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MUSCULOSKELETAL IMAGING

ORIGINAL ARTICLE

Postoperative lumbar spine: modified radiographic projections for detection of bone defects in cadavers

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PURPOSE
Special radiographic projections were evaluated in two cadaveric specimens for depicting postoperative changes after five different lower lumbar surgical procedures. Available literature concerning special radiographic projections of the lumbar spine is limited. The objective of this study was to establish a special radiographic projection that is useful for depicting postoperative changes after lumbar surgical procedures.

MATERIALS AND METHODS
Five different procedures were performed on two cadaveric lumbar spines: laminotomy, total laminectomy, foraminotomy, surgical creation of pars interarticularis defect, and partial facetectomy. A series of radiographs, including routine views and combinations of various obliquity and cephalad angulation, were obtained preoperatively and after each operation. Film analysis was done using a four-point rating system to document the degree of visualization of the postsurgical bone defect at each stage of surgery at each lumbar segment. The best projections were determined by summation of the rating scores of the three lumbar segments. The scores of each projection in different procedures were also summed to determine the best view for clinical use.

RESULTS
The laminotomy defects were more obvious on the shallow-obliquity and low-angulation radiographs. The postoperative changes of total laminectomy were almost equally identified on the AP and lateral views and most of the compound views. The bone changes of foraminotomy were best identified on the 45° routine view. The 30°-15° and 45°-15° compound views were best for depicting a postoperative pars defect. None of the projections delineated the bone changes of partial facetectomy. The 30°-15° compound view had the highest summation of rating scores of the five surgical procedures.

CONCLUSION
The results of this study suggest that the 30°-15° compound view could be useful for the assessment of the postoperative lumbar spine. Further verification of its value requires a large clinical study.

Key words: • laminectomy • lumbar vertebrae • diagnostic imaging

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Lumbar radiographs in anteroposterior (AP), lateral, and oblique projections are frequently obtained in the evaluation of the lumbar spine. AP and lateral views generally are used in the radiographic survey in patients with lumbar problems; 45° oblique projections are often used to demonstrate a defect of the pars interarticularis, which may be difficult to see in the AP and lateral views. However, these routine views are of limited value when applied to the postoperative spine, as they may fail to reveal the bone changes resulting from various decompressive spinal procedures, such as laminotomy, foraminotomy, and partial facetectomy. The purpose of this study was to establish a special radiographic projection to depict postoperative changes after various lumbar surgical procedures.

Materials and methods

Initially, 45 radiographs in various projections were obtained on a cadaveric lumbar spine specimen using combinations of different spinal obliquity (from AP to 60° oblique, with increments of 15°) and tube angulation (from 60° caudad to 60° cephalad, with increments of 15°), with the beam centered at the fourth lumbar vertebra. Projections with better *en face* depiction of the laminae and the facet joints of the lower lumbar segments were determined and used for subsequent parts of the study.

Five different procedures were performed by an orthopedic spine surgeon on two cadaveric lumbar spines. A series of radiographs were taken preoperatively and after each operation. The first procedure was a laminotomy of the third, fourth, and fifth lumbar vertebrae (L3, L4, and L5), a procedure frequently performed during lumbar disc surgery. The second procedure included a partial laminectomy of L3 and complete L4 and L5 laminectomies in the first specimen. Complete laminectomies at all three lower lumbar segments were performed in the second specimen. The third procedure was foraminotomy, which was performed bilaterally over the L3, L4, and L5 nerve roots in the first specimen, and on the right side of the same nerves of the second specimen. This procedure was performed by partial removal of the medial aspect of the pedicle and zygapophyseal process along the course of the nerve root. In the fourth stage, a defect or fracture of the pars interarticularis was created on one side at each lumbar segment, a condition that could occur during or after an extensive decompressive procedure. The final procedure component was partial facetectomy of one side of L3–L4, L4–L5, and L5–S1.

