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Original Article / *Klinik Çalışma - Araştırma*

The Agreement Between Radiographic and Surgical Measurements of Intervertebral Disc Height: A Cadaveric Study

İntervertebral Disk Yüksekliklerinin Radyografik ve Cerrahi Ölçümleri Arasındaki Uyum: Bir Kadavra Çalışması

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Objective: Measurement of disc height has various clinical implications. Radiographic measurement of disc height may present inaccurate results and its direct "surgical" confirmation has not been studied. This study aimed to evaluate the agreement between the radiographic and post-discectomy surgical measurements of human intervertebral discs' height C2-C3 thru L5-S1.

Material and Methods: Eleven cadaver spines (243 discs) were studied. Before discectomies, the heights of all intervertebral discs were measured radiologically, using the method proposed by Frobin et al., which had been originally used for lumbar levels. Then, discectomies were performed and the discs were measured directly, using surgical disc spacers.

Results: Mean values and standard deviations for radiographic and direct measurements of disc heights were, respectively, 4.7±0.6 mm and 4.5±0.6 mm for cervical, 5.1±0.7 mm and 4.9±0.7 mm for thoracic, and 11.3±2.5 mm and 10.9±1.8 mm for lumbar regions. The agreement between radiographic and direct measurements was good.

Conclusion: The results from this study suggest that it is possible to estimate correctly the post-discectomy surgical heights of intervertebral discs for all spine regions by using non-magnified preoperative lateral X-rays and the method described by Frobin et al.

Key words: Intervertebral disc; measurement; roentgenography; surgery; cadaver.

Amaç: Disk yüksekliği ölçümünün birçok klinik anlamı vardır. Disk yüksekliğinin radyolojik ölçümü doğru sonuç vermeyebilir ve bu ölçümün direkt "cerrahi" olarak doğrulanması çalışılmamıştır. Bu çalışmada C2-C3'ten L5-S1'e kadar insan intervertebral disk yüksekliklerinin radyografik ve diskektomi sonrası cerrahi ölçümleri arasındaki uyumu değerlendirilmiştir.

Gereç ve Yöntemler: Onbir kadavra omurgasında (243 intervertebral disk) çalışıldı. Diskektomi öncesi, tüm intervertebral disk yükseklikleri Frobin ve ark.'nın lumbal seviyeler için kullandığı yöntemle radyolojik olarak ölçüldü. Daha sonra diskektomiler gerçekleştirildi ve cerrahi disk spacer'leri kullanılarak disk yükseklikleri doğrudan ölçüldü.

Bulgular: Disk yüksekliklerinin radyolojik ve doğrudan ölçümlerinin ortalama ve standart sapma değerleri sırasıyla, servikal seviyeler için 4.7±0.6 mm ve 4.5±0.6 mm, torasik seviyeler için 5.1±0.7 mm ve 4.9±0.7 mm ve lumbal seviyeler için 11.3±2.5 mm ve 10.9±1.8 mm idi. Radyolojik ve doğrudan ölçüm değerleri uyumlu bulundu.

Sonuç: Bu çalışmanın sonuçları cerrahi öncesi büyütmesiz Lateral X-Ray ile Frobin ve ark.'nın tarif ettiği yöntem kullanılarak, diskektomi sonrası cerrahi intervertebral disk yüksekliklerini tüm omurga bölgeleri için doğru olarak tahmin etmenin mümkün olduğunu desteklemektedir.

Anahtar sözcükler: İntervertebral disk; ölçüm; röntgenografi; cerrahi; kadavra.

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INTRODUCTION

Intervertebral discs have great importance in spinal biomechanics as they stabilize the spine and absorb and distribute load while allowing the spine to flex, extend, or rotate. As intervertebral discs degenerate with age, they show certain structural and functional changes. Although some controversies exist as to the direction of the alteration,[1] it is generally accepted that aging leads to changes in the height of the disc. Thus, measurement of disc height has various clinical implications. During anterior cervical disc surgery, graft or cage height is important in regard to areas of intervertebral foramina and optimal distractive forces. An et al.[2] determined that the interbody grafts should be 2 mm larger than the preoperative height. Although interbody grafts are sized by interference fit at the time of surgery, cervical intervertebral disc height measurement may be used for preoperative radiological templating of intervertebral grafts. In the lumbar area, intervertebral disc height measurements are mainly used to evaluate the relationship between the narrowing of disc height and low back pain,[3] disc herniation,[4,5] degeneration or age.[6] Recent advances in interbody cage surgery and artificial discs may add other implications for disc height measurements.

