Anatomy and pathology of the aging spine

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Abstract

The vertebral column is a complicated anatomical structure which is composed of the intervertebral discs and the vertebrae. Both components develop special degenerative changes and morphologic features during life. This paper first reviews the anatomical fundamentals and then describes the morphological features of the aging intervertebral disc and the subsequent osseous changes of the vertebral bodies and the zygapophyseal joints. The aging intervertebral disc is characterised by processes which are labeled as intervertebral chondrosis and intervertebral osteochondrosis. Often these processes are combined with typical dislocations of intervertebral disc tissue in an anterior or dorsolateral direction. The well known Schmorl's nodules must also be mentioned in this context. Furthermore calcification and ossification of the intervertebral disc tissue can take place. More severe processes lead to osseous changes of the vertebral bodies. In particular, an osteophytosis of the vertebral bodies can be established. These sturdy osteophytes are able to stiffen the vertebral column. Furthermore the arthrotic changes of the zygapophyseal joints are delineated in this paper. The special appearances of these changes are discussed according to the different and specialised regions of the vertebral column. The advanced degenerative changes of the zygapophyseal and uncovertebral joints of the cervical spine are of essential clinical interest because the compression of the vertebral artery or the narrowing of the intervertebral foramina by these processes may cause severe neurological symptoms. The arthrotic changes of the medial atlantoaxial joint, which lead to the crowned odontoid, and the pseudospondylolisthesis (so called M. Junghanns) of the lumbar spine must also be mentioned. It is the aim of this paper, not only to explain and review the degenerative changes, but to illustrate the anatomy and pathology of the aging spine on the basis of macerated osseous specimens in order to make radiological investigations and pictures more understandable and clear. © 1998 Elsevier Science Ireland Ltd. All rights reserved.

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1. General anatomical fundamentals

The spine represents a movable column composed of 24 presacral vertebrae, disci intervertebrales and ligaments. Reflecting the increasing loads, the vertebrae and intervertebral discs increase in a harmonic order from the cranial end in the caudal direction.

For the changes in the structure and composition of the spine with increasing age, the anatomy of the intervertebral discs is of prime importance. An intervertebral disc consists basically of an external fibrous ring, the anulus fibrosus, and a jelly-like center, the nucleus pulposus. The anulus fibrosus can be subdivided into an outer and an inner zone, which show different histological structures. The outer zone is structured into concentric lamellae of tight, collagenous fibers (Fig. 1a), which in the inner zone are followed by fibrous-cartilaginous tissue. Without a distinct borderline, that tissue gradually exhibits a transition into the nucleus pulposus (Fig. 1a). The fibers in the outer zone are primarily type I collagen fibers, while the fibers of the inner zone are mostly collagen fibers of type II. In the individual lamellae of the outer zone, which are sequentially structured similar to the layers of an onion, the fibers are arranged crossing each other clockwise and...

1 Dedicated to Professor Dr med D. Graf von Keyserlingk on the occasion of his 60th birthday.
counterclockwise in helical turns, connecting the ossified vertebral rims of two adjacent vertebrae. In these places the collagenous fibers penetrate into the bony structure as Sharpey’s fibers. This special configuration of the fibers is particularly suitable for compensation of shear forces. The fibers additionally take care of the forces transmitted from the nucleus pulposus as a response on central as well as eccentric loads.

The nucleus pulposus, located eccentrically at the transition between the central and the posterior part of the intervertebral disc [1] contains glycosaminoglycans, which during youth and middle age comprise particularly chondroitin-4-sulphate, chondroitin-6-sulphate and keratane-sulphate. However, in persons of advanced age, dermatane-sulphate is mainly found. The high proportion of glycosaminoglycans and the low content of fibers result in a considerable capacity to retain water. Accordingly, the nucleus pulposus has the properties of a water-filled cushion.

The intervertebral discs exhibit a typical angioarchitecture which varies during the various periods of life [2]. In foetii with a crown-rump length of 7 cm, blood vessels can first be demonstrated between the lamellae of the anulus fibrosus. However, these vessels never reach the nucleus pulposus. Following the second year of life, these blood vessels degenerate. Accordingly, the moistness and hydration of the intervertebral discs decreases and the tendency towards changes characteristic of advanced age is initiated. In healthy persons, the system of vessels of the vertebral body is completely separated from the corresponding system of the intervertebral disc by the cartilage endplates.

