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Detailed pathological changes of human lumbar facet joints L1–L5 in elderly individuals

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Abstract Facet joints play an important role in intervertebral load transmission and are crucial for rotational kinematics. Clinically, the role of facet joints as a possible source of low back pain is seen as controversial and at present is not sufficiently investigated. In this study, human lumbar facet (zygapophysial) joints from donors with advanced age were analyzed macroscopically, for degenerative changes. The aim was to determine the extent and morphology of degenerative changes in these joints. Lumbar facet joints (L1–L5) of 32 donors were studied (mean age 80.1 ± 11.2 years). Joint capsules were carefully removed and joint surfaces (5 zones) examined using magnifying glasses and probes. In the result, the majority of facet joints showed cartilage defects of varying extent. Defects were located mostly at the margins of the articular surface, the central zone being relatively well preserved. Defect localization was

different between superior (most cartilage defects in superior zone) and inferior (most defects inferiorly) facets. Further, defects were more severe caudal (level of L5) and in older persons. Osteophytes were present in up to 30%, located mostly at the latero-dorsal enthesis of the joint capsule on the superior facet. In conclusion, most margins of the articular facets are subject to degenerative changes in the lumbar spine of elderly persons, the topographical pattern being different in superior and inferior facets. This observation can be explained by the segmental motion patterns during extension/flexion movements of the facets. Sometimes, due to the marginal extension, it is obvious that not all changes can be assessed by CT or MRI.

Keywords Degenerative changes · Facet joints · Lumbar spine · Segmental motion · Zygapophysial joints

Introduction

From a biomechanical point of view, the facet joints play an important role in load transmission and are involved in the mechanism of rotational kinematics [1, 22, 24]. To optimally serve this mechanical loading, the concave superior facet (superior articular process) and the convex inferior facet both are composed of a ventral, more frontal oriented part and a dorsal, more sagittal oriented part [24]. Rotational and shear forces in the lumbar vertebral

column are transmitted by the zygapophysial joints, together with the annulus fibrosus; axial forces are transmitted mostly by the vertebral bodies and discs [1, 20, 22]. In normal conditions, between 3% and 25% of segmental load are transmitted over the facet joints, this percentage increasing up to 47% in degenerative facets [38].

Mobility of the lumbar spine is greatest during flexion/extension movements (cumulative mobility in segments L1–L5: flexion and extension 57°) [37]. The amount of lateral bending (L1–L5: 26°) and axial rota-

tion (L1–L5: 8°) is more limited [37]. This is most significant, because the wide range of movement in the lumbar spine during flexion/extension causes physiological gaping of the zygapophysial joints in the final phases of movements [2, 23, 25]. It is suggested, that this can lead to maximum pressure on the lower edge of the inferior facet during extension and on the upper edge of the superior facet during flexion [1, 17, 38].

During the past centuries, various post-mortem studies or investigations using specimens removed during surgery have been conducted to evaluate degenerative/traumatic defects in the lumbar facet joints [5, 30–33, 35]. However, to our knowledge, no systematic study was conducted to evaluate the normal prevalence and precise location of degenerative changes in all lumbar facet joints of elderly individuals. This is somewhat surprising, because the long-lasting load bearing (i.e. overload in particular) in elderly individuals is one of the important factors related to joint degeneration.

Therefore, we have assessed the topographical arrangement of degenerative changes at the articular surfaces of human facet joints (L1–L5), in order to determine, whether these patterns can be related to the described inhomogeneous distribution of load in human facet joints.

Materials and methods

In this study, the lumbar zygapophysial (facet) joints (L1–L5) of 32 human spines (mean age 80.1 years; SD $\pm$ 11.2 years; details see Table 1 and 2) were examined (i.e. a total of 608 lumbar facets). The vertebral columns were obtained during anatomical dissection from cadavers donated to the Anatomy department of the Ludwig-Maximilians University Munich. The specimens were fixed with an embalming fluid containing 5% formalin. Donor history of low back pain was not available; cause of death was heart failure or cancer in most cases. Initial selection was done from 42 vertebral columns. X-ray was used to exclude scoliotic vertebral columns, vertebral fractures, bone tumors and severely deformed osteoporotic spines. The posterior lumbar elements from Th12 – L5 were removed by careful dissection of the pedicles with an oscillating saw. Due to extraction of the vertebral columns, 16 of the L5 inferior facets were damaged. After soft tissue was removed, the

joint capsules were carefully incised dorsally and opened. The inferior and superior articular processes were separated. In the following, the anatomic superior articular facet (process) is abbreviated superior facet as and the anatomic inferior facet (process) as inferior facet, e.g. the motion segment L1/2 consists of the inferior facet of L1 and the superior facet of L2. Care was taken not to injure the facet joints during this maneuver. The surfaces were then controlled macroscopically using magnifying glasses and probes. The advantage of such a procedure over histological sections is that observation of the entire cartilage surface is possible without restriction to small sections. Degenerative changes of the lumbar disc were not correlated with the facet joints in this study, since the relationship between degenerative disc disease and facet joints is already well established in literature [14, 16, 19].