During intervertebral disc surgery, when interbody fusion material (bone graft or cage) is required, measurement of disc height is performed after discectomy by selecting the proper intervertebral disc spacer, which fits into the space without causing either excess distraction or looseness. The height of the best-fit spacer is accepted as the direct or "surgical" height of the intervertebral disc. To the authors' knowledge, no study to date has evaluated the agreement between the measurements obtained by radiological methods and those obtained by direct "surgical" methods. Thus, this study aimed to evaluate the agreement between the pre-discectomy radiographic and post-discectomy surgical measurements of the human intervertebral disc heights C2-C3 thru L5-S1.

MATERIAL AND METHODS

For this study, 11 cadavers (10 males and one female) were used in the Department of Anatomy of Trakya University Medicine Faculty. The average death age for cadavers was 52 years, with ages ranging from 44 to 62 years. These formalin-fixed cadavers were dissected using the midline posterior approach from occiput to sacrum. The spines from C1 to sacrum were removed without damage to bony and ligamentous structures. Anteroposterior and lateral radiographs confirmed that there was no deformity or other anomalies.

The heights of all intervertebral discs (C2-C3 thru L5-S1) of each spine were measured by radiographic and direct methods. Due to excess narrowing or fusion, a few levels could not be measured. Thus, a total of 66 cervical, 129 thoracic, and 48 lumbar intervertebral discs were evaluated. For radiographic measurements, four (one cervical, two thoracic, and one lumbar) digital lateral radiographs were taken (Fuji Digital, Fuji Inc., Japan) for each spine, using standard protocol (110 cm interval between X-ray tube and the spine). To ensure that no magnification was present, control radiographs were taken using an object with a known size. To determine disc height, the method described by Frobin et al.[8] was employed on hard copies of X-rays. The method is shown in Figure 1. All measurements were performed by the same radiologist. To validate the accuracy of the method and assess interobserver error, intervertebral discs of three spines were also evaluated by another radiologist who was blinded to the previous measurements.

For direct measurements of disc heights, discectomies were performed anteriorly through a window at the annulus. The anterior longitudinal ligament, intervertebral disc, and endplate cartilages were removed, while the posterior longitudinal ligament was left intact. The heights of the discs were measured using intervertebral disc spacers, rectangle-shaped surgical tools used for templating before cage insertion of 4 to 14 mm in height (Rabea PEEK and Tetris Systems, Signus Medizintechnik GmbH, Alzenau, Germany). For each level, the spacer that fitted tightly into the space was selected, and the size of the spacer was recorded as the height of that intervertebral disc (Fig. 2). During measurements, spines were supported using folded cloths

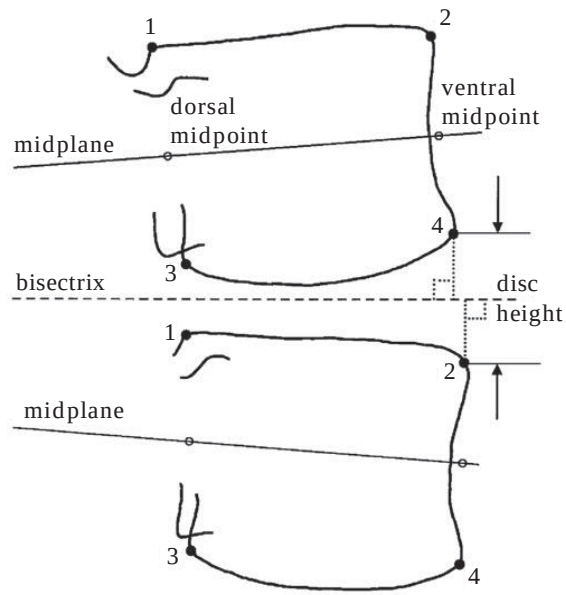

Figure 1. *As the full set of corners may not be visible, measurement of disc height is based on the outermost contours (points 1-4). The ventral height of the intervertebral disc is defined as the sum of the perpendicular distances of corner 4 and corner 2 from the bisectrix.*