In adults, lateral fissures penetrating into the anulus fibrosus and possibly subdividing the entire disc into two halves, occur regularly in the area of the intervertebral discs of the cervical part of the spine. These fissures were first described in 1858 by Hubert Luschka [3] and designated as hemidiarthroses laterales. In 1893, Trolard [4] called them articulationes uncovertebrales, an expression presently still in use. The designations ‘Luschka-joints’ or ‘neurocentral joints’ are also frequently used. These fissures are not present in infants and children of low age [2,5,6] and they can first be observed in children at an age of 9 years [7]. This author associates the development of these fissures with the rising of the uncinate processes. Recently, the appearance of such a fissure was reported in a 1-month-old infant [8]. As far as this observation is concerned, the presence of a true uncovertebral joint remains questionable however, as the fissures did not extend into the anulus fibrosus. These fissures form in perfectly healthy tissue of the intervertebral discs, and cannot be compared with the formation of fissures due to chondrosis intervertebralis. After the formation of the fissures in the anulus fibrosus, a joint-pseudocapsule develops, and closes the fissure laterally. Within this capsule, vascular-
in shape, particularly in postmenopausal women in the course of osteoporosis of the skeleton. As these changes represent an entity of their own, they are not discussed in more detail in this paper.

The chronic degenerative changes of the spine are summarized as spondylopathia deformans (earlier synonyms: spondylitis deformans, polypondylitis marginalis osteophytica or spondychondrosis). As far as the conditions for development of spondylopathia deformans are concerned, it was convincingly argued that a degeneration of the intervertebral discs with a decrease of their elasticity marks the onset of the disorder [10,11]. The subsequent inability to distribute loads equally in all directions later causes the typical modifications at the interface between the bones and the associated cartilage in the spine and the minor joints of the spine (zygapophyseal joints).

The heading spondylopathia deformans can be subclassified, depending on the location of the degenerative changes. In cases of spondylosis deformans the vertebral bodies are affected while the term spondylarthrosis deformans describes degenerative processes at the minor joints of the spine.

2.2. Chondrosis intervertebralis

As the age of a person increases, the quantity of water present in the nucleus pulposus decreases and consequently the swelling by that water and the cushioning effect previously present are reduced. In section, the nucleus pulposus no longer bulges out, but has the appearance of a dry, crumbling mass. The color has likewise changed from a glassy greyish-blue to a yellowish color with a tendency towards brown. This change in color is due to deposition of a brown coloring agent belonging to the class of melanines [12,13] and resulted in the designation of this change as 'brown degeneration'.

Additionally gaps and systems of fissures develop in the intervertebral discs, which are not only present in the nucleus pulposus, but partly radiate also into the anulus fibrosus. Occasionally these fissures appear in roentgenograms brighter than the surrounding tissue, a feature designated as ‘vacuum phenomenon’. Nitrogen was demonstrated to be present in this system of fissures [14]. All these changes, collectively described as ‘chondrosis intervertebralis’, result in considerable reduction of the elasticity of the intervertebral disc, while the height of the space occupied by the intervertebral disc decreases only to a minor extent.

The variable anatomical manifestation of ‘chondrosis intervertebralis’ as a gradual aging process and a decrease in water-content, is termed primary chondrosis intervertebralis. In this context, chronic overloading certainly represents an important factor. Identical morphological changes, which are however consequences of

2. Degenerative disc disease

2.1. General features

During the human lifespan, the spinal column is exposed to many continuously recurring loads, which result in almost consequential changes in the morphological conditions. These changes can be described as degenerative chronic processes on the intervertebral discs, the zygapophyseal joints and the ligaments. Additionally the aging spine undergoes considerable changes
pathological changes outside the intervertebral discs, e.g. following spondylolysis or abnormal deformation of the spine, are designated as secondary chondrosis intervertebralis [15].

If chondrosis intervertebralis has started, the degenerative destruction of the intervertebral disc continues and experiences a transition into osteochondrosis intervertebralis. This stage is characterized by participation of the cartilage endplates and gradual sclerosis of the adjacent spongiosa of the vertebral body.

