All except one had owned the dogs since they were puppies. This indicated that the history was complete for the entire life of each dog, except one.

The first group with a 'negative' history had 33/55 (0.60) dogs affected with vertebral osteophytes. The group considered 'doubtful' had a total of 7/10

(0.70) with vertebral osteophytes. The third group was classified 'possible' and included a total of 15/19 (0.79) with vertebral osteophytes.

The difference in frequency of vertebral osteophytes within these three groups was not significant ($\chi^2 = 2.31$; d.f. = 2).

The medical histories of the dogs in Group B were evaluated by use of criteria presented above. No dogs were classified as having 'doubtful' histories.

An increase in size or number of osteophytes was noted in 10/16 (0.62) with 'negative' clinical signs (Group 1) and in 5/6 (0.83) in which positive clinical signs were judged 'possible' (Group 3).

3. Discussion

Answers were frequently more detailed than necessary and included a great deal of insignificant material. Inclusion of specific dates pertinent to the dog's medical history indicated a thorough knowledge and memory concerning the animal. Additional comments were frequently furnished with detail and exactness.

The question concerning amount of exercise was primarily to ascertain the physical condition of the dog. It also indicated that each dog was exercised regularly. Therefore, any difference in manner of locomotion would more readily be noticed than if the dog were allowed to remain within a home or exercised unescorted.

Throughout the present study, continual effort was made not to underestimate the possibility that clinical signs were associated with spondylosis deformans. If there was doubt concerning the origin of pain, lameness, or weakness, it was always assumed that it could have been related to the vertebral changes.

Group A

The dogs in Group A were considered to have been randomly selected from the cases presented to the Pathology Department.

The interpretation of what should be considered significant pain or disability was subjective. However, the division of the material into three groups made it possible to draw conclusions from the data. It was thought that the questionnaire was valid as a measure of clinical signs of pain, lameness, or paresis.

Interpretation of necropsy findings in relation to medical histories was difficult. Many cases with clinical signs of lameness, or more often, weakness during the last years of life, had necropsy findings which could well explain the signs described. These necropsy findings often included severe cardiac disease, chronic renal disease, or extensive spread of a malignant tumor. These cases were placed in the 'doubtful' (Group 2) category for statistical evaluation.

In contrast, there were medical histories in which owners made positive comments concerning physical activity of their dogs. These often described dogs that had severe spondylosis deformans and had led a physically active life until time of death.

Group B

The material re-examined radiographically was not evaluated statistically because of a selection from clinical material. Unexplained lameness or posterior weakness was seen in 6/22 (0.27) dogs with spondylosis deformans. Of those dogs with no clinical signs of pain, lameness, or posterior weakness, 10/16 (0.62) had an increase in size or number of osteophytes. Some of these had extensive stage four and five vertebral osteophytes.

4. Conclusions

The present study offers proof that spondylosis deformans in the dog is usually present without associated clinical signs.

PART IV

Experimental Production of Vertebral Osteophytes

The present morphologic study indicated that changes in the anulus fibrosus were important for production of osteophytes. The following experiments were designed to test the validity of this finding.

A. Method and Materials

Seven young mature dogs were used for the experiment. No abnormality of the discs could be found on macroradiographs of the vertebral column. The thoraco-lumbar discs of 3 dogs (1, 2, 3) were exposed from the lateral side. Three discs in each dog were punctured with a lancet and mucoid nuclear material exuded. No effort was made to remove nuclear material and no curetting of the discs was performed. Recovery of these dogs was uneventful.

Each of the additional 4 dogs (4, 5, 6, 7) had two different procedures performed on their intervertebral discs. The lumbar discs were exposed through a mid-abdominal incision. All exposed discs appeared normal. Five discs were subjected to experimental injury in each dog. One procedure was to insert a scalpel blade transversely into the ventral anulus in such a manner that neither nucleus nor ventral longitudinal ligament was affected. The other procedure was to cut both ventral longitudinal ligament and outer anulus fibers without injury to the nucleus. In none of these discs did nuclear material protrude. Recovery was uneventful in 3 dogs. Abdominal viscera partially herniated through the incision immediately following surgery in one dog. The incision was reclosed and further recovery was uneventful. The period of time between surgery and necropsy was recorded (Table 3).