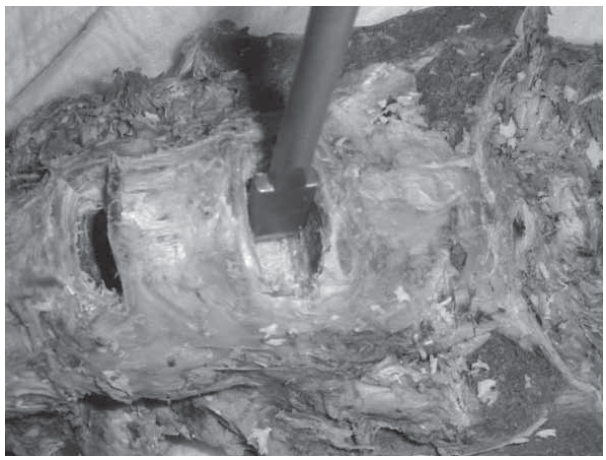

Figure 2. *Measurement of direct "surgical" disc height of a lumbar level using a disc spacer.*

on the table, so their natural lordotic and kyphotic alignments were maintained. While spacers were being inserted, adjacent discectomy levels were obliterated in order to prevent distraction. Each level was measured by two researchers (CK and TK), each blinded to the other's results. After all measurements were taken, the results were checked. In cases where there was no agreement on the result of the level in question, the two researchers performed measurements together to reach a final conclusion.

Statistical Analysis

For cervical (C2-C3 through C7-T1), thoracic (T1-T2 through T12-L1) and lumbar (L1-2 through L5-S1) regions, mean and standard deviation values were obtained. The statistical significance of the difference between radiographic and direct measurements was assessed by the t test for paired data. The analyses were performed using Minitab 13 software (Minitab Inc, State College, PA). Inter-examiner bias was assessed by using the Bland-Altman method of plotting the differences between the two measurements against the average of the two measurements.[7] The statistical significance for the tests was at the 5% level.

RESULTS

Cervical Region (C2-C3 / C7-T1)

The inter-examiner agreement between the two radiologists was good [mean±SD of the differences was 0.03±0.12 mm, lower and upper limits were -0.26 and 0.20 mm at 95% confidence level, all 18 pairs lay into the limits]. In the same way, agreement between the two direct measurements was good [mean±SD of the differences was 0.14±0.46 mm, lower and upper limits were -0.77 and 1.04 mm at 95% confidence level, 65/66 of pairs (98.5%) lay into the limits]. Disc heights of cervical levels for radiographic and direct methods are presented in Figure 3. Comparison of the radiographic and direct methods revealed that the mean of radiographic measurements was slightly greater than that of the direct method: 4.65±0.59 mm (radiographic), 4.45±0.58 mm (direct). This difference was statistically significant according to a paired t-test ($p<0.0001$). However, when Bland-Altman analysis was employed, the agreement between the two methods could be considered as good (Fig. 4).

Thoracic Region (T1-T2 / T12-L1)

The interexaminer agreement for measurements for both the radiographic [mean±SD of the differences was 0.01±0.09 mm, lower and upper limits were -0.19 and 0.17 mm at 95% confidence level, 35/36 (97.2%) pairs lay into the limits] and the direct method was good [mean±SD of the differences was 0.02±0.34 mm, lower and upper limits were -0.65 and 0.69 mm at 95% confidence level, 123/129 (95.3%) of the measurement differences were in the limits]. Disc heights of thoracic levels are presented in Figure 5. Comparison of the radiographic and direct methods revealed that the mean of radiographic measurements was slightly greater than that of the direct method: 5.06±0.74 mm (radiographic), 4.90±0.71 (direct). This difference is statistically significant according to a paired t-test ($p<0.0001$). However, when the Bland-Altman analysis was employed, the two methods showed good agreement (Fig. 6).