2.3. Osteochondrosis intervertebralis

Osteochondrosis intervertebralis has to be considered as a process changing the structure of the intervertebral disc into a condition prone to crumbling, accompanied by a considerable reduction in the height of the space occupied by the intervertebral disc. The material of the former intervertebral disc presents as dry, crumbly, grayish-white or brown-dark tissue between the vertebral bodies and frequently contains a cavity resulting from the process of decomposition. Within such a cavity, sequestra may be present as detached particles. The process in the direction of crumbling may spread into the inner layers of the anulus fibrosus, with the outer fibrous systems remaining, and appearing convexly arched towards the outside [16]. The cartilage endplates of the vertebral bodies are likewise affected by the degenerative changes or even destroyed completely. Frequently numerous irregular proliferations of cartilage and ossifications within small foci are located on the endplates of the vertebral bodies (Fig. 1b,c). The adjacent spongiosa of the vertebral body shows reactive sclerotization since the function of the disc equalizing and distributing pressures and shocks has largely decreased. The processes described may basically develop in all intervertebral discs, but take place predominantly in the two lowest lumbar and less frequently in the lower cervical intervertebral discs. Osteochondrosis intervertebralis may materialize in two special manifestations. In one, the brittle bony structure of the endplates of the vertebral bodies and the sclerotized spongiosa may break like the two wings of a door, resulting in erosive osteochondrosis [17]. In the other manifestation, blood vessels grow into the intervertebral discs and trigger an ossification, which can result in a complete ossification of the intervertebral disc (synostosing osteochondrosis) (Fig. 2a).

2.4. Calcification and ossifications

In 1858, Luschka [3] mentioned small foci of calcification in the area of the nucleus pulposus. However, Schmorl was the first to investigate this manifestation in more detail and to classify it into primary and secondary forms [15]. According to his opinion, the primary calcification is the consequence of degenerative processes, while secondary calcification is the result of earlier inflammation (e.g. tuberculosis). Another classification separates chronically degenerative manifestations from inflammatory-rheumatoid calcification [18].

Chronic degenerative calcification is predominantly located in the central thoracic and the upper lumbar vertebrae and may be localized in the nucleus pulposus as well as in the anulus fibrosus. In the jelly-like part of the nucleus pulposus it appears as small, crumbly, white spots, mostly associated with the system of fissures of the nucleus pulposus.

In the anulus fibrosus the calcification appears as irregular particles in small foci, often associated with tears and necroses; 71% of the calcification is located in the anulus fibrosus and 6.5% in the nucleus pulposus [19].

In this context, the deposits of bony structures within the intervertebral disc, manifesting as a consequence of degenerative changes, merit attention. These ossifications may manifest themselves in two different ways: First as a consequence of the healing of a chondrosis or

Fig. 3. (a) Osseous top-plate of a thoracic vertebra exhibiting an irregular cavity resulting from a cartilaginous nodule (Schmorl’s nodule) (72 years, male). (b) Frontal section through a cavity resulting from a cartilaginous nodule (Schmorl’s nodule). The arrow points to the sclerotising osseous reaction (85 years, male).
an osteochondrosis intervertebralis. In the course of the process of healing, blood vessels sprout from the vertebral bodies through defects in the cartilage endplates into the degeneratively damaged intervertebral disc and induce the formation of bony structures. In most cases, these structures result in the blockade of the respective segment of motion. This course of the healing process may be described as healing and amending of the degenerative processes by rigidization.

The second manifestation is present in the anterior parts of the anulus fibrosus. Here, blood vessels may sprout into radial or concentric fissures between the fibers and trigger formation of bony structures. A small, spongious bony body results, located between the bony margins of two adjacent vertebral bodies (Fig. 2b). These small ossicles should not be confused with osteophytes, isolated osteophytes or intercalate bones due to spondylosis deformans. These ossifications of the anulus fibrosus definitely do not represent a disturbance in the ossification of the vertebral rim as was assumed in literature [20].

3. Dislocations of intervertebral tissues

3.1. General features

In the aftermath of chronic degenerative changes in the intervertebral disc, a dislocation of tissues of the intervertebral disc (of the anulus fibrosus as well as of the nucleus pulposus) may occur. Such a dislocation may take place in two major modes: as a protrusion or as a prolapse. Bulging of an intervertebral disc in a dorsal, lateral or ventral direction is called a protrusion. In most cases, a protrusion derives from a fissure in the inner zone of the anulus fibrosus. The tissue of the nucleus pulposus pushes outwards and bulges the fibers of the outer zone outwards while no tissue of the nucleus pulposus will prolapse or escape. If the fibers of the outer zone tear however, the pressurized tissue of the nucleus pulposus is pushed outwards and a prolapse of the intervertebral disc results. Depending on the topology, such a dislocation of tissue may be directed cranially or caudally or in the dorsal, dorsolateral or ventral direction.

3.2. Schmorl's nodules

Schmorl’s nodules of cartilage represent a dislocation of tissue of the nucleus pulposus through the cartilage endplate into the vertebral body. Subsequently proliferation of cartilage and reactive ossification may develop in the vicinity of the tissue dislocated from the nucleus pulposus. This ossification encloses the dislocated tissue like a shell and segregates it from the spongiosa of the vertebral body (Fig. 3a,b and Fig. 4).