Based on the analysis of the preoperative radiographs in the first part of this study, 22 projections were obtained preoperatively and after each stage of surgery in the first specimen, including 4 routine views (AP, lateral, and bilateral 45° oblique views) and 18 compound views (combinations of 15°, 30°, or 45° of obliquity, both right and left anterior, with 15°,

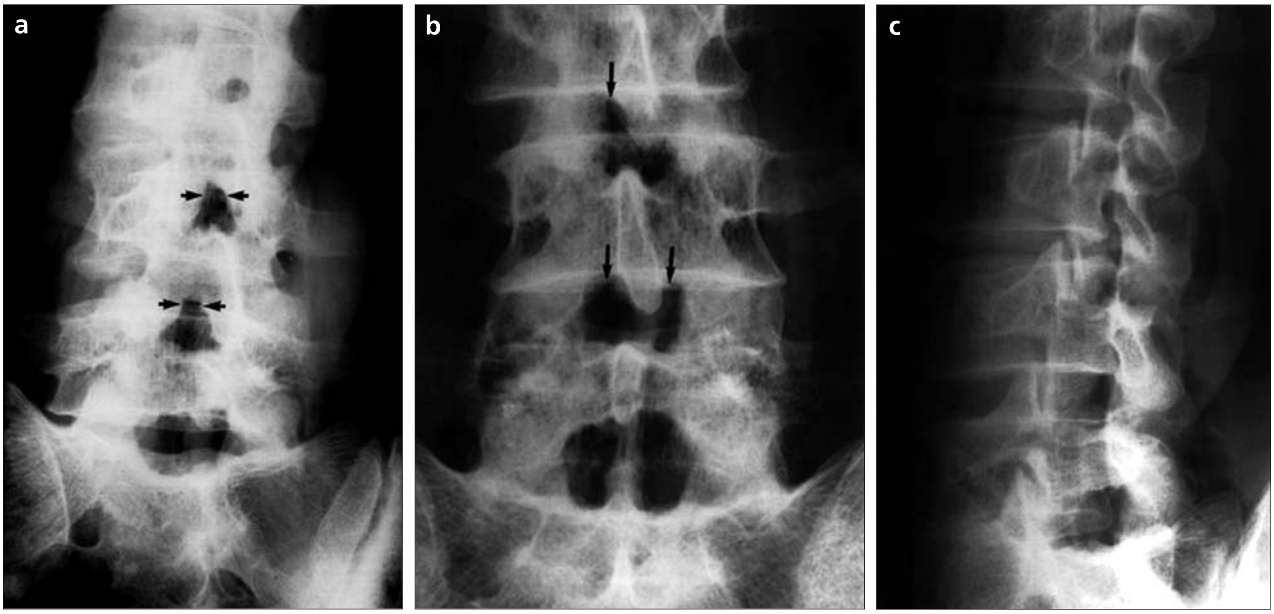

Figure 1. a–c. Laminotomy. Left anterior oblique 15°-15° compound X-ray view **(a)**. Cortical irregularities were identified at the L3–4, L4–5, and L5–S1 along the superior and inferior borders of the right sides of the laminae. The surgery performed on L5–S1 was limited, and minimal cortical defects were identified. Two larger cortical defects are well demonstrated *(arrows)*. The laminar cortex at the L2–3 was left intact for comparison. The defects of the left side of the laminae were also well demonstrated on the contralateral compound view (not shown). Anteroposterior (AP) X-ray view of the same specimen **(b)**. The laminotomy defects are more subtle on the AP view *(arrows)*. Routine 45° left anterior oblique X-ray view **(c)**. The defects are much more difficult to identify.

30°, or 45° of cephalad angulation). In the second specimen, eight compound views (combinations of bilateral 15°and 30° obliquity with 15° and 30° cephalad angulation) and the four routine views were obtained after each stage. Analysis of the films was done by two radiologists in consensus, using a four-point rating system to document the degree of visualization of the postsurgical bone defect after each stage of surgery at each lumbar segment (3, excellent visualization; 2, suboptimal visualization; 1, difficult visualization; 0, nonvisualization). The best projections for each stage of the surgery were determined by summation of the rating scores of the three lumbar segments. The scores of each projection in different stages of surgery were also summed to determine the best view for clinical use.