Lumbar Region (L1-L2 / L5-S1)

The interexaminer agreement for measurements for both the radiographic [mean±SD of the differences was 0.10±0.66 mm, lower and upper limits were -1.19 and 1.40 mm at 95% confidence level, all 48 pairs lay into the limits) and the direct method was good [mean±SD

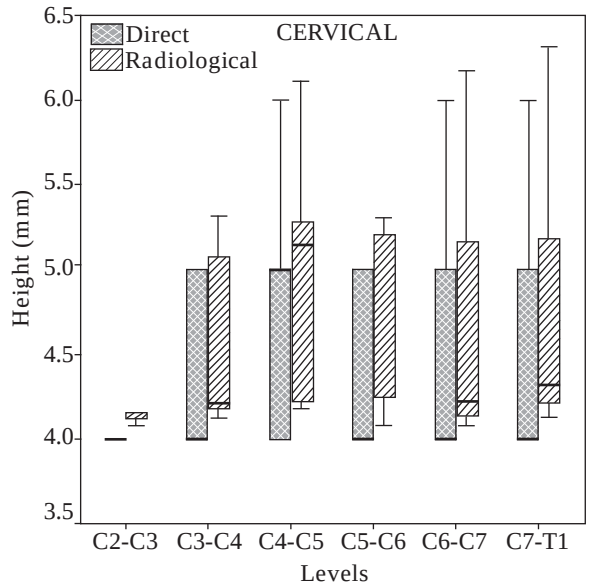

Figure 3. *Comparison of direct and radiographic measurements for cervical levels (n=66). Horizontal black lines represent median values.*

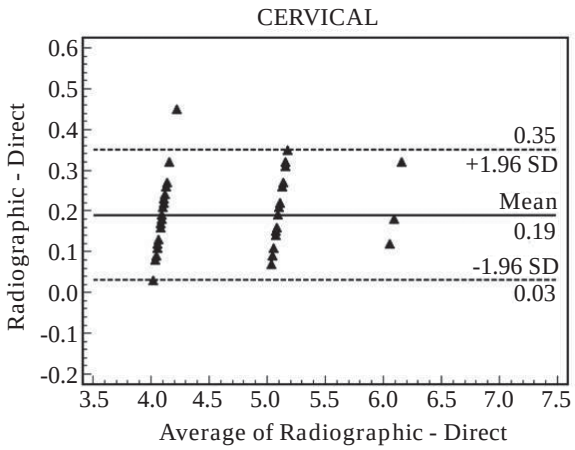

Figure 4. *Cervical region. Agreement analysis between radiographic and direct measurements using the Bland-Altman method (n=66). Mean±SD of the differences was 0.19 ± 0.08 mm, lower and upper limits were 0.03 and 0.35 mm at 95% confidence level. 65/66 pairs (98.5%) lay within the limits.*

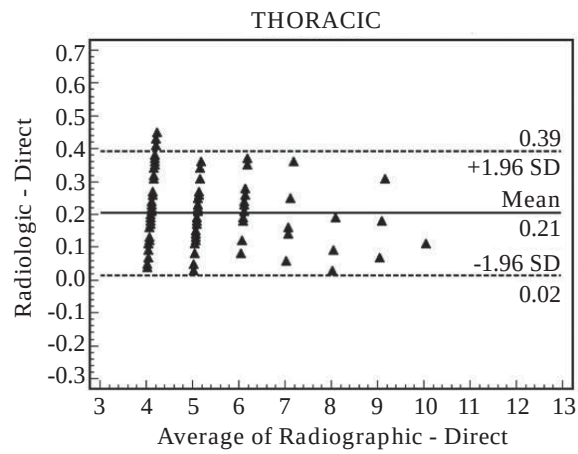

Figure 6. *Thoracic region. Agreement analysis between radiographic and direct measurements using the Bland-Altman method (n=129). Mean±SD of the differences was 0.21±0.10 mm, lower and upper limits were 0.02 and 0.39 mm at 95% confidence level. 126/129 pairs (97.7%) lay within the limits.*