The structure, which can now be demonstrated radiologically, represents the typical cartilaginous nodule (Schmorl’s nodule) [21]. For compensation of a larger Schmorl’s nodule, in juveniles an increased growth opposite to the nodule may develop on the cartilage endplate on the adjacent vertebral body and results in an osseous projection resembling an exostosis (Edgren-Vaino’s sign). If no cartilaginous or bony barrier is

![Image](image_url)
established, more and more material of the nucleus pulposus can enter into the vertebral body, resulting in an extensive process, which should be termed a nucleus pulposus prolapse or an intraspongious prolapse of the nucleus pulposus [21]. Unfortunately, the actual nomenclature reflects the conditions in an abbreviated form only. Sometimes no distinction is therefore made between the cartilaginous nodule and the intraspongious prolapse of the nucleus pulposus and both terms are used synonymously.

Schmorl’s nodules are seen more frequently in men than women, a condition attributed to larger spinal loads in men [15]. Frequently the nodules are located in the lower thoracic and in the lumbar region of the spine. In most cases they are established in the center of the vertebral body, since in that region the cartilage endplate is thin because of the earlier passage of the chorda dorsalis. The mechanical loads damage this locus minoris resistentiae until it finally yields and the pressurized tissue of the nucleus pulposus penetrates into the spongiosa of the vertebral body. If the prolapsed tissue of the nucleus pulposus necrotizes, the cartilaginous nodule may become ‘resorbed’. If this rare ‘healing process’ does not take place, Schmorl’s nodules may continue to exist throughout the remaining life of the carrier.

3.3. Lateral or dorsolateral dislocation

In Schmorl’s autoptical series of investigations, a dislocation of tissue of the nucleus pulposus in the dorsal or dorsolateral direction takes place in 15.2% of
spines and shows a slight preference for the female sex [15]. These prolapses are located in 95% of the cases between L4 and L5, or between L5 and S1 [22].

In the cervical region such prolapses occur predominantly in the segments of motion C5/6 and C6/7 [23]. The dorsal prolapse is located between the dorsal side of the intervertebral disc and the posterior longitudinal ligament, in most cases slightly lateral to the ligament. In the prolapsed tissue fine spots of calcification can be demonstrated, which cannot be identified radiologically however. Depending on the shape and morphology of the dorsal or dorsolateral prolapse of the intervertebral disc, various configurations can be distinguished: (1) Dangling prolapse—in this case, tissue of the nucleus pulposus issues from a fissure in the anulus fibrosus, but may return into the initial place in the course of particular motions. (2) Incarcerated prolapse—the prolapsed tissue is trapped in the fissure of the anulus fibrosus in such a fashion that a return is impossible. This configuration of a prolapse represents an early stage of a sequestrated prolapse, in the course of which the prolapsed material becomes detached and may subsequently be dislocated cranially or caudally. Such cases are also described as ‘migrating prolapses’. If sequestrated material penetrates the dura mater and floats subsequently in the liquor, an intradural prolapse exists, which only happens extremely rarely. In cases of a dorsolateral prolapse, the displaced tissue is located in the intervertebral foramen and causes a compression of the spinal nerves. In the cervical region a compression of the vertebral artery may also occur. The topographical location of the spinal nerves relative to the intervertebral disc is decisive for the efficiency of the mechanism of compression. In the cervical and lumbar region of the spine the intervertebral disc is located at the same level as the spinal nerve in the intervertebral foramen. For this reason a compression of the nerve may occur easily in this region. In the thoracic region, the spinal nerve is located cranially of the intervertebral disc behind the vertebral body. Accordingly, the nerve will rarely be contacted by the prolapse and the symptoms of nerve compression are seldom observed.

3.4. Ventral dislocation

Ventral dislocation of intervertebral disc tissue may occur in two different ways: The anteriorly prolapsed tissue rarely penetrates ventrally between the frontal side of the spine and the anterior longitudinal ligament cranially or caudally. Such cases are therefore of only minor importance in practice [15].

