

Anatomical Variations of the Paranasal Sinuses and Nasal Cavity and their association with Radiologically Evident Sinus Disease on Computed Tomography

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ABSTRACT

Introduction: Sinonasal anatomical variations, frequently seen on paranasal sinus CT, can predispose disease by obstructing ventilation and mucociliary clearance. Their recognition is essential for accurate diagnosis and effective surgical planning. This study evaluated the prevalence of these variations in Nepalese patients and their associations with gender, ethnicity, and radiologically detected sinonasal disease.

Methods: This cross-sectional study retrospectively reviewed 348 non-contrast paranasal sinus CT scans performed at Bir hospital from November 2024 to May 2025. Variations assessed included deviated nasal septum (DNS), concha bullosa, agger nasi cells, uncinat process pneumatization, Haller cells, Onodi cells, paradoxically curved middle turbinate (PCMT), and sinus septations. Sinonasal disease was determined radiologically. Associations with gender, ethnicity, and disease were analyzed using Chi-square or Fisher's exact tests ($p < 0.05$ significant).

Results: The mean age of patients was 39.9 ± 18.4 years; 180 (51.7%) were male. The most common variation was DNS at 87.9%, followed by agger nasi cells (38.7%), concha bullosa (26.4%), sinus septations (25.3%), and Haller cells (16.3%). Radiological sinonasal disease was present in 217 patients (62.4%). No significant differences in anatomical variations were found by gender or ethnicity (all $p > 0.05$). Significant associations with disease included uncinat process pneumatization, concha bullosa, agger nasi cells, and Haller cells. DNS was paradoxically more prevalent in patients without disease, likely due to referral bias.

Conclusions: Sinonasal anatomical variations are common in the Nepalese population and several variants particularly those involving the Osteomeatal complex are significantly associated with radiologically evident sinus disease.

Keywords: Anatomical Variation; Computed Tomography; Nasal cavity; Paranasal Sinuses; Sinusitis.

INTRODUCTION

The paranasal sinuses are air-filled extensions of the nasal cavity that develop through pneumatization, gradually expanding within surrounding bones.¹ Anatomical variations often occur during this process, especially in the ethmoid labyrinth, and can influence sinonasal physiology and disease patterns.^{2,3} Computed tomography of the paranasal sinuses is the preferred imaging modality for evaluating sinonasal anatomy, detecting variants, achieving accurate diagnosis, facilitating optimal surgical planning, and minimizing intraoperative complications.^{4,5}

Varying prevalence and clinical significance of sinonasal

anatomical variations across populations have been reported, likely influenced by ethnic, genetic, and environmental factors.⁶⁻¹⁰ In Nepal, research remains limited, with existing studies constrained by small sample sizes (none exceeding 150 participants).¹¹⁻¹³ Given Nepal's ethnic diversity and geographical variation, larger-scale studies are needed to clarify prevalence and associations with sinonasal pathology. This study aimed to assess the frequency of sinonasal anatomical variations on CT in Nepalese patients and their associations with radiologically evident sinonasal disease.

METHODS

This single-center observational cross-sectional study was conducted at Department of Radiodiagnosis, Bir Hospital. It retrospectively reviewed computed tomography (CT) scans of the paranasal sinuses (PNS) performed over a six-month period (November 2024 to May 2025) in patients referred from the Department of Otorhinolaryngology (ENT) for evaluation of sinonasal diseases or related conditions. The study population included all patients who underwent CT PNS during the defined period and whose Digital Imaging and Communications in Medicine (DICOM) images were available in the institutional picture archiving and communication system (PACS). Patients aged ≥ 15 years were included, as most paranasal sinuses, including sphenoid and frontal sinuses, achieve near-adult morphology by this age, ensuring more stable anatomical assessment and minimizing confounding effects from ongoing sinus development. Exclusion criteria included prior sinonasal surgery, known sinonasal tumors or malignancies, craniofacial trauma, congenital anomalies, or deformities affecting normal sinonasal anatomy, or CT scans of poor quality or with artifacts precluding accurate assessment.

Taking reference of the Study by Sharma et al, 16 which had prevalence of 68.5% of anatomical variation on CT scan, sample size of 334 was calculated using this formula: $n = (Z^2 * P * (1 - P)) / E^2$, where Prevalence (P): 68.5% (0.685)16, Margin of Error (E): 5% (0.05), Confidence Level: 95%, Z-value for 95% confidence: 1.96.

