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Original Research Article

A cross-sectional study on diaphragmatic thickness among critically ill Indian patients in a tertiary critical care unit and its association with age and gender

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ABSTRACT

Background: Diaphragmatic ultrasonography provides non-invasive bedside assessment of respiratory muscle morphology. The relationship between diaphragmatic thickness, age, and sex in critically ill Indian patients remains insufficiently studied. The objective is to assess diaphragmatic thickness and its association with age and sex in critically ill patients admitted to a tertiary-care unit.
Methods: This cross-sectional study included 60 critically ill patients (30 males, 30 females). Day 1 diaphragmatic thickness was compared across five age groups and between sexes using appropriate non-parametric and parametric tests. Associations were assessed using Spearman's correlation and univariable linear regression.
Results: Mean age was 41.75±14.38 years. Males were older than females (47.77±12.36 vs. 35.73±13.89 years; p=0.002). Diaphragmatic thickness differed significantly across age groups (p=0.003), with the highest median in the 41–50-year group (2.16 mm, IQR 1.95–2.29) and lowest in the 61–70-year group (1.61 mm, IQR 1.36–1.86). Only the 41–50 versus 51–60-year comparison was significant after adjustment (p=0.011). Age inversely correlated with thickness (ρ=−0.42, 95% CI −0.63 to −0.16; p<0.001), decreasing by 0.009 mm annually (R^2=0.152). Males had greater mean thickness than females (1.99±0.33 vs. 1.81±0.27 mm; p=0.025). Female sex was associated with 0.180-mm lower thickness (95% CI −0.337 to −0.023; R^2=0.084).
Conclusions: Older age was associated with lower diaphragmatic thickness, whereas males had greater mean thickness than females. Larger studies with multivariable adjustment are needed to confirm these associations.

Keywords: Diaphragm, Diaphragmatic thickness, Ultrasonography, Critical care, Intensive care unit, Age, Sex, India, Respiratory muscle

INTRODUCTION

The diaphragm is the principal muscle of inspiration and plays a central role in maintaining effective ventilation. In critically ill patients, respiratory muscle impairment may arise from systemic inflammation, sepsis, malnutrition, immobility, neuromuscular dysfunction and exposure to mechanical ventilation. Diaphragmatic dysfunction has been associated with difficulties in ventilator liberation, prolonged mechanical ventilation, and adverse clinical outcomes.[1-4]

Clinical assessment of diaphragmatic function is challenging in critically ill patients because conventional bedside examination is affected by sedation, altered consciousness, respiratory distress and concurrent cardiopulmonary disease. Diaphragmatic ultrasonography offers a non-invasive, repeatable bedside technique for

evaluating respiratory muscle morphology and movement. B-mode ultrasonography can measure diaphragmatic thickness, while M-mode ultrasonography can assess diaphragmatic excursion. The diaphragmatic thickening fraction provides additional information regarding inspiratory muscle contraction.[1,2,5]

Diaphragmatic thickness is influenced by several physiological and technical factors. In healthy populations, ultrasound studies have reported differences in thickness between males and females, whereas findings regarding age-related changes have been inconsistent. Boon et al. reported that diaphragmatic thickness and contractility were minimally affected by age and gender in their cohort of 150 healthy subjects.[6] In contrast, van Doorn et al found greater end-expiratory and maximal inspiratory thickness in men than women, without a significant age-related change in thickness.[7] These differences suggest that demographic associations may depend on population characteristics, measurement methodology and the clinical setting.

The interpretation of diaphragmatic thickness in critically ill patients is further complicated by acute illness, changes in respiratory effort, fluid balance, nutritional status, and ventilatory support. Reference values derived from healthy volunteers may therefore not be directly transferable to patients receiving critical care. Moreover, diaphragmatic thickness alone does not necessarily indicate preserved contractile function; thickness and functional measures such as thickening fraction and excursion provide different, complementary information.[2,5,9] Although diaphragmatic ultrasonography has been studied extensively in relation to mechanical ventilation and weaning outcomes, demographic associations in critically ill Indian adults remain clinically relevant. Understanding these associations may improve interpretation of bedside measurements and inform the design of future studies evaluating diaphragmatic dysfunction in heterogeneous critical care populations.