Schmorl [21] drew the physician’s attention to a second form of ventral dislocation of intravertebral disc tissue. At the inner edge of the ossified vertebral rim a stepwise transition exists from the smooth rim into the porous endplate of the vertebral body (Fig. 1b) and forms a locus minor resistentiae, into which tissue of the nucleus pulposus may penetrate. If this should be the case, the prolapsed tissue works its way in an oblique direction outwards through the bone, finally detaching the ventral edge of the vertebral body as a triangular piece of bone [21]. The prolapsed tissue subsequently becomes crushed by the now abnormally mobile detached piece of bone and on the corresponding areas of the bones a fibrous-cartilaginous coating develops as some kind of pseudoarthrosis. These manifestations are mainly observed at the upper edges of the lumbar vertebrae and at the upper edge of the sacral bone. Based on pathological investigations an incidence of 5% was quoted [21]. In the course of a series of radiological investigations an incidence of 1% was found [24]. The difference was explained by the impossibility of identifying all pieces of detached bone radiologically. Following the same principle of materialization, lateral or infrequently even dorsal pieces of bone may break off the edges of the vertebral bodies [25]. The triangular bony elements resulting from these detachments from the edges of the vertebrae were formerly considered as persistent epiphyses of the vertebral bodies [20,26], an opinion which has been disproved by extensive investigations [21,24,27–29]. The anterior detachment of bone from the edge of the vertebral body has to be distinguished unambiguously from pieces of bone torn from the edge of the vertebra traumatically [30]. Degenerative detachments of the anterior edge of the vertebral bodies are only of minor clinical importance [24].

4. Spondylosis deformans

4.1. General features

In cases of spondylosis deformans, bony osteophytes and excrescences develop in the region of the vertebral bodies. These manifestations represent chronic degenerative changes, which are predominantly located in the cervical, lower thoracic and lumbar region of the spine. The incidence increases with advanced age. In Schmorl’s series of 4253 specimens of the spine collected in the course of autopsies, at an age of 49 years, 60% of female and 80% of male spines showed osteophytes of the vertebral bodies. At an age of 79 years, both sexes were equally affected in approximately 95% of cases [15]. The results of a large-scale investigation of spondylosis deformans in the cervical region of the spine were published by Aufdermaur (1960) [23] who also added comments on the interpretation of the statistically determined incidences during various periods of life. A connection between the manifestation and the extent of this disorder and the occupational loads and stresses seems to be questionable and is discussed con-
troversially in the literature [31,32]. Concerning the initiation of spondylosis, two different pathogenetic concepts are currently discussed: the first hypothesis is based on the extensive investigations by Schmorl and has been discussed exhaustively [15]. In his opinion, the formation of fissures in the outer zone of the anulus fibrosus (the ‘Randleistenanulus’ according to Schmorl) is the cause of subsequent changes. The anatomical conditions at the ‘Randleistenanulus’ are characterized by the prominent fibers of Sharpey, which extend into the bony structure of the ossified vertebral rim of the vertebral body. If this fixation is reduced or torn as a consequence of the formation of a fissure, or even suspended, the intervertebral disc maintains less connection with the adjacent vertebral bodies and may engage in unphysiological movements. These circumstances may cause excessive loading of the anterior longitudinal ligament and result in the formation of bony peaks at the insertions of the ligament. If the nucleus pulposus has not yet been degenerated, pressure exerted against the anterior longitudinal ligament causes additional pulling forces on the points of ligament-insertion. This concept explains the observation of particularly large osteophytes predominantly in persons in which the nucleus pulposus has not degenerated and the height of the spaces occupied by the intervertebral discs has dropped only to a minor extent. This interpretation of the processes involved clearly confirms the earlier opinions [10,11] of the cause for spondylosis deformans to be located in the intervertebral discs and not in the vertebral bodies.

A second concept addressing the development of spondylosis deformans has been presented by Collins [33], who also confirms the degeneration of the intervertebral disc to mark the early stage of the disorder and believes the special anatomical conditions in the region of the anterior longitudinal ligament to be responsible for the development of the osteophytes. He claims this ligament retains tissue from the intervertebral disc expanding as a consequence of the formation of fissures and the detachment of the ‘Randleistenanulus’. Laterally, where the anterior longitudinal ligament ends comparatively sharply and abruptly, changing to a weak membrane of connective tissue, such a dislocation of tissue is not stopped, but results in detachment of the periost from the vertebral body. Consequently, periosteal development of bone starts, resulting in the formation of osteophytes.

A unilateral partisanship for the first or second concept does not appear to be advisable, since the typical manifestations of spondylosis deformans very likely develop both ways, in a combined action [30].

Evidence supporting the concept of Collins [33] is the ossifications histologically frequently to be found below the anterior longitudinal ligament and showing no connection or at most a secondary extension to the anterior longitudinal ligament only. Details observed at the cervical region of the spine, such as the osteophytes located ventrally (Fig. 4a) in most cases also favor the concept of Collins. As the anterior longitudinal ligament of the cervical region of the spine is much weaker than in the thoracic or lumbar region, pressing back of the tissue of the intervertebral disc will be much less effective. This condition may be advantageous for the formation of ventral osteophytes, as this has been observed.

4.2. Spondylosis cervicalis and spondylosis uncovertebralis

The degenerative changes in the cervical region of the spine have to be subdivided into the actual spondylosis cervicalis and the spondylosis uncovertebralis.