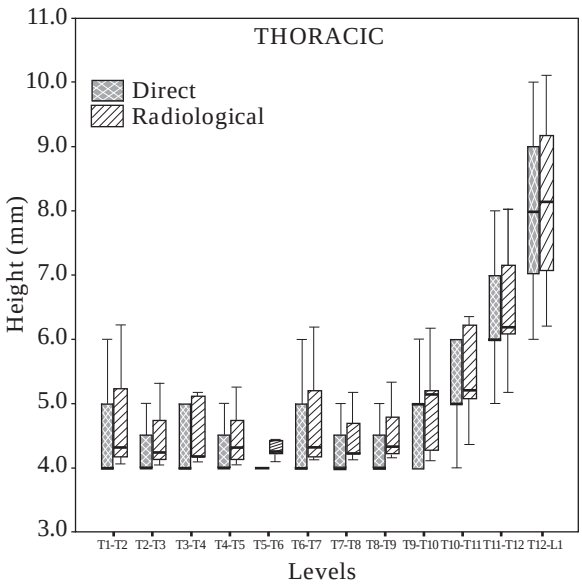

Figure 5. *Comparison of direct and radiographic measurements for thoracic levels (n=129). Horizontal black lines represent median values.*

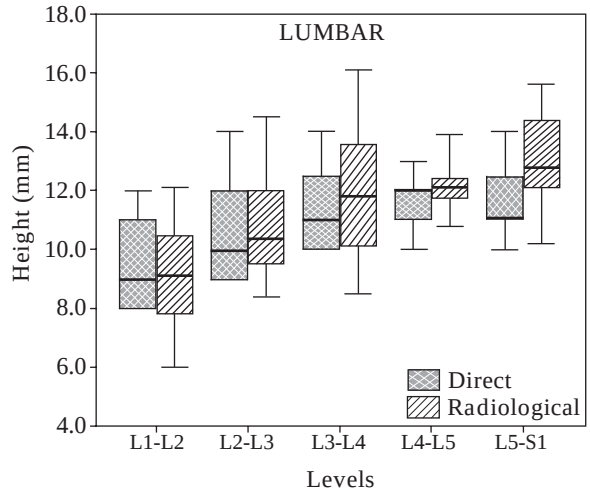

Figure 7. *Comparison of direct and radiographic measurements for lumbar levels (n=48). Horizontal black lines represent median values.*

of the differences was 0.04±0.67 mm, lower and upper limits were -1.35 and 1.27 mm at 95% confidence level, 47/48 pairs (97.9%) lay into the limits]. Disc heights of lumbar levels are presented in Figure 7. Comparison of the radiographic and direct methods revealed a small difference: 11.29±2.47 mm (radiographic), 10.90±1.77 (direct). This difference was not statistically significant according to a paired t-test (p=0.16). When the Bland-Altman analysis was employed, the agreement between the two methods was considered as good (Fig. 8).

DISCUSSION

Radiographic measurement of disc height presents some difficulties. Because intervertebral discs exhibit negligible absorption of X-rays, they are not visible on radiographs. Thus, a measurement of disc height has to rely on the contours of vertebral bodies. However, three-dimensional anatomy of the vertebrae requires specific measures when interpreting the radiographic image. In a true lateral position, if a central beam passes through a disc in a direction parallel to the endplates and the factor of radiographic magnification is known, the true height of the disc can be determined.[8] However, in the clinical setting, this ideal condition rarely exists and image distortion resulting from unavoidable off-central projec-

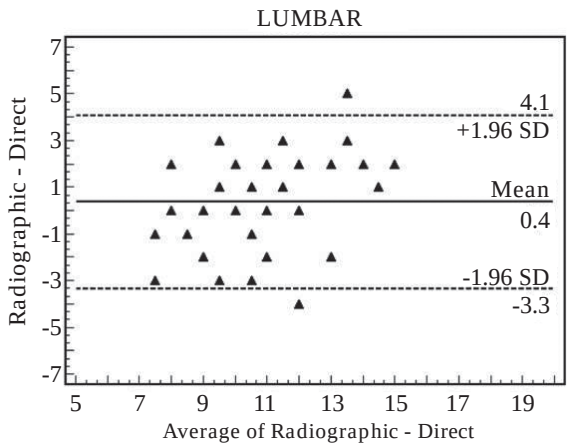

Figure 8. *Lumbar region. Agreement analysis between radiographic and direct measurements using the Bland-Altman method (n=48). Mean±SD of the differences was 0.40±1.90 mm, lower and upper limits were -3,33 and 4.61 mm at 95% confidence level. 46/48 pairs (95.8%) lay within the limits.*