The present study aimed to assess day 1 diaphragmatic thickness among critically ill patients admitted to a tertiary critical care unit in India and determine its relationship with age and gender. The study also examined differences in diaphragmatic thickness across predefined age groups.

METHODS

Study designs and settings

This was a cross-sectional observational study conducted among critically ill patients admitted to the critical care unit of a tertiary-care hospital in India.

Study centre

The study was carried out in CCU, IPGMER & SSKM Hospital.

Study period

The study period was August 2024 to May 2026.

Study population

The study included 60 critically ill patients, comprising 30 males and 30 females.

Inclusion criteria

Adult patients aged 18–70 years admitted to the critical care unit of a tertiary-care hospital. Patients of either sex. Patients admitted with critical illness requiring intensive monitoring and/or organ support. Patients in whom diaphragmatic thickness could be assessed adequately using bedside ultrasonography. Patients whose informed consent was obtained directly or through a legally authorized representative, as applicable under the approved ethics protocol.

Exclusion criteria

Patients with a known history of neuromuscular disorders affecting diaphragmatic function, such as motor neuron disease, myasthenia gravis, or muscular dystrophy. Patients with known diaphragmatic paralysis, established phrenic nerve injury, or previous diaphragmatic surgery. Patients with major thoracic or diaphragmatic anatomical abnormalities that precluded reliable ultrasound measurement. Patients in whom adequate diaphragmatic visualization or reproducible thickness measurement could not be obtained. Patients with incomplete demographic data or missing day 1 diaphragmatic thickness measurements. Patients for whom consent could not be obtained in accordance with the approved ethics protocol.

A non-probability consecutive sampling method was used to recruit eligible patients admitted to the critical care unit of a tertiary-care hospital in India during the study period. Patients who fulfilled the predefined inclusion and exclusion criteria were screened for eligibility and enrolled consecutively until the required sample size of 60 participants was achieved. The study population comprised 30 males and 30 females.

Demographic characteristics, including age and sex, were recorded, and diaphragmatic thickness was assessed using bedside ultrasonography on day 1. All enrolled participants with available demographic and ultrasound data were included in the analysis. All the participants were on invasive mechanical ventilation since day 1 to minimum 7 days for further evaluation.

Assessment of diaphragmatic thickness

Diaphragmatic thickness was measured using ultrasonography on day 1. Diaphragm ultrasound typically measures the muscle in the zone of apposition, with a linear transducer positioned over an intercostal space and

the thickness measured between the pleural and peritoneal echogenic interfaces, excluding the interfaces themselves.[2,5]

Probe selection

High-frequency linear probe (7–12 MHz); curvilinear probe (3–5 MHz) when deeper visualization was required.

Site and imaging

Right hemidiaphragm examined at the 8th–9th intercostal space along the mid-axillary line using B-mode and M-mode ultrasonography.

Diaphragmatic thickness (DT) was measured at end-expiration.

Expert consensus and systematic reviews have emphasized the importance of standardized acquisition and reporting.[2,5]

Study variables and outcomes

The principal outcome was day 1 diaphragmatic thickness, expressed in millimetres (mm). The main explanatory variables were age and sex.

Statistical analysis

Continuous variables were summarized using means and standard deviations or medians and interquartile ranges, as appropriate. Categorical distributions were described using frequencies and percentages. The Mann–Whitney U test was used to compare age distributions between males and females. The Kruskal–Wallis test was used to compare day 1 diaphragmatic thickness across the five age groups. Post-Hoc pairwise tests for Kruskal-Wallis test performed using Dunn Test method with Sidak correction. The relationship between continuous age and diaphragmatic thickness was assessed using Spearman's rank correlation coefficient.

The difference in mean diaphragmatic thickness between males and females was assessed using an independent-samples t-test. Univariable linear regression was used to estimate the association between age and diaphragmatic thickness and between gender and diaphragmatic thickness. Effect estimates were reported with 95% confidence intervals where available. A two-sided p value below 0.05 was considered statistically significant.

Ethical considerations

Ethics committee approval was obtained from IPGMER and SSKM Hospital Institutional Ethics Committee before study initiation, if applicable. Informed consent was obtained from participants or their legally authorized representatives as approved by the ethics committee. The study was conducted in accordance with applicable institutional requirements and the Declaration of Helsinki.