The capacity for motion is most pronounced in the region of the segment of motion C5/C6 and continuously decreases cranially. This anatomical condition correlates with the observation that spondylosis deformans manifests mostly in the region of the segments C5/C6 and C6/C7 and seldom occurs cranially [23].

Fig. 7. (a) Cervical vertebra exhibiting a typical, dorsal located accessory transverse foramen on both sides (arrows) (72 years, male). (b) Cervical vertebra exhibiting a medial located, pseudoaccessory transverse foramen (arrow) in an osteophytary addition of the vertebral body (92 years, female).
Spondylosis deformans in the cervical region is characterized by osteophytes primarily developed in the ventral direction (Fig. 4a), because of the weakly developed anterior longitudinal ligament. Osteophytes developed in the dorsal direction also occur but are often only of minor size. The configurations of the osteophytes are very diversified, and they can merge, blocking the respective segment of motion (Fig. 4b). Osteophytes never start at the edges of a vertebral body, but only slightly below [23]. They are composed of lamellar bone structure and contain a more or less compact spongiosa, the marrow spaces of which are connected to the marrow spaces of the vertebral bodies.

Osteophytes on the uncinate processes characterize the spondylosis uncovertebralis [30]. The various configurations of spondylosis uncovertebralis can also be observed in the region C3–C7. Distinct manifestations are however found predominantly on the lower segments C5/C6 and C6/C7 [30,34]. The regular uncinate processes are positioned higher and steeper in the cranial region of the cervical spine than in the caudal region. Additionally, in most cases they are dorsolateral, i.e. where they assume a topographical connection to the intervertebral canal, and with a flatter shape than in the lateral region, where they are located next to the transverse foramen (Fig. 5a). A flat uncinate process is a preferred place for the development of osteophytes [30]. Fully developed osteophytosis however results in brimming of the uncinate process into a shape similar to a console. Such a console may have a height of 2–3 mm and accordingly almost define a horizontal plateau on which the next vertebral body above rests with a corresponding lateral trough.

In cases in which the lateral brimming of the uncinate processes is located in the dorsal region, a narrowing of the intervertebral foramen results (Fig. 5b), causing a corresponding compression of the spinal nerve. A simultaneous spondylarthrosis will worsen the situation, since in such a configuration, osteophytes also grow from the dorsal direction into the intervertebral foramen and the spinal nerve will partly be trapped by these projections like the jaws of pliers (Fig. 6b).

If the console-shaped brimming also takes place in the opposite region of the uncinate process at the adjacent higher vertebral body, such an arthritic osteophyte can project into the transverse foramen. A perforation and formation of a hole may develop in the osteophyte, simulating a partitioned transverse foramen (Fig. 7b). The true partitioned transverse foramen is an insignificant anatomical variety, observed frequently, particularly in the caudal cervical vertebrae for the passage of veins. This accessory transverse foramen is regularly located dorsal of the transverse foramen (Fig. 7a) while the pseudoaccessory transverse foramen is located medial. Furthermore it is closed by connective tissue or fibrous cartilage. The osteophytes developed at the anterior section of the uncinate processes may compress the vertebral artery from the medial direction. Such a configuration has quite some significance, as chiropractical manipulations may result in dissection of...
the vertebral artery on the osteophytes of the uncinate processes with serious consequences for the blood supply to the vertebral region [35].

4.3. Spondylosis thoracalis

Inspection of a macerated preparation will be more instructive for the characteristic details of pronounced spondylosis thoracalis than any description (Fig. 8a). The osteophytes always arise slightly below or above the ossified rim of the vertebral body (Fig. 8b). They may contact each other, interlock mutually and finally fuse together. They are frequently located below the anterior longitudinal ligament and ossification of this ligament will be a secondary phenomenon only. The large thoracic osteophytes will cause a blockage of the respective segments of motion (Fig. 8a).

The formation of osteophytes in the region of the thoracic part of the spine occurs predominantly ventrolaterally, but also dorsally (Fig. 9a). However, these dorsal osteophytes are small in size, shaped like the flame of a candle and are mostly located parameidian. The low extent of the dorsal osteophytosis is based on the anatomical conditions determined by the posterior longitudinal ligament. This ligament inserts primarily at the rear of the intervertebral disc and with only a few fibers at the vertebral body. The vertebral body is not available for insertion of a ligament across a large area, as it shows the basivertebral foramen offering passage for voluminous veins. The typical dorsal osteophytes (Fig. 9a) must be differentiated from calcification and ossification forming around the ‘posterior Schmorl’s nodules’. These bony objects are located in an irregular pattern at the back edge of the vertebral body and are frequently associated with depressions harboring these nodules (Fig. 9b).