Following necropsy of the experimental dogs, macroradiographs of the vertebral column were made using standard and multiple oblique projections. Macroscopic examination was performed and tissue for conventional histologic examination was taken from the vertebral columns of 5 dogs (1, 2, 3, 4, 5). It included transverse sections of the disc. Sagittal and frontal sections included portions of both vertebrae and intervening discs. Sections of discs adjacent to those operated upon were used for controls. The 2 other dogs (6, 7) were examined macroscopically in such a way that tissues for histologic examination was not available.

Specimens for microradiographs were obtained in the same manner as described previously (Page 26).

The techniques used in preparation of the histologic sections and microradiographs were similar to those described earlier (Pages 38, 26).

B. Results

Macroscopic and Macroradiographic Studies

Changes around the discs operated upon were classified in three categories according to macroscopic or macroradiographic changes (Table 3). The first category included discs without evidence of fibrous tissue proliferation or osteophytes. Signs of surgical intervention were easily identified in all but two discs (dog 1, disc 19; dog 2, disc 21). The second category included discs with fibrous tissue proliferation. This created a mound of firm tissue adjacent to the disc. A surgical scar was noted in all of these discs. The third category included discs with radiographic evidence of new bone proliferation. In one case, the new bone growth involved the attachments of the crura of the diaphragm. The resulting osteophyte was located further from the disc space than usually seen (dog 4, disc 22).

The smallest gross changes were noted following puncture of the nucleus with a lancet. The highest percentage of larger osteophytes resulted from

Table 3. Results of Experimental Production of Vertebral Osteophytes.

Case number	Breed	Sex	Age in months at surgery	Post-operative period before necropsy in days	Disc numbers								
					17	18	19	20	21	22	23	24	25
1	Mongrel	F	12	156	1_a		1_a		1_c				
2	Dalmatian	F	13	256	1_c		1_c		1_a				
3	Dalmatian	F	13	300	1_b		1_b		1_b				
4	Fox terrier	F	23	224					3_c	2_c	3_a	3_c	2_c
5	Fox terrier	F	23	220				2_c	3_c	2_b		3_c	2_b
6	Mongrel	F	12	220					2_b	2_c	3_a	3_c	3_c
7	Mongrel	M	12	217					2_c	3_c	2_c	3_c	3_c

1 = Lancet passed into nucleus pulposus through anulus fibrosus.
2 = Ventral part of anulus fibrosus cut with a scalpel introduced ventro-laterally.
3 = Ventral part of anulus fibrosus and longitudinal ligament cut with a scalpel.

a = No gross changes.
b = Formation of soft tissue mass.
c = Formation of osteophyte.

cutting of the longitudinal ligament and outer anulus. However, 2 discs treated in this manner had no gross evidence of tissue proliferation even though the surgical scar was evident. All discs with injury to only the anulus fibrosus had proliferative changes, but not as extensively as had the discs with additional injury to the longitudinal ligament.

The nucleus was mucoid or in early stages of fibroid metamorphosis in all discs except those in which the experiment involved the nucleus. The nuclei of fenestrated discs (procedure 1) were less mucoid in appearance and had lost their normal configuration. They remained in the normal location except for one that had shifted in a controlateral direction (dog 2, disc 19). Occasionally minimal discoloration of the entire disc was noted (dog 2, disc 17; dog 3, disc 19). There were no gross signs of hemorrhage associated with the changes.

Generally the location of changes corresponded closely with the site of the experimental lesion. When the tissue proliferation was small, it was located only at the point of incision.

Small dorsal protrusions of type II were noted in 2 dogs (dog 4, discs 22, 24; dog 5, disc 21). There was no grossly apparent compression on the spinal cord.

As seen macroradiographically, the operated disc spaces remained of normal width with two exceptions of narrowing. No evidence of increase in the amount of bone within the vertebral end plates was noted.