Each projection was given an abbreviated title based on two figures: the first represented the degree of spinal obliquity and the second represented the degree of cranial angulation of the x-ray beam (e.g., projection with 30° of obliquity and 15° of cranial angulation was abbreviated as 30°-15° compound view).

Results

The projections with highest rating scores for each procedure are summarized in Table 1. The laminotomy defects were more obvious on the shallow-obliquity and low-angulation radiographs (15°-15°, 15°-30°, and 30°-15° compound views). These defects were suspected on the AP view after careful inspection, but were more subtle than on the above three views. The routine 45° views did not allow good visualization of the laminotomy defects (Fig. 1).

Table 1. Optimal radiographic views for each stage of surgery

	Specimen 1		Specimen 2	
	Projection	Score[a]	Projection	Score[a]
Stage 1 (laminotomy)	15°-15°	9	15°-15°	8
	15°-30°	9	15°-30°	8
	30°-15°	8	30°-15°	8
Stage 2 (total or partial laminectomy)	15°-15°	9	15°-15°	9
	30°-15°	9	15°-30°	9
	AP-lateral	9	30°-15°	9
			30°-30°	9
			AP-lateral	9
Stage 3 (foraminotomy)	45°-15°	3	45° routine	9
	45° routine	2	30°-15°	8
	45°-30°	2	30°-30°	8
Stage 4 (surgically created pars fracture or defect)	30°-15°	9	30°-15°	8
	45°-15°	9	15°-15°	7
			30°-30°	7
Stage 5 (partial facetectomy)	None		15°-30°	3
			30°-15°	3
			15°-15°	3
			30°-30°	3

[a]Summation of the rating scores on L3, L4, and L5 (for stage 1, 2, and 4 operations) or on L3–4, L4–5, and L5–S1 (for stage 3 and 5 operations).
AP, anteroposterior.

Figure 2. a–f. Total laminectomies with right foraminotomies. Sagittal view of the specimen **(a)**. Note the bone defects created during foraminotomies *(interrupted circles)*, which were performed by partial removal of the bone along the course of the nerve root. Anteroposterior (AP) X-ray view **(b)**. The bone changes of total laminectomy are clearly demonstrated, but those of foraminotomies are not identified. Routine 45° right anterior oblique (RAO) X-ray view **(c)**. Routine 45° left anterior oblique (LAO) view **(d)**. The bone changes of foraminotomies are identified in **(c)**, with loss of cortical lines of the facets *(thin arrows)* and thinning of the right pars interarticularis *(open arrows)*. Thickness of the normal left pars interarticularis is shown in **(d)**. 30°-15° RAO X-ray view **(e)**. The bone changes *(thin arrows)* with thinning of the right pars interarticularis *(open arrows)* are also identified. 30°-15° LAO X-ray view **(f)**. The cortex of the left neural foramen is intact and the thicknesses of left pars interarticularis are normal.

The postoperative changes of total laminectomy were well identified on the AP and lateral views. Although the compound views also revealed the bone changes, none provided additional information beyond that derived from the AP and lateral views. In the partial L3 laminectomy, a noticeable difference was found between the results derived from views with cephalad angulation greater than 30° and those of views obtained with lesser angulation. The former provided poorer depiction of the laminae because of overlap with L2.

Foraminotomies were difficult to identify on the radiographs of the first specimen. The changes were not seen at L3–4 and L5–S1 and only partially identifiable at L4–5, but only on three views: 45°-15°, 45° routine, and 45°-30°. In the second specimen, the bone changes were seen more easily than in the first specimen, and were best identified on the 45° routine view, followed by 30°-15° and 30°-30° compound views. Other views (including the AP view) did not allow clear delineation of the bone changes (Fig. 2).