RESULTS

Demographic characteristics

The study included 60 participants, comprising 30 males (50%) and 30 females (50%). The overall mean age was 41.75±14.38 years. Male participants were significantly older than female participants. The mean age was 47.77±12.36 years among males and 35.73±13.89 years among females. Which was statistically significant. The reported mean age difference was 12.03 years (95% CI 5.24–18.83). Females were more frequently represented in the 18–30- and 31–40-year age groups, whereas males were more frequently represented in the 41–50 and 51–60-year age groups.

Association between age and day 1 diaphragmatic thickness

There was a significant difference between the 5 groups in terms of Diaphragm Thickness (mm) (day 1) ($\chi 2$=15.688, p=0.003), with the median diaphragm thickness (mm) (day 1) being highest in the 41-50 Years age group, whereas the lowest median thickness was observed among those aged 61–70 years. Post-hoc Dunn–Sidak testing identified a statistically significant difference only between the 41–50- and 51–60-year groups (adjusted p=0.011). The reported association size was (Kendall's Tau)=0.27, indicating a relatively small effect according to the study's reported interpretation.

Non-parametric tests (Spearman correlation) were used to explore the correlation between the two variables, as at least one of the variables was not normally distributed. There was a moderate negative correlation between age (years) and diaphragm thickness (mm) (day 1), and this correlation was statistically significant (rho=-0.42, p=<0.001).

Univariable linear regression estimated that diaphragmatic thickness decreased by 0.009 (~ 0.01) mm for each additional year of age (95% CI −0.014 to −0.003). The model R^2=0.152, indicating that age alone accounted for approximately 15.2% of the observed variation in diaphragmatic thickness under the fitted linear model.

Association between gender and day 1 diaphragmatic thickness

Mean day 1 diaphragmatic thickness was 1.99±0.33 mm in males and 1.81±0.27 mm in females. There was a significant difference between the 2 groups in terms of diaphragm thickness (mm) (day 1) (t=2.300, p=0.025), with the mean diaphragm thickness (mm) (day 1) being highest in the gender: male group. Strength of association (Point-Biserial Correlation) = 0.29 (Medium effect size).

The univariable linear-regression model estimated that female sex was associated with a 0.180-mm lower diaphragmatic thickness than male sex (95% CI −0.337 to −0.023). The model R^2=0.084, indicating that gender alone accounted for approximately 8.4% of the observed variation in thickness. The reported point-biserial correlation was 0.29, consistent with a modest-to-moderate association.

Summary of principal findings

Diaphragmatic thickness differed significantly across age groups. Increasing age was associated with lower diaphragmatic thickness in continuous-variable analysis. Males had greater mean diaphragmatic thickness than females. Males were also significantly older than females, raising the possibility of confounding in the unadjusted gender comparison. The regression analyses were univariable; therefore, the independent contributions of age and sex have not been established.

Table 1: Distribution of age.

Variables	Parameters	Total	Gender		Difference (95% CI)	Significance
			Male	Female		
Age (Years)	Mean±SD	41.75±14.38	47.77±12.36	35.73±13.89	12.03 (5.24 to 18.83)	W = 664.000, p = 0.002[m]
	Median (IQR)	43.00 (26.50 - 57.00)	50.00 (44.00 - 57.00)	31.50 (25.00 - 42.00)		
Age	18-30 Years	18 (30.00%)	5 (16.67%)	13 (43.33%)	-26.67% (-48.85% to -4.48%)	χ^2 = 3.889, p = 0.047[f]
	31-40 Years	9 (15.00%)	0 (0.00%)	9 (30.00%)	-30.00% (-46.40% to -13.60%)	χ^2 = 8.366, p = 0.002[f]
	41-50 Years	13 (21.67%)	11 (36.67%)	2 (6.67%)	30.00% (10.58% to 49.42%)	χ^2 = 6.285, p = 0.010[f]
	51-60 Years	16 (26.67%)	12 (40.00%)	4 (13.33%)	26.67% (5.33% to 48.00%)	χ^2 = 4.176, p = 0.039[f]
	61-70 Years	4 (6.67%)	2 (6.67%)	2 (6.67%)	0.00% (-12.62% to 12.62%)	χ^2 = 0.000, p = 1.000[f]

[t] = t test, [m] = Mann-Whitney U Test, [f] = Fisher's Exact Test

Table 2: Day 1 diaphragmatic thickness according to age group.