One operated disc (dog 1, disc 21) had severe changes that were atypical when compared with the others. Macroradiographic changes consisted of destruction of the central portion of the adjacent vertebral end plates with an increase in the amount of bone surrounding the lytic areas. There was associated collapse of the disc space. These signs were first noted 22 days post-operatively and were interpreted as due to a discospondylitis. No evidence of osteophytes was seen on the macroradiographs and the other disc spaces appeared radiographically normal. Extensive palpation over the vertebral column elicited no sign of pain. Radiographic changes remained essentially the same and the dog was without clinical signs during the time preceding necropsy. At gross examination the affected disc was hemorrhagic, collapsed, and with large osteophytes on both ventro-lateral borders of each adjacent vertebrae. Most severe change was at the site of surgical invasion of the disc. Hemorrhagic material from the disc was cultured with a negative result.

Unoperated portions of the vertebral column were negative for spondylosis deformans. Vertebral synovial joints and costo-vertebral joints were normal by gross determination.

All of the control discs were normal on gross examination except one (dog 5, disc 26). This disc had undergone severe change with a type II protrusion resulting.

All dogs were healthy, active, and without clinical signs of pain during the period of time between surgery and necropsy.

The appearance of the osteophytes as observed on conventional histologic preparations was similar to that seen in spontaneously occurring spondylosis deformans (Figure 43 A). The experimental incision was recognized in most discs and did not involve the nucleus in discs treated by procedures 2 and 3. The severed ends of the surgically incised anular lamellae were tapered in some cases and had become deeply basophilic. However, none of the earlier discussed lamellar or intra-lamellar changes were observed (page 43).

Focal necrosis in the vertebral end plate was identified in several sections. However, the changes were minimal and did not include severe necrosis and subsequent avulsion of bone fragments.

The osteophytes developed through the same stages as described in the spontaneous material (Figure 43 B, C). The addition of collagenous tissue ventral to the anulus was not as great as would have been expected in spontaneous cases.

The microradiographs of the experimentally produced osteophytes were similar to the spontaneously occurring spurs (Fig. 44). The calcified cartilage on the surface was thicker, however.

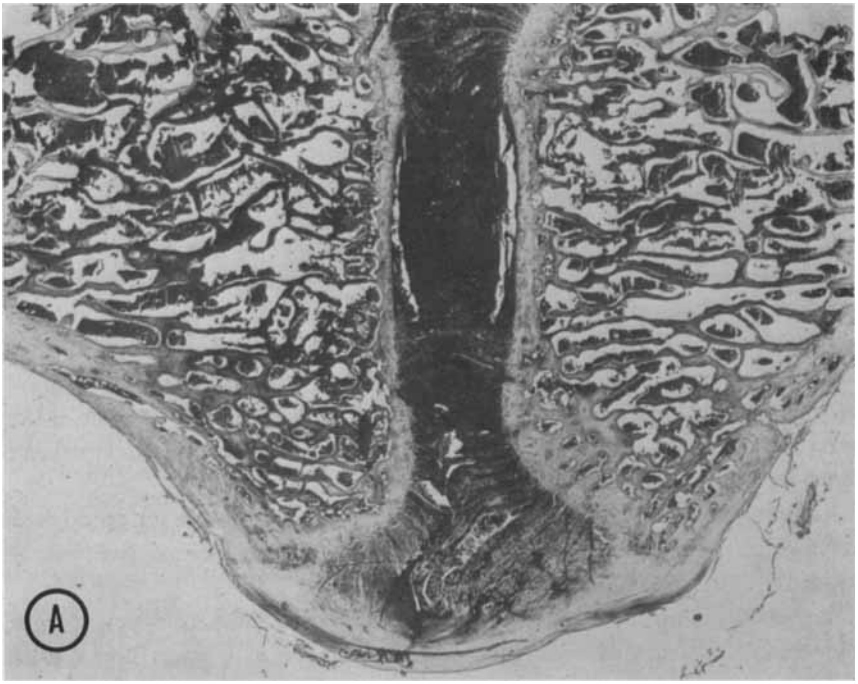
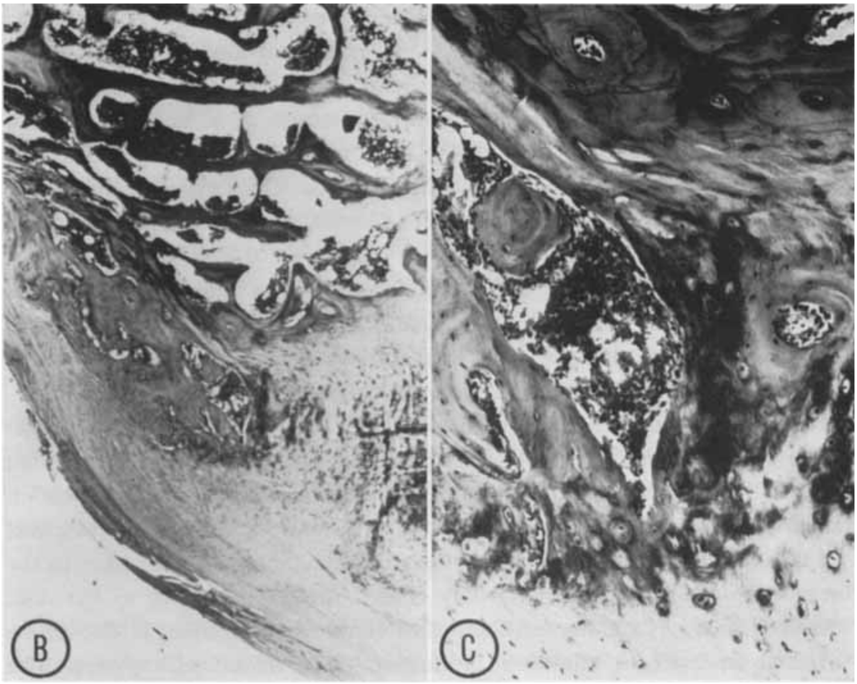