Ethical approval was obtained from the Institutional Review Board (IRB) of NAMS (Reference number: 1549/2081-2082, dated 2082/2/5) with a waiver of informed consent, as this was a retrospective study. CT PNS images acquired on the Philips Ingenuity 128-slice CT scanner at Bir Hospital within the past six months and stored in the local drive were retrieved and reviewed using RadiAnt DICOM Viewer (version 2025.1). CT images of patients meeting all inclusion criteria and exclusion criteria were thoroughly assessed by all authors, and the final entries were recorded in a predesigned proforma. All DICOM images were de-identified and stored for future reference if required.

The completed proformas were reviewed for accuracy and completeness of data. Data were then entered into Microsoft Excel 2021 with password protection, accessible only to the investigators. Statistical analysis was performed using the Statistical Package for the Social Sciences (IBM SPSS Statistics 29.0.2). Descriptive statistics were summarized as frequencies, percentages, means, and standard deviations (SD). Associations between categorical variables were evaluated using the Chi-square test or Fisher's exact test if required (when number of observations < 5) and a p-value < 0.05 was considered statistically significant. Ethnicity was assigned based on

the patient's surname, a commonly used proxy in Nepalese epidemiological studies. For ambiguous surnames or those not clearly corresponding to a recognized ethnic group, ethnicity was confirmed by contacting the patient or their family by phone. When contact could not be established, the individual was categorized under "Others." This group included diverse populations such as Tharus, Chepang, Muslims, and other minority or unclassified caste groups.

RESULTS

Table 1. Demographic profile of the study group.

Characteristic	Category	Frequency	Percent (%)
Ethnicity	Brahmin/Chhetri	175	50.3
	Janajati	55	15.8
	Newar	52	14.9
	Madhesi	29	8.3
	Dalits	25	7.2
	Others	12	3.4
	Total	348	100
Age Group (Years)	15–30	146	42
	31–45	81	23.2
	45–60	59	17
	>60	62	17.8
	Total	348	100
Gender	Male	180	51.7
	Female	168	48.3
	Total	348	100

As seen in Table 1, the study included 348 participants with complete data. The Brahmin/Chhetri group was the largest ethnic category, followed by Janajati, Newar, Madhesi, Dalits, and Others. Age distribution was highest in the 15–30 years group, followed by 31–45, >60, and 45–60 years. Gender was nearly balanced (51.7% male, 48.3% female).

As seen in Table 2, Deviated nasal septum (DNS) was the most common variation, followed by agger nasi cells, concha bullosa, sinus septations, and sphenoethmoidal (Onodi) cells. Less frequent findings included Haller cells, uncinate process pneumatization, paradoxically curved middle turbinate, supraorbital ethmoid air cells, and septal pneumatization.

Table 2. Frequency distribution of anatomical variations.

Anatomical Variations	N	%
Septal pneumatization (SP)	21	6
Uncinate process pneumatization	53	15.20
– Right	30	8.60
– Left	2	0.60
– Bilateral	21	6
Deviated nasal septum (DNS)		
– C shaped	128	36.8
– Reverse C	130	37.4
– S shaped	22	6.3
– Reverse S	26	7.5
Total DNS	306	87.0
Concha Bullosa		
– Right	35	10.10
– Left	21	6
– Bilateral	36	10.40
Total Concha Bullosa	92	26.40
Agger nasi cell (AN)	135	38.70
Infraorbital Haller Cell (HC)	57	16.30
Sphenoethmoidal Onodi Cells (OC)	71	21
Paradoxically Curved Middle Turbinate (PCMT)	33	9.50
Total Septations in sinuses	88	25.30
Supraorbital ethmoid air cells	25	7
Presence of sinonasal disease	217	62.4

Table 3. Frequency distribution of anatomical Variations and association with Gender.

Anatomical Variation	Females (n=168) N (%)	Males (n=180) N (%)	Total (n=348) N (%)	p-value
Septal pneumatization (SP)	11 (6.55)	10 (5.56)	21 (6.03)	0.698
Uncinate process pneumatization	27 (16.07)	27 (15.00)	54 (15.52)	0.783
Deviated nasal septum (DNS)	146 (86.90)	160 (88.89)	306 (87.93)	0.057
Concha Bullosa	53 (31.55)	39 (21.67)	92 (26.44)	0.052
Agger nasi cell (AN)	64 (38.10)	71 (39.44)	135 (38.79)	0.796
Infraorbital Haller Cell (HC)	33 (19.64)	24 (13.33)	57 (16.38)	0.112
Sphenoethmoidal Onodi Cells (OC)	37 (22.02)	34 (18.89)	71 (20.40)	0.468
Paradoxically Curved Middle Turbinate (PCMT)	13 (7.74)	20 (11.11)	33 (9.48)	0.283

When stratified by gender, the frequency of anatomical variations differed between males and females; however, these differences were not statistically significant for any variation ($p > 0.05$, Chi-square test, Table 4), indicating that gender did not have a measurable effect on the distribution of the observed anatomical variants.