4.4. Spondylosis lumbalis

The manifestations of spondylosis lumbalis are similar to the configurations in spondylosis thoracalis, except for their substantially larger size, which may reach grotesque dimensions, and the higher incidence of isolated bony elements located as intercalate bones between the osteophytes. In cases of pronounced decrease in the height of the intervertebral discs, the spinous processes of adjacent vertebra may contact each other. Between the grinding bony parts sclerotization, grinding-facets and also pseudoarthroses may develop (Fig. 10a–c). These manifestations are known as osteoarthrosis interspinosa [36], kissing spines or Bastrup’s disease.

As a peculiarity, a helmet-shaped sclerotization of the spongiosa on top of an intervertebral disc may develop, in most cases in the two lower lumbar vertebral bodies. This manifestation, in most cases seen against a generally degenerative background, is designated spondylosis hemisphaerica or Dihlmann’s syndrome [37,38].
5. Spondylarthrosis

5.1. General features

The term ‘spondylarthrosis’ describes degenerative changes in the zygapophyseal joints. Unfortunately, in some careless generalizations this terminology is also used in the current literature for changes in the intervertebral discs and vertebral bodies. This practice should be discontinued to maintain a clearly defined nomenclature without ambiguities. A continuously increasing incidence of degenerative changes in the minor joints of the vertebrae, particularly in the cervical and lumbar region of the spine, is seen in patients of more than 30 years of age, as these joints are substantially loaded by the large range and frequency of motion [39].

Changes in the intervertebral discs (chondrosis intervertebralis and osteochondrosis intervertebralis) resulting in a decrease in the height of the intervertebral disc, are assumed to be responsible for the pathogenesis of spondylarthrosis. Such a decrease in height results in loosening of the segment of motion and in unphysiological loading of the minor joints of the vertebral column. The decrease in height also causes a caudal dislocation of the inferior articular processes and stressing of the capsules of the joints. Additionally a dorsal dislocation of a vertebra (retrolisthesis) may develop. All three factors mentioned contribute to the degenerative changes in the zygapophyseal joints. In this context however, the simple pathogenic concept ‘decrease in the height of the intervertebral discs and subsequent irregular loading of the minor joints of the vertebral column’ only partially represents the whole truth, for time and again, cases with manifest osteochondrosis intervertebralis are seen in which no spondylarthrosis of the associated minor joints of the vertebrae is present at all. On the other hand, cases with considerable degenerative changes of the zygapophyseal joints without simultaneous damage to the intervertebral discs are known. Within these inconsistencies, the observation must be mentioned that the spondylarthrosis develops most frequently in the segment Th 4/5 [39]. However, this segment of motion exhibits the lowest degree of mobility of the entire spine. Other, unknown factors, must therefore be considered contributing to the pathological concept just presented. The morphological manifestations of spondylarthrosis do not differ from the manifestations in cases of arthrosis deformans of the large joints. Progredient damage of the cartilage, showing fissures, grinding-facets and eburnisations have been observed. The subchondral lamella also show strong sclerotization and cysts may develop. Furthermore typi-
cally osteophytes may be formed at the joint facets. The meniscoid folds of the minor joints of the vertebral column are much less delicate and show fibroization and hyalinization. Frequently detritus, consisting of fragments detached from the cartilage, rests in the joints. The articular capsule shows ribbon-like fibrozation causing isolation of the joint from the surrounding structures [30]. Since spondylarthrosis exhibits special peculiarities in the various parts of the spine resulting from the anatomical conditions typical for the respective section of the spine, the characteristic details are presented separately below.