The 30°-15° and 45°-15° compound views were best for depicting a postoperative pars defect. However, most of the other compound views (e.g.,

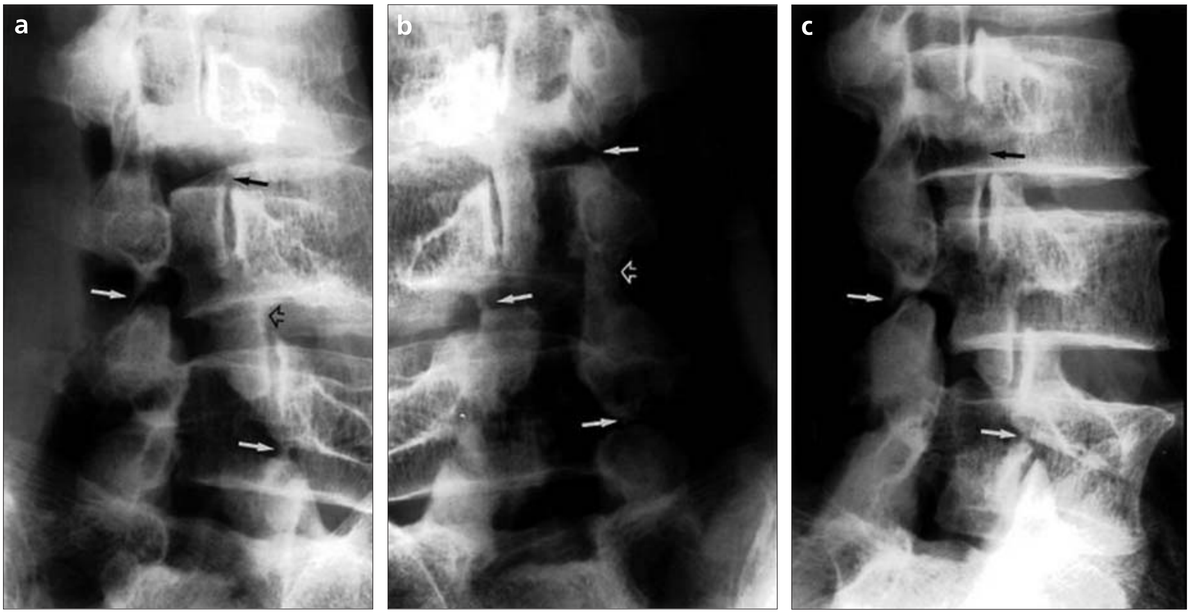

Figure 3. a–d. Pars interarticularis defects or fractures. 30°-15° right anterior oblique (RAO) X-ray view **(a)**. 30°-15° left anterior oblique (LAO) X-ray view **(b)**. Routine 45° RAO X-ray view **(c)**. Routine 45° LAO X-ray view **(d)**. The L3 pars fracture is well identified on both 30°-15° views and routine 45° views *(upper arrow)*, but the L4 pars fracture *(middle arrow)* is better demonstrated on 30°-15° view than on routine 45° views. Thinning of L5 pars *(lower arrow)* is identified in **(a)**, **(b)**, and **(c)**, but is less distinct in **(d)**. The open arrow indicates a normal pars interarticularis viewed on different oblique projections **(a, b)**.

45°-30°, routine 45°, 15°-15°, 15°-30°, and 30°-30°) were also useful for demonstrating the defects, except those views with extreme angulation (45°). The routine 45° oblique view was of moderate value in its ability to allow identification of the pars interarticularis defects (Figs. 3, 4).

On the radiographs obtained after partial facetectomy, most of the defects were not evident except at the L5–S1 level of the second specimen. This defect was equally demonstrated with the 15°-15°, 15°-30°, 30°-15°, and 30°-30° compound views, and slightly less well defined on the 45° routine view. Bone changes at other levels and changes in the other specimen were not delineated by routine and compound views (Fig. 4).

The summations of rating scores from stage 1 to stage 5 of surgery for each radiographic projection are listed in Table 2. The 30°-15° compound view had the highest score in both specimens.

Discussion

It is not uncommon in clinical practice for a radiologist or spine surgeon to encounter films of a patient with a prior history of lumbar surgery but with no details available about the procedure that had been performed. Although CT scan is the most sensitive and specific study for postoperative evaluation of a postoperative spine, plain radiographs are usually the first study performed for evaluation of patients, including those who have undergone decompressive surgery. Routine AP and lateral radiographs may reveal the postoperative changes after total or partial laminectomy, but these radiographs are usually inadequate in the delineation of the bone defects after laminotomy and procedures involving the neural foramen, such as foraminotomy and facetectomy. The routine 45° oblique view also is not informative in this regard. Many physicians have abandoned its routine use in the postoperative evaluation of the lumbar spine.