Table 4. Frequency distribution of anatomical Variations and association with Ethnicity

Condition	Brahmin/ Chhetri (N = 175) N (%)	Janajati (N = 55) N (%)	Newar (N = 52) N (%)	Madhesi (N = 29) N (%)	Dalits (N = 25) N (%)	Others (N = 12) N (%)	P-value (Fisher's Exact)
Septal Pneumatization (SP) Present	12 (6.9)	3 (5.5)	6 (11.5)	0	0	0	0.192
Any Uncinate Process Pneumatization	27 (15.4)	6 (10.9)	10 (19.2)	8 (27.6)	2 (8.0)	1 (8.3)	0.288
Any Deviated Nasal Septum (DNS)	156 (89.1)	48 (87.3)	44 (84.6)	26 (89.7)	22 (88.0)	10 (83.3)	0.951
Any Concha Bullosa	47 (26.9)	16 (29.1)	15 (28.8)	5 (17.2)	7 (28.0)	2 (16.7)	0.822
Haller Cell Present	30 (17.1)	8 (14.5)	10 (19.2)	5 (17.2)	4 (16.0)	0	0.729
Agger Nasi Cell Present	70 (40.0)	21 (38.2)	25 (48.1)	11 (37.9)	4 (16.0)	4 (33.3)	0.179
PCMT Present	21 (12.0)	2 (3.6)	4 (7.7)	4 (13.8)	2 (8.0)	0	0.343
Onodi Cell Present	38 (21.7)	12 (21.8)	12 (23.1)	6 (20.7)	1 (4.0)	2 (16.7)	0.457
Sinonasal Disease Present	108 (61.7)	36 (65.5)	31 (59.6)	17 (58.6)	19 (76.0)	6 (50.0)	0.652
Pneumosinus Dilatans Present	13 (7.4)	4 (7.3)	6 (11.5)	6 (20.7)	2 (8.0)	1 (8.3)	0.515

As shown in Table 4, the distribution of sinonasal anatomical variations and sinonasal disease was compared across ethnic groups using Fisher's exact test (due to small expected cell counts). No statistically significant differences were observed for any variant or condition (all $p > 0.05$). Deviated nasal septum (DNS) remained highly prevalent across all groups (83.3–89.7%). Other variations, including agger nasi cells, concha bullosa, Haller cells, Onodi cells, uncinat process pneumatization, PCMT, septal pneumatization, and pneumosinus dilatans,

showed no ethnic-specific patterns. Sinonasal disease prevalence ranged from 50.0% (Others) to 76.0% (Dalits), with no significant variation by ethnicity.

This indicates that sinonasal anatomical variations are similarly distributed across ethnic groups in this Nepalese cohort, with no evidence of ethnic differences in prevalence.

Table 5. Frequency distribution of Anatomical Variations and Association with Sinus Diseases

Variation	Absence of sinonasal disease (N=131) N (%)	Presence of sinonasal disease (N=217) N (%)	X ² value	P -value
Septal pneumatization (SP)	6 (4.6%)	15 (6.9)	0.784	0.376
Uncinate process pneumatization	13 (9.9%)	41 (18.9)	5.014	0.025
Deviated nasal septum	124 (94.6%)	182 (83.8)	8.954	0.003
Concha Bullosa	26 (19.8%)	66 (30.4)	4.691	0.03
Agger nasi cell (AN)	23 (17.6%)	112 (51.6)	39.900	<0.001
Infraorbital Haller Cell (HC)	9 (6.9%)	48 (22.1)	13.869	<0.001
Sphenoethmoidal Onodi Cells (OC)	31 (23.7%)	40 (18.4)	1.376	0.241
Paradoxically Curved Middle turbinate (PCMT)	11 (8.4%)	22 (10.1)	0.289	0.591
Pneumosinus dilatans	11 (8.4%)	19 (8.8)	0.382	0.826
Septations in sinuses	32 (24.4%)	58 (26.7)	2.454	0.783
Supraorbital ethmoid air cells	12 (9.1%)	13 (5.9)	1.231	0.267