Fig. 43. A. Sagittal section of experimentally produced spondylosis deformans in disc 24 of a fox terrier (2 yr ♀). The osteophytes are in stage two. The effect of the surgical incision on the anulus can be seen. H & E (× 8).



B. Detail of the osteophyte on the left of A, but taken from adjacent tissue section. H & E (× 25).

C. Detail of the surface of the osteophyte in B. A large number of osteoblasts are present. H & E (× 100).

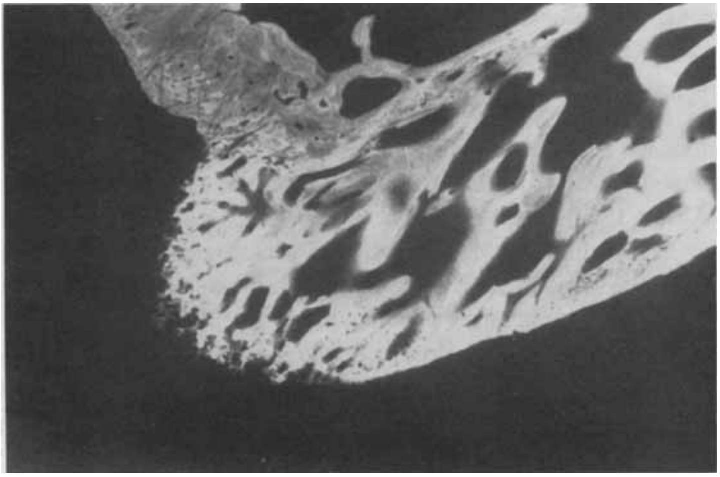


Fig. 44. Microradiograph of a sagittal section of an experimentally produced osteophyte at disc 21 of a fox terrier (2 yr ♀). (× 50).

C. Discussion

The experimental lesions in the discs and/or ventral longitudinal ligaments consistently produced vertebral osteophytes. The first procedure involved minimal injury to the anulus and permitted escape of a small amount of nuclear material. The longitudinal ligament was left intact. In the second procedure, injury was to the anulus alone. In the third type of lesion, the longitudinal ligament and the outer anular fibers were severed without directly damaging the nucleus.

A common factor in the three procedures was an injury to the anulus fibrosus. The degree of change to the anulus appeared to be directly related to the degree of bony response. The associated injury to the nucleus or longitudinal ligament did not appear to alter the type of response.

The operative intervention showed that surgical lesions to normal discs gives rise to vertebral osteophytes. The specific mechanism causing the formation of the bony spurs was not completely understood. The surgical intervention probably caused an instability of the disc. This is logical when the assumed function of the anulus fibrosus is considered. If this is true, the damage to the nucleus or longitudinal ligament only caused further instability to the disc. Selective damage to either of these structures alone is thought not to be sufficient in itself to stimulate production of vertebral osteophytes. The possibility that the surgical procedure alone might stimulate the formation of osteophytes should also be considered.