Available literature concerning special radiographic projections of the lumbar spine is limited. Abel et al. (1, 2) have emphasized an AP view with

Table 2. Summation of the total rating scores of each radiographic view

	Specimen 1	Specimen 2
AP-lateral	13	15
Routine 45° oblique	13	23
15°-15°	25	28
15°-30°	24	26
15°-45$^{\text{O}}$	13	NA
30°-15°	26	36
30°-30°	22	34
30°-45°	12	NA
45°-15°	15	NA
45°-30°	12	NA
45°-45°	5	NA

NA, not available; AP, anteroposterior.

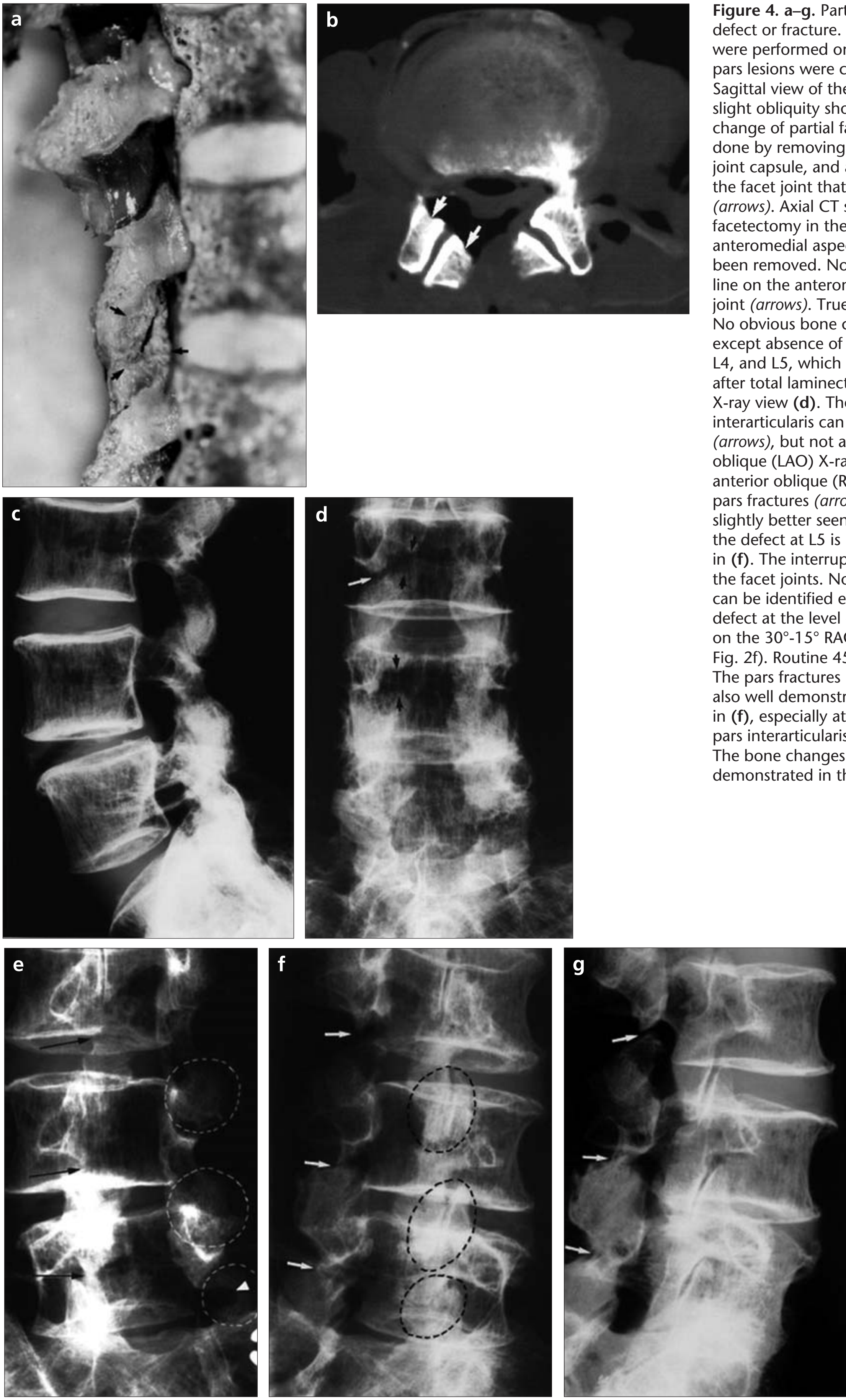

Figure 4. a–g. Partial facetectomy and pars defect or fracture. The partial facetectomies were performed on the left side and the pars lesions were created on the right side. Sagittal view of the specimen **(a)** with slight obliquity showing the postoperative change of partial facetectomy, which was done by removing ligamentum flavum, joint capsule, and anteromedial aspect of the facet joint that faced the spinal canal *(arrows)*. Axial CT scan **(b)** of the partial facetectomy in the other specimen. The anteromedial aspect of the facet joint has been removed. Note the loss of the cortical line on the anteromedial aspect of the facet joint *(arrows)*. True lateral X-ray view **(c)**. No obvious bone change can be identified except absence of the spinous process of L3, L4, and