As shown in Table 5, several anatomical variations were significantly associated with radiologically confirmed sinonasal disease. Uncinate process pneumatization (18.9% vs. 9.9%, $p = 0.025$), concha bullosa (30.4% vs. 19.8%, $p = 0.030$), agger nasi cells (51.6% vs. 17.6%, $p < 0.001$), and infraorbital (Haller) cells (22.1% vs. 6.9%, $p < 0.001$) were significantly more prevalent in patients with sinonasal disease compared to those without. In contrast, deviated nasal septum was paradoxically more common in patients without disease (94.6% vs. 83.8%, $p = 0.003$). No significant associations were observed for septal pneumatization, sphenoethmoidal (Onodi) cells, paradoxically curved middle turbinate (PCMT), Pneumosinus dilatans, sinus septations, or supraorbital ethmoid air cells (all $p > 0.05$).

DISCUSSION

This study evaluated anatomical variations of the nasal cavity and paranasal sinuses in 348 patients using computed tomography (CT) and examined their association with gender, ethnicity, and sinonasal disease. The prevalence of anatomical variations was highest among middle-aged individuals, with a mean age of 39.86 ± 18.39 years. This finding is consistent with the findings of previous studies.^{11,15,17} The higher prevalence in this age group may be attributed to their active working lifestyle and greater health awareness, leading to increased healthcare-seeking behavior and hospital visits for evaluation and treatment.

The most prevalent variation was deviated nasal septum (DNS), present in 87.9% of patients, followed by agger

nasi cells (38.7%) and concha bullosa (26.4%). Other variations, such as septations within paranasal sinuses (25.3%), sphenoethmoidal (Onodi) cells (20.4%), and infraorbital (Haller) cells (16.3%), were also frequently observed, while supraorbital ethmoid air cells (7.0%) was less common. The current study found a high prevalence of deviated nasal septum (DNS) at 87.9%, which is notably higher than rates reported by Pokhrel et al. (73.1%),¹¹ Shrestha et al. (64.5%),¹⁷ and Nautiyal et al. (21.9%),¹⁸ but comparable to the 83.4% reported by Devaraja et al.¹⁹ and markedly higher than the 20.18% observed by Onwuchekwa et al.²⁰ This variation across studies may be attributed to ethnic differences, variations in diagnostic criteria, and, importantly, differences in study population characteristics. Papadopoulou et al.¹⁶ also identified DNS as one of the most common anatomical variations in their systematic review of 18,118 patients, supporting its widespread occurrence. The high rate in our cohort aligns with broader epidemiological evidence that septal deviation is among the most frequent anatomical variants worldwide,²¹ with similar trends reported by Sharma BN et al. (68.2%) and Shpilberg KA et al. (98.4%).^{7,14}

Agger nasi cells were identified in 38.7% of our patients, which is lower than the prevalence of 75.8% reported by Yadav et al.¹³ and 83.3% by Shpilberg et al.⁷ but falls within the range described by Al-Abri et al. (49%),⁹ Pokhrel et al. (59.3%),¹ and Kantarci et al.,²² who also reported similar rates. Concha bullosa was observed in 26.4% of our cases, comparable to Pokhrel et al. (24.6%),¹¹ Shrestha et al. (19.7%),¹⁷ and Kayalioglu et al. (28.9%),²³ but lower than Devaraja et al. (49%),¹⁹ Yadav et al. (35.9%),¹³ and Maru et al. (42.6%).²⁴ Earlier studies such as that by Messerklinger

reported a much lower prevalence of concha bullosa (10–15%),²⁵ likely due to the lack of CT imaging at the time, which limited the accurate detection of paranasal sinus anatomical variations.

In terms of less common variations, our prevalence of infraorbital (Haller) cells (16.3%) is comparable to Yadav et al. (15.7%) and slightly lower than Devaraja et al. (39%) and Nautiyal et al. (22.91%).^{13,18,19} Onodi cells were present in 20.4% of our cohort, consistent with Onwuchekwa et al. (18%) and Yadav et al. (18.8%).^{13,20} The observed prevalence of septal pneumatization (6.0%) in our study is in line with prior literature describing these as rare findings.^{16,19}

The association between sinonasal anatomical variations and the presence of sinonasal disease was evaluated in a total of 348 patients, of whom 131 had no evidence of disease and 217 had radiologically confirmed pathology. Several anatomical variants demonstrated a statistically significant association with disease, suggesting a potential role in predisposing individuals to chronic inflammation, while others appeared incidental.