The minimal differences between the structure of experimentally produced and spontaneously occurring osteophytes can be explained by the more rapid growth of the former. The rapid formation of the osteophyte exceeded the production of the collagenous tissue ventral to the disc. The number of chondrocytes in various stages of deposition of mineral in the matrix and the number of osteoblasts were much greater than in the spontaneously affected material.

Experiments have been performed in dogs (Keyes and Compere 1932, Compere and Keyes 1933, Haas 1946, Sullivan and Compton 1957, Sullivan and McCaslin 1960, Pettit 1960) and in rabbits (Lob 1933, 1934, Smith and Walmsley 1951) with resulting production of osteophytes. A direct comparison of these studies was difficult since the procedures were more severe and extensive than those used in the present study.

Other investigators have injured the disc but subsequently stabilized the interspace. Jenkner *et al.* (1953) attempted intervertebral fusion in monkeys following a fenestration technique in which he carefully re-sutured the anular flap. Humphries and Hawk (1959) packed the disc space of dogs with bone chips and used an anteriorly placed plate to create stability. Key and Ford (1948) attempted to produce posterior protrusions of the disc in dogs by damaging the posterior longitudinal ligament and dorsal anulus fibrosus. All of these experiments damaged the disc. However, when stability was re-established, the production of osteophytes was minimal, if present at all.

Macroscopically observable changes in the rest of the intervertebral articulation were not noted in the experimental cases. Instability of the disc may also produce an environment resulting in production of arthrosis in the vertebral synovial or costo-vertebral joints. If this is true, it apparently requires a longer interval of time before macroscopic changes are found.

The experimental studies reported in the present investigation are in agreement with earlier experimental studies. However, it would appear that only a small degree of trauma is necessary to create the instability within the disc that is thought to be important in production of vertebral osteophytes. It is suggested that the role of the nucleus or longitudinal ligament is not as important in production of osteophytes as is the damage to the anulus.

D. Conclusions

Three different experimental procedures which damaged the intervertebral disc produced vertebral osteophytes. The procedures all damaged the anulus fibrosus. The results of the experiment support the conception that changes in the anulus fibrosus precede formation of vertebral osteophytes.

PART V

Comparative Aspects

A. Morphologic Appearance

The structure of spondylosis deformans in the dog was similar to the condition as it was described in man (Junghanns 1931, Oppenheimer 1942, Hirsch and Riley 1947, Bick 1952, 1955 a, b, Bohatirchuk 1955, 1957, 1963, Schmorl and Junghanns 1959). In man, as in the dog, there were two types of osteophytes reported. The most common was associated with a disc space of near normal width and had a curved shape. The less common type was found around disc spaces that were narrowed, and the osteophyte was less curved and more pointed (McRae 1956, Schmorl and Junghanns 1959).

Osteophytes in the bull (Thomson 1965) and in the cat (Read 1966) had a similar morphologic appearance to that noted in the dog and in man.

A difference in structure was related to the amount of bone within the osteophyte. Vertebral osteophytes in the bull were described as being sclerotic (Thomson 1965). This was not noted in studies of man and the cat, and rarely in the present study of the dog. This finding in the bull was based primarily on macroscopic techniques.

The blending of the trabecular pattern between the osteophyte and the vertebral body appeared to be more complete in man, the cat, and the dog, than in the bull.

The similarities between man and the dog are noteworthy because of postural differences and differences in shape and architecture of the vertebrae.

The incidence of vertebral osteophytes in the dog increased with higher age. This was in agreement with studies in man (Junghanns 1931, Roche 1957, Jonck 1961, Nathan 1962), in the bull (Thomson 1965), and in the cat (Beadman *et al.* 1964, Read 1966).

In the present study, there was no sex difference in the incidence of spondylosis. In man, there was evidence of earlier occurrence in the male, with the female equally affected at an older age (Junghanns 1931). Jonck(1961) and Nathan (1962) also reported a higher frequency of spondylosis in the male. Roche (1957) reported a higher incidence in the female. However, with increasing age, the incidence in the male equaled or exceeded that in the female. No sex difference was found in the incidence of spondylosis in the cat (Read 1966). In contrast, the nearly complete absence of spondylosis in the cow and the high frequency in the bull was recognized (Hansen 1956, Bane and Hansen 1962, Thomson 1965).