L5, which were postoperative defects after total laminectomies. Anteroposterior X-ray view **(d)**. The defects of the right pars interarticularis can be identified at L3 and L4 *(arrows)*, but not at L5. 30°-15° left anterior oblique (LAO) X-ray view **(e)**. 30°-15° right anterior oblique (RAO) X-ray view **(f)**. The pars fractures *(arrows)* at L3 and L4 are slightly better seen in **(f)** than in **(e)**, whereas the defect at L5 is better identified in **(e)** than in **(f)**. The interrupted circles **(e, f)** indicate the facet joints. No definite bone change can be identified except a possible lucent defect at the level of L5–S1 (*arrowhead,* **e**) on the 30°-15° RAO view (compare with Fig. 2f). Routine 45° RAO X-ray view **(g)**. The pars fractures *(arrows)* at L3 and L4 are also well demonstrated, but not as well as in **(f)**, especially at L4. The defect of the pars interarticularis of L5 is not identified. The bone changes of the facet joints are not demonstrated in this view.

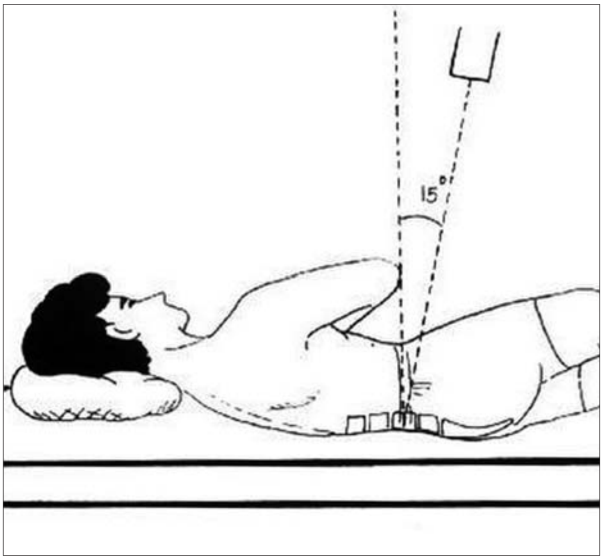

Figure 5. Schematic representation of the suggested compound view for routine use. The patient is positioned 30° obliquely to the table and the central beam of the X-ray is directed at L4 and angulated 15° cephalad. Both oblique views should be taken.