In the first step, the degree of the overall articular cartilage preservation of the facets was scored by two observers collaboratively using criteria similar to those used by Wang et al. [35] for grading microscopic slides. Four grades were used: grade 1 describes an overall normal glossy surface with occasional occurrence of small, peripherally circumscribed defects; grade 2, a dull, slightly uneven surface; grade 3, a more uneven surface with some full cartilage defects between preserved cartilage; grade 4, considerable defects of the cartilage surface up to eburnation of the entire cartilage in extreme cases (see Fig. 1a–d). In the next step, the precise locations of the cartilage defects and of osteophytes (selective bony apposition) were recorded in the articular cartilage of the facets in the motion segments L1/2, L2/3, L3/4 and L4/5. Therefore, the facets were divided in five regions: superior, medio-ventral, latero-dorsal, inferior, and in the central zone (see Fig. 2).

Statistical analysis of overall articular cartilage preservation was carried out using Prism GraphPad Version 4.0 for Macintosh (GraphPad Software, San Diego, USA). Wilcoxon matched pairs test was used for each facet joint to evaluate differences between the right and left facet joints. Mann–Whitney test was used to evaluate differences between male and female and younger and older subjects.

Results

Statistical correlation between degenerative changes in right and left facet joints at all joint levels of all subjects showed no side preference (Wilcoxon $P > 0.05$). Defects were equally located in right and left facet joints, so for the following analyses, the right and left specimens were grouped together.

Comparison of the cartilage score between males ($n = 18$, mean age 79.8 years) and females ($n = 14$, mean age 80.5 years) shows the following difference: In the L1 superior ($P = 0.013$), L1 inferior ($P = 0.010$), L2 superior

Table 1 Statistical data of specimens used for study

	Number of Patients (<i>n</i>)	Age	Mean	SD
Male	18	52.3–96.6	79.8	12.7
Female	14	61.1–91.4	80.5	9.3
Both	32	52.3–96.6	80.1	11.2

Fig. 1 Overall articular cartilage preservation was assessed in four grades (presented are examples of inferior facets): (a) Grade 1 describes an overall normal glossy surface; (b) grade 2, a dull, slightly uneven surface; (c) grade 3, a more uneven surface with some circumscribed defects between preserved cartilage; and (d) grade 4, considerable defects of the cartilage surface

($P=0.046$) and L3 superior ($P=0.007$) facets, women show markedly more degenerated articular surfaces than males; in the deeper spinal segments, slightly more degenerative changes were observed in male facet joints, however, these observations showed no statistical significance.

When the donors were divided into a group of younger (<80 years of age, $n = 14$ (male=8, female=6), mean age = 70.0 years) and of older individuals (≥ 80 years of age, $n = 18$ (male=10, female=8), mean age = 87.9 years), a difference in joint preservation could be seen. The articular surfaces of facets from younger subjects in general were better preserved ($P < 0.05$ in facet L1 superior, L1 inferior, L2 superior, L3 superior and L4 inferior) than those from older individuals (data not shown). An overview of the data for overall cartilage preservation split between males and females and age groups <70, 70–80, 80–90 and >90 years, but not for individual facets, is shown in Table 2. It is remarkable that people over 90 years show better results, although the number of specimen investigated is too small to draw any conclusion.

The results of the cartilage preservation (grades 1–4; 1 = best, 4 = worst) for the whole study population are

shown in Fig. 3. Joint preservation is better in the cranial (mean cartilage grade for superior facet L1: 2.8) than in the caudal region (mean cartilage grade for inferior facet L5: 3.7) of the lumbar vertebral column. The mean cartilage preservation in facets of one motion segment does not differ between superior and inferior defects, although the inferior facets seem to have slightly more small defects at the margins (Fig. 3).