Diaphragm thickness (mm) (Day 1)	Age					Kruskal Wallis test	
	18-30 years	31-40 years	41-50 years	51-60 years	61-70 years	χ2	P value
Mean (SD)	1.96 (0.32)	2.00 (0.20)	2.06 (0.33)	1.70 (0.22)	1.61 (0.29)	15.688	0.003
Median (IQR)	1.97 (1.67-2.2)	1.92 (1.8-2.1)	2.16 (1.95-2.29)	1.66 (1.61-1.85)	1.61 (1.36-1.86)		
Min - max	1.53 - 2.5	1.8 - 2.3	1.4 - 2.4	1.3 - 2.05	1.36 - 1.86		

Table 3: Day 1 diaphragmatic thickness according to gender.

Diaphragm thickness (mm) (Day 1)	Gender		t-test	
	Male	Female	t	P value
Mean (SD)	1.99 (0.33)	1.81 (0.27)	2.300	0.025
Median (IQR)	2.02 (1.7-2.2)	1.81 (1.62-1.97)		
Min - Max	1.3 - 2.5	1.36 - 2.3		

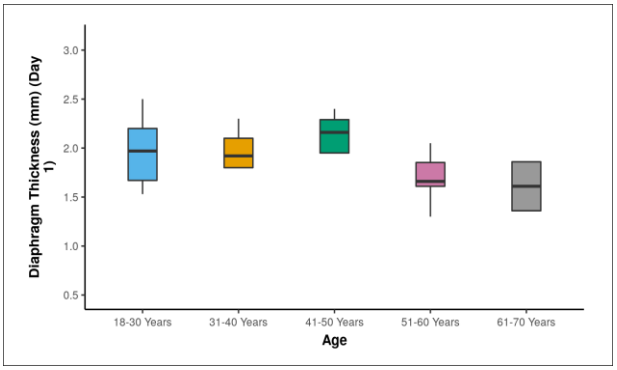


Figure 1: Association between age group and diaphragm thickness (mm) (day 1).

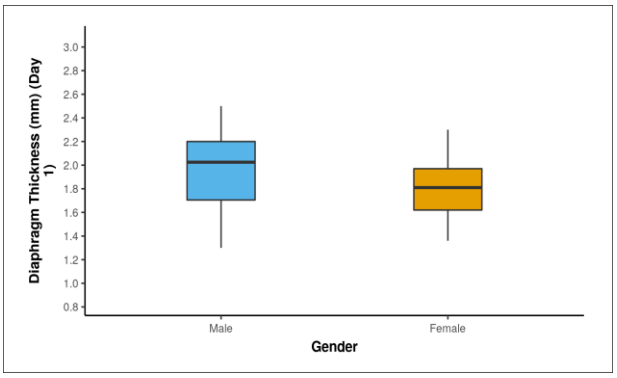


Figure 2: Association between gender and diaphragm thickness (mm) (day 1).

DISCUSSION

Principal findings

This cross-sectional study evaluated Day-1 diaphragmatic thickness in 60 critically ill Indian patients and examined its relationship with age and gender. Three principal findings emerged. First, diaphragmatic thickness varied significantly across the five age groups, with the lowest median values observed in the two oldest groups. Second, age demonstrated a moderate inverse correlation with diaphragmatic thickness. Third, male participants had greater mean diaphragmatic thickness than female participants. These findings suggest that demographic characteristics may be relevant when interpreting diaphragmatic ultrasound measurements in critical care. However, the observed relationships should be interpreted as associations within this study population rather than evidence of causal effects or established age and sex-specific reference ranges.

Age and diaphragmatic thickness

The inverse association between age and diaphragmatic thickness was one of the most important findings. Spearman's correlation coefficient was −0.42, and the univariable regression model estimated a reduction of 0.009 mm in thickness per additional year of age. The age-only model explained 15.2% of the observed variation in diaphragmatic thickness.

The age-group analysis provided a complementary perspective. Median thickness was relatively similar in the two youngest groups and was highest in the 41–50-year group, followed by a lower median in the 51–60-year group. The 61–70-year group had the lowest median thickness. However, the post-hoc analysis identified a statistically significant difference only between the 41–50- and 51–60-year groups. Therefore, the results do not establish that every successive increase in age is associated with a statistically significant reduction in thickness.