5.2. Spondylarthrosis cervicalis and arthrosis of the median atlantoaxial joint

In the cervical region of the spine some peculiarities result from the special morphology of the two upper cervical vertebrae. In this context, the expression ‘spondylarthrosis cervicalis’ not only covers the degenerative processes in the minor joints of the vertebrae, but also the degenerative processes of the atlantooccipital joints, of the median atlantoaxial joint and the lateral atlantoaxial joints. Only in the median atlantoaxial joint do the degenerative changes represent a major disorder however, resulting in extensive and characteristic morphological changes. According to radiological investigations, persons above 61 years of age show degenerative alterations of this joint in 88% of the cases [40]. The morphological changes in the median atlantoaxial joint are on the one hand characterized by the typical joint-changes seen in degenerative disorders. On the other hand, manifestations specific for this location are also seen. At the upper edge of the anterior arch of the atlas, bony excrescences are established in a semilunar shape, resembling a coulisse (Fig. 11a), which manifest on a.p. roentgenograms as a peridental aureole. These bony appositions may isolate themselves, and subsequently form independent accessory elements [41], located between the anterior rim of the occipital foramen and the anterior arch of the atlas. This ‘coulisse of the atlas’ may also extend substantially in the cranial direction, resulting in physical contact with the anterior border of the occipital foramen. The
coulisse of the atlas resulting from arthrosis can also get bent in the dorsal direction and be placed over the apex dentis like a roof. This configuration was termed a ‘Processus opercularis atlantis’ [42]. Recently a picture of a typical specimen was published [41]. The degenerative changes in the median atlantoaxial joint cause typical manifestations on the dens axis itself. Here the anterior articular facet is partly dislocated in the cranial direction by rolling action, resulting in a bony addition in the shape of a coulisse at the anterior edge of the apex dentis (Fig. 11b). In the literature, this configuration is designated as ‘crowned odontoid process’, ‘crowned dens’, ‘peridental aureole’ or ‘arthrotic coulisse of the dens’ [43–46]. This coulisse of the dens is characterized by the smooth structure of the frontal area (possibly forming an articulation with a coulisse of the atlas) and by numerous cysts on the back area and structures similar to trabeculae (Fig. 11b). Parts may break away from the coulisse and turn into independent bony elements [43] which in the course of differential diagnosis must not be mixed up with isolated ossicles of phylogenetic origin.

The typically degenerative changes of the ‘crowned odontoid’ and in the coulisse of the atlas should not be mixed up with calcination (tendinitis calcarea) or ossification of the ligaments. Spondylarthrosis cervicalis also manifests at the zygapophyseal joints of the cervical region of the spine, resulting in a grotesque deformation and enlarging of the joint surfaces due to osteophytary additions (Fig. 12a,b). As the anterior parts of the zygapophyseal joints approach the intervertebral foramen directly from the rear, such osteophytes result in considerable reduction of this narrow passage (Fig. 6a) and in compression of the spinal nerve. In cases with simultaneous spondylosis uncovertebralis, the compression of the spinal nerve, which, figuratively speaking, is caught by the osteophytes partly ‘between the jaws of pliers’ (Fig. 6b), represents a particularly serious condition. Narrowing of the intervertebral foramen is caused most frequently solely by spondylosis uncovertebralis, less frequently by a combination of spondylosis uncovertebralis and spondylarthrosis, and least frequently solely by spondylarthrosis [23,34].

5.3. Spondylarthrosis thoracalis

Spondylarthrosis thoracalis shows no significant deviations from the common arthrosis deformans. The descension of the inferior articular processes, initiating formation of bulges similar to consoles in the arcus vertebrarum of the next vertebra below and thus limiting the degree of descension, is noteworthy however. If the spaces occupied by the intervertebral discs experience further reduction in height, the vertebral bodies tilt forwards to some extent and increased kyphozation takes place. Because even in cases of pronounced spondylarthrosis thoracalis, major osteophytes will rarely grow into the intervertebral foramen, compression of the spinal nerves is only observed infrequently. Other conditions reducing the incidence of compression of the nerves by prolapses of intervertebral discs from a ventral direction are the protected cranial location of the spinal nerves and the comparatively large dimensions of the intervertebral foramina.

5.4. Spondylarthrosis lumbalis

The degenerative changes developing in the course of this disorder are distinctly serious and result in grotesque deformation of the zygapophyseal joints (Fig. 13a,b). All manifestations of arthrosis deformans, such as cysts, porozation, grinding-facets, eburnizations and joint-deformations may simultaneously be seen in a great variety of combinations. In cases of advanced spondylarthrosis lumbalis, a vertebra may slide forwards (Fig. 14), predominantly in females. In most cases the vertebra L4 is involved. This anterior dislocation takes place while the arch of the vertebra is intact. No relationship with spondylolisthesis exists therefore. Junghanns [47,48] noticed this phenomenon and termed
it ‘Pseudospondyloolisthesis.’ Cases of pseudospondyloolisthesis show pronounced spondylarthrosis of the minor joints of the affected section of motion, which is usually less severe in the adjacent joints. Based on this observation, a hypoplastic or excessively flat development of the articular facets between L4 and L5 triggering this anterior sliding dislocation has therefore been assumed. The resulting unphysiologic distribution of the loads then causes the development of substantial spondylarthrosis in this segment of motion. This pseudospondyloolisthesis (M. Junghanns) has however to be strictly set apart from spondylolisthesis in cases of pseudospondylolisthesis (M. Junghanns) has however to be

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