Next, the mean prevalence and location of the defects of all specimens are shown (Fig. 3). While most of the central regions of the articular joint surface were often relatively well preserved, many of the facet joints show circumscribed defects at the edges. When examining the superior and inferior facet of a motion segment (L1/2, L2/3, L3/4, L4/5), one can discover corresponding regions with cartilage defects on both facets (Fig. 4 l), but the location of circumscribed defects is different: in the superior facet, cartilage defects are located mostly at the superior pole (See Figs. 3, 4 a–c), whereas in the inferior facet the cartilage defects are located at all margins with the inferior pole being most severely damaged (see Figs. 3, 4 d–f). The medio-ventral and latero-dorsal margins of both superior and inferior facets generally had fewer defects. In summary, L1/2–L4/5 motion seg-

Fig. 2 The locations of the cartilage defects and of the osteophytes were recorded and grouped into five locations: superior, medio-ventral, latero-dorsal, inferior, and in the central zone

ments had defects located in the superior articular processes: in the superior zone, in 70% of cases; medio-ventral, 36%; latero-dorsal, 46%; inferior, 46%; central zone, 8%; and in the inferior articular processes: superior, 56%; medio-ventral, 46%; latero-dorsal, 50%; inferior, 61%; central zone, 14%. These defects were most pronounced in the motion segment L4/5, where over 80% of specimens showed cartilage defects in the respective locations.

Table 2 Data of mean overall cartilage preservation of all segments L1–L5 in younger and older males and females

Age (years)	< 70		70–80		80–90		> 90	
Gender	M	W	M	W	M	W	M	W
<i>n</i>	3	2	5	4	5	5	5	3
Mean cartilage Preservation	3.1	2.8	3.1	3.3	3.5	3.8	3.2	3.5
L1sup–L5sup

Fig. 3 Overall cartilage surface score (score: 1 best–4 worst; see text for details; SD standard deviation) and the location of cartilage defects divided in 5 zones, sorted for the different facets from L1 to L5 (grouped in motion segments). The percentages present the percentage of specimens with defects in the respective location

Osteophytes were seen in less than 40% of all facet joints (see Fig. 5). In the superior facet, the majority of osteophytes was found at the latero-dorsal margin, where the dorsal capsule attaches (Fig. 4 g,k). Some osteophytes also occurred at the superior pole, where degenerative changes of the articular surface most often were observed. Fewer osteophytes were seen in the inferior facet, where most of the osteophytes were located at the inferior pole (Fig. 5). Osteophytes were rarely seen on the medio-ventral side. The most common location of the osteophytes (L4 superior facet on the latero-dorsal margin) was related to the overall facet preservation (of L4 superior). When osteophytes were present, the facets were in worse condition ($n=30$, mean overall cartilage preservation 3.8) than without ($n=34$, mean overall cartilage preservation 3.4).

Fig. 4 Superior facets showing (a) combined cartilage (*asterisk*) and bone (*arrow*) defects or b/c sole cartilage defects (*asterisks*) on the superior pool. Inferior facets displaying d large chondral defects (*asterisks*), leaving cartilage (C) only centrally, e osseous defects (*arrow*) or f inferiorly located cartilage defects (*asterisks*). g Totally destroyed cartilage surface (*asterisk*). h Localized circumscribed small defect (*arrow*) in the cartilage surface (C), covered by meniscoid fold (mF). i Corresponding histological section through a facet joint with superior and inferior facet (sF/iF) (from 19 with permission from Thieme Verlag, Stuttgart). Cartilage surface (C) peripherally shows a localized, small circumscribed defect, covered by a meniscoid fold (mF). k Superior facet showing osteophyte apposition (*asterisk*) on the lateral margin. l Superior and inferior facets showing corresponding mirror-like defects (*asterisks*). m Inferior facet with large osseous defect inferiorly (*arrow*) with good preservation of the remaining cartilage surface

Fig. 5 The cumulative appearance of osteophytes in all facets (L1 superior–L5 inferior), split for inferior and superior facets, showing two major locations of osteophyte formation (see text for details)

Discussion

We choose to macroscopically observe the whole cartilage surface in order to record the precise location of even small surface defects that would not be visible in a few randomly taken histological sections of the facet joint. However, microscopic subtle signs of cartilage degenerations are not depicted by our method. In a comparable study, the extent and location of facet joint cartilage damage in 31 facet joints was examined, using similar macroscopic observations [30]. One major limitation of that study was, however, that only the motion segment L1/L2 was analyzed. In that segment, significant damage was recorded in specimens younger than 30 years, and damage was predominantly located peripherally, an observation we confirm here. All other anatomical studies evaluated selected histological sections, where damage, especially when small or located peripherally, could easily be missed [7, 13, 31–33, 35].

Degenerative changes are well known in facet joints and may often be aggravated by degenerative disc disease [9, 16, 19, 30]. In accordance with reports in the literature, the facet joints in our study showed degenerative cartilage changes more often in the older population [31, 35]. It is also well known that the damage normally is much worse in caudal motion segments (L4/L5) than in cranial motion segments (L1/L2) [18, 35].