45° caudal angulation as valuable in revealing the posterior elements of the lumbar spine. Libson and Bloom (3) suggested using a 30° cranially angulated AP view to detect defects of the pars interarticularis. Amato et al. (4) compared the frequency of detecting isthmus defects on AP, lateral, 45° oblique, 30° cephalad angled AP, and collimated lateral views, and found the collimated lateral view to be most sensitive. Saifuddin et al. (5), after studying spondylolytic lesions, suggested that CT scans should be used instead of oblique radiography for the assessment of spondylosis, as only 32% of defects were oriented within 15° of the 45° lateral oblique plane. Based on our experience derived from our initial specimen, the caudad angulated views rendered the laminae foreshortened and narrowed, such that a small surgically created laminar defect may be obscured. In contrast, on cephalad angulated views the laminae are seen more *en face*, thus allowing better visualization of small laminar defects.

In our specimen, the bone defects following laminotomy were visualized only partially on the standard AP and 45° oblique views. They were best visualized on the 15°-15° and 15°-30° compound views, followed by the 30°-15° compound view. The finding that the compound views with 15° of obliquity allow better depiction of the laminae than those with 30° of obliquity correlates with the fact that the laminae of the lumbar spine are oriented approximately 15° obliquely with regard to the coronal plane of the body.

In this study the bone changes from foraminotomies were better identified in the second specimen, in which a more extensive operation had been performed. They were best visualized by the routine 45° oblique views, followed by 30°-15° and 30°-30° compound views, but they were completely invisible on the routine AP and lateral views.

At the fourth stage of surgery, a defect or fracture of the pars interarticularis was iatrogenically created to simulate one complication of a decompressive operation; such fractures may occur during or after the operation if the pars interarticularis was weakened by the osseous removal of the posterior elements. In both specimens, the plane of the surgically created pars fracture differed from that of an isthmic spondylolysis. Specifically, a right-sided pars defect occurring in isthmic spondylolysis is usually seen more easily on the right anterior oblique view, whereas a surgically created one is delineated more clearly on the left anterior oblique view. Therefore, both oblique views should be obtained, since they may complement one another. In this study, the 30°-15° compound view was better than the routine 45° oblique view for identification of the surgically created pars fracture. The AP and lateral views were not useful for this purpose.

Most of the bone changes following partial facetectomy were not evident in the routine and compound views. This probably relates to the fact that the portion of bone removed was oriented *en face* to the X-ray beam rather than in profile (Fig. 4b). We have tested a 70° oblique view, which might show the surgical defect in profile. However, the results of this view also were poor because of superimposition of the contralateral facet joint.

Of all the compound and routine views, the 30°-15° view had the highest total score in both specimens, and thus is recommended as the best view for the general evaluation of the postoperative lumbar spine (Fig. 5). This view was the best for demonstration of osseous changes related to total laminectomies and pars interarticularis defects, and was second best for delineation of such changes related to laminotomy and foraminotomy. In our studies, the central beam used for this view was localized to L4, which is relatively lower than that employed for routine AP and oblique views. We chose this lower level because most lumbar operations are performed at the lower segments of the lumbar spine. Obviously, focusing the center beam on the region of primary concern helps optimize the radiographic examination.

Theoretically, the degree of lumbar lordosis may influence the results obtained with this special view. The degree of lumbar lordosis in our specimens was within normal limits; thus, 15° to 30° cranial angulation is adequate for demonstrating laminotomy and other surgical defects. In a patient with exaggerated lordosis, a cranial angulation greater than 30° may be necessary. Therefore, to achieve the best results in a specific patient, it may be necessary to adjust the degree of angulation based on the degree of lumbar lordosis. However, adjusting the angulation patient by patient will render this special view less practical for daily use. We believe that our screening view is suitable for most patients, and that slight adjustments of angulation generally will not be required.

This study was limited by the small number of specimens. Subjective bias from the reading radiologist was another limitation of this study. Other limitations may relate to the facts that we did not evaluate all types of surgery or surgery at other levels, study the benefits of this compound view in patients without surgery, and assess visualization of other findings such as degenerative disc disease and osteoarthrosis.

In conclusion, the results of this cadaveric study suggest that the 30°-15° compound view may be useful for the assessment of the postoperative lumbar spine. Further verification of its value requires a large clinical study.

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