tion is a significant problem. Inappropriate simplifications and assumptions may cause inaccurate results. Anderson et al.[9] determined that accurate measurements cannot be performed from routine radiographs. Various methods have been described for precise disc height measurement.[10,11] Pope et al.[12] studied six different methods of measuring disc height on radiographs and concluded that adequate compensation for radiographic magnification, proper tube-target-film distances and optimal radiographic protocols to visualize the bony landmarks are all essential for accuracy. A newer method proposed by Frobin et al.[8] seems to be adequately precise and has been widely quoted in the recent literature. The Frobin method uses four visible corners and a bisectrix between midplanes of adjacent vertebrae. The results are independent of distortion, axial rotation and lateral tilt. Using this method and standard lateral radiographs, it is possible to measure the height of lumbar discs with a precision of approximately±4%.[8] Because this method was initially described and used for lumbar levels only, the current study investigated its utilization in the cervical and thoracic regions as a secondary goal.

Flexibility of the spine poses further problems for accurate measurement of disc heights. Ventral disc height depends on the angle of lordosis. In a living body, to make the measurement independent of the individual's posture, a correction should be applied to convert disc height measured at arbitrary angles to height at standard angles. Because intervertebral disc height shows positional and even diurnal[13] changes, the time period between radiographic measurement and its verification (i.e., if radiographic measurement reflects true disc height) is important, so verification should be performed in a timely manner. Since the cadaver specimens we used were in a stable condition and unchanged position, they were good subjects for testing a radiographic method followed by its direct surgical confirmation.

The results of the current study demonstrated that the method described by Frobin et al. produced good interobserver agreement, not only for the lumbar region, but also for the cervical and thoracic regions. Lumbar levels revealed no difference between radiographic and direct measurements. This finding is in line with the prior study,[8] which reported high sensitivity of the radiographic method when used at lumbar levels. In cervical and thoracic regions, the average of the radiographic measurements was 0.2 mm higher than those of the direct measurements. This difference was found to be statistically significant. However, the Bland-Altman analysis showed that the two methods agree satisfactorily. In this method, the difference of the paired two measurements is plotted against the mean of the two measurements, and it is recommended that 95% of the data points should lie within the±1.96 SD of the mean difference.[7] In the current case, as the difference was small (0.2 mm), it lay within the±1.96 SD interval most of the time. Thus, if 0.2 mm difference could be overlooked, radiographic and direct measurements of cervical and thoracic intervertebral disc heights agreed. Considering that surgical measurement via a disc spacer has 1 mm sensitivity, the 0.2 mm difference is not important in the clinical setting.

In an operating theatre, removal of the anterior longitudinal ligament, the anterior part of the annulus, and the nucleus pulposus are expected to result in a widening of the disc interspace, and thus may adversely affect the comparison of preoperatory radiographical and intraoperatory direct measurements. We did not observe this finding and found comparable measurements in the cadavers. The reason for this may lie in the fact that the formalin-fixed cadaveric tissues were much stiffer than the fresh tissues, thus their response to discectomy was less than that of fresh tissue. However, in a living body, surrounding viscera and musculature may act as a stabilizing factor and decrease this "loosening" effect of the discectomy. Thus, as a result of these two counterbalancing factors (that is, elasticity of the ligaments and the stabilizing effect of the surrounding structures) in a living body, the actual result of the discectomy may resemble the results obtained from cadaveric specimens (that have stiffer tissues but no surrounding muscles) in the current study. However, it is clear that formalin-fixed specimens and lack of surrounding structures create the main limitations of the current study.

The results of the current study suggest that using non-magnified preoperative lateral X-rays and the method described by Frobin et al., it is possible to estimate accurately the actual post-discectomy surgical heights of intervertebral discs in all the spinal regions. However, because of abovementioned limitations, the results presented here should be treated cautiously in the clinical

setting. For the final interpretation, the results of the current experimental study should be verified by a clinical one that compares preoperative radiographs and intraoperative direct measurements after discectomy.

To the authors' knowledge, this is the first study investigating intervertebral disc height in the Turkish population. However, because the heights of intervertebral discs may be affected by many factors, such as age and gender; the specimen number used in the current study is not sufficient to create a complete profile of the population. However, since our results showed a good agreement between radiographic and direct measurements of disc height for all the spine regions, proceeding with radiographic studies should be encouraged.

Conflict of Interest

No conflict of interest declared by the authors.

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