Furthermore, degenerative changes were more often reported on the superior facet than on the inferior facet [31, 35]. In our study, we cannot confirm this assertion. Instead, we found the location of damage to be different between superior and inferior facets. This fact, in our opinion, should reflect the physiological loading situation *in vivo*. Damage is most pronounced during physiological gaping *i.e.* small opening of the joint at endpoints of flexion/extension movements (see Fig. 6) [23]. The superior facet shows most damage at the superior pole, where during flexion movements the inferior facet causes maximum pressure. The inferior facet shows most cartilage damage at the superior and inferior poles, whereas bony appositions are almost exclusively seen at the inferior pole, where bony contact between the inferior pole of the inferior facet and the arch of the superior facet can take place during extension movements. [1, 17, 38]. The

inferior and superior pole are especially stressed at the extremes of movement and it has been shown that gaping indeed occurs in the final phases of flexion and extension [23, 25]. In 1983 Adams *et al.* have already suggested such points of overload, but in their work could not prove the concept to be valid [1]. Here in a large study group, it was shown that the most damage in the facet joints is indeed found at these locations.

Osteophyte formation was not as frequently found as cartilage defects. Osteophytes formed mainly on the superior facet on the lateral margin (in 33% of cases), where the dorsal capsule is attached. Recent work has shown that axial lumbar rotation results in a wrap-around situation for the contralateral joint capsule. This mechanical environment promotes changes in the dorsal capsular attachment and subsequently to fibrocartilage metaplasia in association with bone spur formation [4–6]. The phenomenon is most prominent in degenerated specimens, where higher axial rotation places more stress on the dorsal capsule [5]. Accordingly, we found osteophytes on the lateral margin more frequently in severely degenerated facets (especially in the L4 superior

Fig. 6 Schematic drawing showing the contact points between superior and inferior facets during flexion/extension movements: during flexion, the inferior facet slides over the superior facet and maximal pressure occurs at the superior pole of the superior facet. During maximal extension, the inferior facet comes in contact with the arch of the superior facet

facet). The second most common location was at the inferior pole of the inferior facet (in 15% of cases), where the inferior facet contacts the isthmus of the neural arch of the corresponding superior facet during extension. In all other locations, the prevalence was less than 10%. The overall relative low prevalence of osteophyte formation is confirmed by Eisenstein, who found severe cartilage lesions with subchondral bone erosion in 12 patients, while osteophyte formation was markedly absent in all cases [13].

The role of the small articular facet joints for low back pain was long overlooked, until Ghormley described it in 1933 [15]. He first ascribed symptoms as seen in traumatic or degenerative arthritis in other joints to the degeneration of the facet joints [15]. The prevalence of the facet syndrome or facet predominant chronic low back pain varies between 15 and 40% of cases; when defined as pain relief after diagnostic facet joint injections of 50% or more [27, 28]. Most studies concerning the role of the facet joints in low back pain suffer from identical limitations. Clinical examination of the facet joints is difficult, since there are no specific tests or predictors of facet-related pain [10, 26–28]. Especially the small sized facet joints are difficult to evaluate with modern imaging (CT and MRI), which, at its best, is capable of detecting larger defects at the facet joint surface, whereas small defects may go unnoticed [29, 36]. The best diagnostic test so far is an anesthetic injection into the facet joint with a confirmatory block [26, 27]. In contrast to in vivo investigations, anatomical studies offer the advantage of direct inspection of the pathological changes, although postmortem studies normally do not allow to correlate clinical with anatomical find-

ings. Consequently, the role of lumbar facet joints as one cause of low back pain is still insufficiently explained. In order to better understand the normal prevalence and morphology of degenerative changes in the lumbar (L1–L5) facet joints, this study presents detailed pathological findings of a comparably large number of individuals who died of old age. Recent studies have shown that the facet joints are well innervated [3, 8, 11]. Therefore, these small defects may be related to the generation of pain, although this has not been proven clinically. Whereas most of the time, extreme movements are prevented and therefore bony contact is avoided, especially during extreme positions in flexion/extension movements, bony contact may produce pain. Pain relief by diagnostic application of facet joint injections with a local anesthetic confirms this observation [10, 12, 21, 26, 27]. In case of using an artificial disc prosthesis, it is important to recognize the state of the facet joints also, since the motion segment is a three-joint complex and replacement of only the disc may lead to a worse outcome, when the facets are badly degenerated and painful [34].

In conclusion, degenerative defects have a relatively high prevalence in the elderly population. Certain locations are prone to bare a defect (articular margins, predominantly at locations where highest biomechanical stress occurs), while others are relatively free of degenerative changes (central parts). Furthermore, these defects often happen to be of relatively small size, which makes it difficult to localize them, even with modern imaging methods. In future studies, a correlation between clinical symptoms, modern imaging and gross appearance of the facet joints would be of interest, in a few selected patients.

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