Differences in the incidence of vertebral osteophytes between the various races of man were described (Stewart 1947, Roche 1957, Nathan 1962). Thomson (1965) suggested that differences in breed incidence in the bull were also possible. In the present study, different breed incidences were found, but because of the nature of the material, complete information on this point was not obtained.

Stewart (1958) found an increase with age in the number of vertebral segments involved, rather than great increases in size of individual osteophytes. This finding in man agrees with that noted in the dog.

The similarities in structure of vertebral osteophytes in different species are more evident than the differences. However, spondylosis deformans in the bull does not conform to the general pattern as closely as the other species.

B. Pathogenesis

Both the morphologic and experimental observations in the present study suggested that changes in the anulus fibrosus lead to ruptures of its fibers This was shown to be of great importance for the occurrence of osteophytes.

In man, Schmorl and Junghanns (1959) reported typical tears in the outer fibers of the anulus fibrosus with resulting detachment from the vertebral rim as the change preceding osteophyte formation. An explanation for the rupture of the anulus fibrosus was not given. Thomson (1965) described focal changes in the anulus of the bull that were similar to the ones described in the dog. He considered them of great importance for the occurrence of osteophytes. However, any tears or clefts noted were considered to be artifacts resulting from sectioning. Ruptures of the anulus in the dog, that may be similar to those noted in the bull, were thought to be intravital in the present study.

There are studies in man in which more widespread changes in the discs were associated with osteophyte formation (Beadle 1931, Shore 1935, Collins 1949). Read (1966) reported that many different changes in the disc of the cat could predispose to formation of osteophytes.

The pathogeneses of spondylosis deformans reported in the above studies are in general agreement that a prerequisite for vertebral osteophytes is some type of change in the disc.

One interesting point in the comparative discussion of spondylosis deformans is the distinct pattern of osteophytes throughout the vertebral columns of individuals of different species. From earlier reports, it was evident that each of the four species studied had its own characteristic pattern. In man, there are three reports including distribution patterns (Shore 1935, Ingelmark *et al.* 1959, Nathan 1962). The highest incidence was found in the caudal thoracic and the lumbar regions. The next highest incidence was found around C5—6. In the cat, there are two studies with distribution figures (Beadman *et al.* 1964, Read 1966). The incidence was shown graphically in this species as a bell-shaped curve with the peak at disc 13. The single study in the bull (Thomson 1965) reported two peaks on the distribution curve. One was located at disc 9 and the other at disc 19. In the present study it was shown that in the dog there were two peaks of equal height. One was located at disc 15 and the other at disc 26.

The difference in distribution along the vertebral column of different species probably reflects a difference in the bio-mechanics of the vertebral columns. It could mean that factors such as posture, type of physical activity, and range of mobility of different segments of the vertebral column, are of importance for the occurrence of disc changes. These disc changes may then cause the occurrence of osteophytes. It is also possible that the cause of the degeneration of the discs may be unrelated to the bio-mechanical factors. However, once degenerated, the discs become susceptible to further injury. This may lead to an instability in areas where stress and motion are greater and result in changes in the anulus fibrosus that lead to osteophyte formation.

Either explanation of the difference in distribution patterns of osteophytes suggests the importance of bio-mechanical factors in the pathogenesis of osteophytes.

Another finding that supports the concept of a bio-mechanical influence is the distribution of the osteophytes on the vertebral margin. In man (Allbrook 1957, Jonck 1961, Nathan 1962), in the cat (Read 1966), and in the dog, there was a tendency for the osteophytes to be more ventrally located in the lumbar region and more laterally located in the thoracic region. This similarity in distribution pattern could possible reflect the fact that torsion of the vertebral column is almost entirely limited to the thoracic region in these species.