The observed pattern may be compatible with age-associated changes in skeletal muscle structure and respiratory muscle reserve. Ageing can be accompanied by changes in muscle mass, fibre characteristics, neuromuscular function and physical activity. Nevertheless, the present study did not directly measure these mechanisms and their contribution to the observed association remains hypothetical.

Importantly, evidence from healthy populations is not entirely consistent with the findings of the present study. Boon et al evaluated diaphragmatic ultrasound in 150 healthy subjects and reported that thickness and contractility were minimally affected by age or gender.[6] Similarly, van Doorn et al found no significant age-related change in end-expiratory thickness, maximal inspiratory thickness, or thickening ratio in healthy subjects.[7] These findings contrast with the inverse age–thickness association observed in our critically ill cohort.

The relatively younger age distribution compared to Western ICU cohorts may reflect demographic differences, delayed healthcare access among younger patients with severe infection, and the high prevalence of sepsis-related critical illness in low and middle-income countries.[8]

Several factors may explain this discrepancy. Healthy volunteers and critically ill patients differ in disease burden, physical activity, nutritional status, systemic inflammation, and exposure to treatments that may influence muscle structure. In addition, diaphragmatic thickness measured during acute illness may reflect both pre-existing muscle characteristics and illness-related changes. Differences in ultrasound technique, respiratory phase, body composition, and participant selection may also contribute to inconsistent findings between studies.[2,5,7]

Accordingly, the present results should not be interpreted as demonstrating that ageing invariably reduces diaphragmatic thickness in the general population. Rather, they suggest that age was associated with thickness in this particular critical care cohort and that the relationship merits further investigation.

Gender differences in diaphragmatic thickness

Male participants had a mean diaphragmatic thickness of 1.99±0.33 mm, compared with 1.81±0.27 mm among female participants. The unadjusted difference was 0.18 mm and was statistically significant. The corresponding univariable regression model estimated a 0.180-mm lower thickness in females, with a 95% confidence interval from −0.337 to −0.023 mm.

This finding is broadly consistent with evidence from healthy populations. Van Doorn et al reported greater end-expiratory and maximal inspiratory diaphragmatic thickness in men than in women, although age was not significantly associated with thickness in their study.[7] Oguri et al also investigated gender differences in diaphragmatic thickness among healthy young adults, providing further evidence that sex-related differences may be detectable depending on the measurement method and study population.[10]

A plausible explanation is the influence of differences in body size, skeletal muscle mass and overall body composition. However, the current study did not provide adjustment for height, weight, body mass index or other measures of body composition. It is therefore not possible to determine whether the observed gender difference reflects an independent association with sex or differences in these correlated characteristics.

A further consideration is that male participants were significantly older than female participants in this cohort. Because age was inversely associated with diaphragmatic thickness, this imbalance complicates interpretation of the unadjusted gender comparison. The observed higher mean thickness among males occurred despite their greater mean age, but the magnitude and direction of the independent sex association cannot be reliably determined without a multivariable model.

Future studies should assess the relationship between sex and diaphragmatic thickness after adjustment for age, body size, illness severity, nutritional status and relevant respiratory support variables. Until then, the present result should be interpreted as an unadjusted difference between male and female participants rather than an independent sex-specific effect.

Clinical relevance of diaphragmatic thickness in critical care

Diaphragmatic ultrasonography is useful because it permits bedside evaluation of respiratory muscle morphology and function without ionizing radiation. Measurement of diaphragmatic thickness may help identify structural changes, while thickening fraction and excursion provide complementary information regarding contraction and movement.[1,2,5,9]

Research in mechanically ventilated patients has shown that diaphragmatic thickness may change during ventilation and that changes in thickness can be associated with respiratory muscle activity and ventilatory support. Goligher et al demonstrated the feasibility and reproducibility of measuring diaphragmatic thickness in mechanically ventilated patients.[11] Subsequent work has also described heterogeneous patterns of thickness change during mechanical ventilation, emphasizing that a single measurement cannot fully characterize the dynamic behaviour of the diaphragm.[12]