The manner of formation of the vertebral osteophytes in man was generally reported to occur through endochondral ossification of fibrocartilagenous tissue (Hirsch and Reilly 1947, Schmorl and Junghanns 1959). However, Collins (1949) reported osteophytes in man formed by sub-periosteal apposition of bone. Bick (1952) reported the growth to be a reactive osteogenic process and distinguished it from calcification in the vertebral ligaments. Oppenheimer (1942) described osteophytes in man forming in a potential triangular space formed by the vertebral body, longitudinal ligament, and anulus fibrosus. He stressed that new bone could not form in normal connective fibers. However, Bick (1955 a, b, 1956 a, b) described the osteophytes infiltrated the ligaments surrounding the intervertebral space.

Stress resulting from disc degeneration and acting on the ventral longitudinal ligaments was considered of major importance in formation of vertebral osteophytes in man (Beadle 1931, Junghanns 1931, Bick 1955 a, b, 1956 a, b, Schmorl and Junghanns 1959). However, other studies in man (Oppenheimer 1942, 1945), in the bull (Thomson 1965), and in the cat (Read 1966), discounted the importance of stress on the longitudinal ligament. This was also found to be true in the dog in the present study. Thomson (1965) reported the conversion of the longitudinal ligament to bone in the bull. This was not found in the dog in the present study or in the study of the cat (Read 1966). It has not been reported in man.

There have been those who felt that the disc in man bulged or protruded and thus provided a matrix on which the osteophyte developed (Collins 1949). Others described the formation of osteophytes in newly added tissue outside the original lamellae (Saunders and Inman 1940, Inman and Saunders 1947). Thomson (1965) also described formation of new connective tissues outside the disc. It is possible that this new connective tissue has been mistaken for bulging anular lamellae. In the present study of the dog, the presence of newly formed connective tissue was firmly established.

Spondylosis deformans as it occurs in different species seems to be closely associated with disc degeneration. The distribution patterns suggested that dynamic and mechanical factors are of importance in the pathogenesis.

C. Clinical Significance

There are studies in other quadrupeds than the dog, and in man, that suggest a clinical significance of spondylosis deformans. Bane and Hansen (1962) studied vertebral changes in the bull. They concluded that spondylosis deformans occurred more or less regularly in the ageing bull, and was a cause of inability to serve in the older animal.

Thomson (1965) stated in the introduction of his study of vertebral osteophytes in the bull that this was one of the causes of impaired serving ability. However, only 5 per cent of his material was slaughtered because of serving inability, while over 80 per cent had vertebral osteophytes.

A clinical significance has also been reported in cases of cervical spondylosis in man. This may result from compression of spinal nerve roots (Clarke and Robinson 1956, Teng 1960). Störtebecker (1960) and Taylor (1964) thought that osteophytes were one cause of a myelopathy due to the hindrance of an adequate arterial blood supply to the spinal cord. Krogdahl and Torgersen (1940) and Friedenberg *et al.* (1959) reported that laterally located osteophytes could impinge on vertebral arteries or sympathetic nerve plexes at the foramina of the transverse processes.

Numerous reports have doubted a relationship between bony changes in the vertebral column of man and co-existing back pain (Cushway and Maier 1929, Horwitz and Smith 1940, Breck *et al.* 1944, Collins 1949, Allen and Lindem

1950, Colcher and Hursh 1952, Hult 1954, Bohatirchuk 1955, Fullenlove and Williams 1957, Friedenberg and Miller 1963, Bick 1963). This is in agreement with the findings in the dog.

The only well documented relationship between osteophytes and clinical symptoms and signs is found in the cervical region of man. The reason for this is obscure. However, a combination of factors such as great range of motion and the common dorso-lateral location of osteophytes allows for greater trauma and irritation to occur. The low incidence and ventral location of the osteophytes in the cervical region of the dog prevents a similar syndrome.

D. Etiology

It has been suggested in man that any condition leading to a weakening of the vertebral body could give rise to vertebral osteophytes (Beadle 1931, Bick 1955 a, b, 1956 a, b, 1963, 1964, Weinman and Sicher 1955, Bick and Copel 1952, Nathan 1962). Senile osteoporosis and metastasizing neoplasia are considered common causes of this weakness. These conditions occurred only rarely in the dog in the present study.

Repeated trauma that caused minute fractures to the vertebrae has also been suggested as a cause of osteophytes in man. The resulting formation was then considered to be similar to callus formation (Oppenheimer 1942, 1945). The changes in the dog did not have the appearance of healing fractures, and no evidence of trauma to the bone was found.

On the basis of the more complete studies of spondylosis deformans in the four species discussed, the theory of an infectious etiology can be ruled out.

A sharp line has not always been recognized in differentiating between ankylosing spondylitis and spondylosis deformans. Ankylosing spondylitis in man is characterized by bony ankylosis across the true synovial joints, ossification of the ligamentous structures, or ankylosis across the intervertebral space. Uro-genital infections have been considered by some investigators to have an important role in the pathogenesis. None of the changes in the vertebral column that are typical of ankylosing spondylitis were found in the dog. No detailed study was made of the uro-genital organs of the dogs, but there was no apparent relationship between spondylosis deformans and uro-genital disease.

The possibility of hormonal control over production of vertebral osteophytes has been suggested (Erdheim 1931, Hájková 1965). The changes described by Erdheim are different from those seen in spondylosis deformans in the dog. In comparison with osteophytes in the dog, changes in hypophysectomized rats treated with growth hormone have some similarities, but also marked differences (Asling *et al.* 1955). The manner of growth of the new bone was periosteal, but as in the dog, a fibrous tissue formed outside the anulus fibrosus. The possibility of hormonal influence playing a part in breed predisposition toward spondylosis deformans was not investigated in the present study.

The role of disc changes in the pathogenesis of spondylosis deformans was emphasized by the present study. It indicated that the cause of spondylosis deformans will not be known until the etiology of disc degeneration is determined.

Summary and Conclusions

1. Spondylosis deformans was defined as a condition of the vertebral column which was characterized by vertebral osteophytes at the intervertebral spaces.
2. A morphologic and experimental study of the condition in the dog was presented. Radiological and clinical observations were included. Technics employed were macroradiography, macroscopic dissection, microradiography, tetracycline labelling, and conventional histologic procedures.
3. The morphologic study was based on 100 spontaneously affected dogs. Incidence was determined in a randomly selected group of 126 dogs from a necropsy material.
4. The incidence was higher with increasing age, and the size and number of osteophytes on each vertebral column was greater in certain breeds.

5. Specific distribution patterns were noted on both the margins of the vertebral bodies and throughout the vertebral column.
6. Osteophytes usually occurred at disc spaces that were of normal width. When they occurred at narrowed disc spaces, they had a different shape. Osteophytes were located on the ventral, lateral, and dorsolateral aspects of the vertebral margins. Osteophytes projecting into the spinal canal were rare. Bony ankylosis between adjacent osteophytes was not common.
7. In principle, the structure of the osteophytes did not differ from that of the vertebral bodies. Eventually they became an integral part of the vertebrae.
8. The intervertebral discs were found to be of importance in the pathogenesis of spondylosis deformans. Changes within the anulus fibrosus led to intradiscal fissures that predisposed to formation of the osteophytes.
9. No association could be made between changes in the nucleus pulposus, cartilage plate, and vertebral end plate, and the formation of osteophytes. The ventral longitudinal ligament influenced the direction of growth of the bony spur, but played no role in its initiation.
10. The osteophytes developed mainly through endochondral ossification. This type of bone formation occurred at the surface of the osteophyte, toward the disc and on the tip. Growth on the ventral and lateral surface was through bone formation by the cambium layer of the periosteum. Free segments of bone formed in the fibrous tissue outside the anulus fibrosus.
11. A macroradiographic study of 22 selected dogs from a clinical material showed an increase in number and/or size of osteophytes, irrespective of age, breed, or sex. Growth of the osteophyte could cease at any age and at any stage of growth.
12. Clinical significance was evaluated by use of a questionnaire sent to owners of 84 dogs. No correlation was established between clinical signs and spondylosis deformans.
13. Vertebral osteophytes were experimentally produced in 7 young mature dogs. The experimental lesions involved: (1) nucleus pulposus and anulus fibrosus, (2) anulus fibrosus, and (3) anulus fibrosus and ventral longitudinal ligament. All operative procedures led to formation of vertebral osteophytes.
14. A comparison of spondylosis deformans in the dog was made with spondylosis deformans in man, the cat, and the bull. Similarities in morphologic appearance and pathogenesis were found and outweighed the differences. The distribution patterns suggested that dynamic and mechanical factors are of importance in the pathogenesis of spondylosis deformans.

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