The present study adds demographic observations from a critically ill Indian cohort. The inverse association between age and thickness suggests that age may be a relevant covariate in studies evaluating diaphragmatic morphology. Similarly, the observed difference between males and females suggests that demographic characteristics should be documented when comparing diaphragmatic measurements across patients or research populations. However, diaphragmatic thickness should not be used in isolation to diagnose diaphragmatic dysfunction. A thicker diaphragm does not necessarily imply better contractility, and a thinner diaphragm does not independently establish clinically significant weakness. Respiratory phase, ventilator settings, patient effort, fluid status and measurement technique can influence interpretation. Assessment of diaphragmatic function should therefore integrate thickness with appropriate functional measurements and the patient's clinical context.[2,5,9]

The study also does not establish a diagnostic threshold for diaphragmatic dysfunction or demonstrate an association between thickness and patient-centred outcomes such as duration of ventilation, weaning success, ICU length of stay or mortality. Such questions require dedicated analyses with appropriate clinical outcomes.

Interpretation of the statistical findings

The continuous-variable analysis identified a statistically significant inverse relationship between age and diaphragmatic thickness. The Spearman correlation coefficient of −0.42 suggests a moderate monotonic association, while the regression coefficient quantifies the estimated linear change in thickness per year of age.

The R2 value of 0.152 indicates that age alone explained a limited proportion of the observed variability. This is important because diaphragmatic thickness is likely to be influenced by multiple demographic, physiological, clinical and technical factors. The findings therefore support an association with age but do not imply that age is the predominant determinant of diaphragmatic thickness. Similarly, the gender-only regression model explained 8.4% of the observed variability. The statistically significant unadjusted difference should not be equated with independent explanatory value, particularly because age differed between the gender groups.

The significant Kruskal–Wallis test indicates that at least one age-group distribution differed from the others. It does not establish a uniformly decreasing trend across every age category. The post-hoc results reinforce this distinction because only the comparison between the 41–50- and 51–60-year groups reached statistical significance.

A multivariable linear regression model including age and sex simultaneously would help determine whether each association persists after adjustment for the other. Depending on the data available, further adjustment for body mass index, illness severity, diagnosis, nutritional status, and mechanical ventilation exposure could improve interpretability. Given the modest sample size of 60 participants, such modelling should remain parsimonious to avoid overfitting.

Implications for future research in Indian critical care populations

The results provide preliminary evidence that demographic factors may influence diaphragmatic thickness measurements in critically ill Indian patients. Further research should include larger, preferably multicentre cohorts with standardized ultrasound acquisition and a prespecified statistical analysis plan.

Studies should record anthropometric measurements, including height, weight and body mass index, as well as relevant clinical variables such as illness severity, diagnosis, nutritional status, ventilator settings and duration of ventilation. Serial measurements would help distinguish baseline differences from changes developing during critical illness. Future work should also examine whether age- and sex-related differences persist after adjustment for these variables and whether thickness measurements provide incremental information beyond diaphragmatic thickening fraction, excursion, and conventional clinical assessment.

The EXODUS consensus statement emphasizes the need for standardized acquisition methods and consistent reporting of diaphragmatic ultrasound-derived parameters.[2] Applying such standards across Indian critical care centres could improve comparability between studies and support the development of clinically meaningful reference distributions. Overall, the present findings should be considered hypothesis-generating. They support further investigation of demographic associations but do not establish population norms, independent predictors, or clinical thresholds.

Limitations

Small sample size (n=60) from a single centre limits generalizability. Cross-sectional analysis precludes causal inference and assessment of temporal changes. Age differences between genders and the absence of multivariable adjustment may have introduced confounding. Anthropometric factors, illness severity, nutritional status and ventilatory variables may have influenced diaphragmatic thickness. Ultrasound measurements may be affected by operator dependency and methodological variability. No healthy control group or assessment of clinical outcomes was available. Only one age-group pair showed a significant post-hoc difference, limiting conclusions regarding age-specific changes.

CONCLUSION

Diaphragmatic thickness was inversely associated with age and was greater in males than females among 60 critically ill Indian patients. Thickness decreased by an estimated 0.009 mm per year of age. However, potential confounding and the univariable analysis preclude conclusions regarding independent effects. Larger multicentre studies with standardized ultrasonography and multivariable adjustment are needed to validate these findings.

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