Uncinate process pneumatization was significantly more prevalent in patients with disease (18.9%) than in those without (9.9%) ($\chi^2 = 5.014$, $p = 0.025$). This association may reflect its anatomical impact on the osteomeatal complex, as expansion of the pneumatized uncinate can narrow the ethmoid infundibulum, impairing drainage of the maxillary and anterior ethmoid sinuses, and thereby promoting mucus stasis and recurrent infection.

Concha bullosa was present in 30.4% of patients with disease compared to 19.8% without disease ($\chi^2 = 4.691$, $p = 0.030$), likely due to its obstructive effect on the middle meatus and potential to compress adjacent structures involved in sinus ventilation. This finding is inconsistent with multiple studies, including Pokhrel et al.¹¹

Agger nasi cells were significantly more common in patients with disease (51.6%) than in those without (17.6%) ($\chi^2 = 39.900$, $p < 0.001$), consistent with their tendency to encroach upon the frontal recess and compromise frontal sinus outflow, making them plausible contributors to chronic frontal sinusitis.

Haller cells were also significantly associated with disease (22.1% in diseased vs. 6.9% in disease-free patients, $\chi^2 = 13.869$, $p < 0.001$), likely because their infraorbital location can compress the maxillary sinus ostium, particularly when large, impeding drainage and increasing susceptibility to infection.

Overall, anatomical variants that directly compromise the osteomeatal complex or sinus ostia may indeed predispose patients to pathology by impairing mucociliary clearance or narrowing critical drainage pathways,^{26,27} contrary to the findings of Shpilberg et al.,⁷ who reported no significant relationship between most variants and sinonasal disease,

possibly due to differences in study design, population characteristics, or imaging interpretation criteria.

In contrast, several other variations did not show a statistically significant association with disease. Sphenoidal (Onodi) cells were present in 23.7% of the non-diseased group and 18.4% of the diseased group ($p = 0.241$), indicating no meaningful link, which aligns with the understanding that while Onodi cells are surgically significant due to their proximity to the optic nerve, they rarely obstruct functional drainage pathways unless exceptionally developed. Paradoxically curved middle turbinate showed nearly identical prevalence in both groups (8.4% vs. 10.1%, $p = 0.591$), suggesting that this anatomical variant, despite its potential to narrow the middle meatus, may not independently contribute to disease pathogenesis in most cases. Septal pneumatization showed no significant association with sinonasal disease ($p = 0.376$) and given its low prevalence and minimal anatomical impact on airflow or sinus drainage, it is likely a benign or incidental finding. Pneumosinus dilatans, septations within sinuses and supraorbital ethmoid air cells all demonstrated no significant association with disease ($p > 0.05$), which is consistent with their classification as rare or functionally neutral variants that do not typically interfere with mucociliary clearance or sinus ventilation. The lack of association for these findings supports the notion that not all anatomical differences confer disease risk, and their identification should be interpreted cautiously in the absence of symptoms. Deviated nasal septum, observed in 83.8% of diseased individuals compared to 94.6% of those without disease, was also significantly associated ($p = 0.003$), which may seem counterintuitive at first; however, this finding must be interpreted within the context of the study population. Patients were referred from the ENT department for CT paranasal sinuses, often for evaluation of either DNS or sinonasal disease, or both. As a result, individuals with prominent DNS but no active sinus inflammation may be overrepresented in the “no disease” group due to routine imaging for septal deviation, such as pre-surgical assessment for septoplasty. Furthermore, in some cases, DNS may be a secondary finding rather than a primary driver of pathology, particularly when coexisting with more obstructive variants like concha bullosa or agger nasi cells. Thus, the observed lower frequency of DNS among patients with sinonasal disease does not imply that it lacks pathogenic potential but rather reflects the selection criteria of a referral-based population. Thus, while DNS is a recognized contributor to chronic rhinosinusitis in the general population, its lower frequency in this study’s diseased group reflects the clinical context of a tertiary care referral population rather than a true lack of pathogenicity.^{11–13,19,26,27}

When stratified by gender, variation frequencies differed between males and females; however, these differences were not statistically significant ($p > 0.05$, Chi-square test,

Table 3), suggesting that gender does not significantly influence the distribution of sinonasal anatomical variants. The finding is consistent with studies by Tiwari et al. and Bora et al.^{28,29} The distribution of sinonasal anatomical variations across ethnic groups revealed no statistically significant differences, despite some numerical trends. Uncinate process pneumatization was more frequent in the Madhesi group (27.6%) and agger nasi cells less common in Dalits (16.0%), but these differences did not reach significance (Fisher's Exact Test, all $p > 0.05$), likely due to small sample sizes, particularly in the "Others" group ($n = 12$) and limited statistical power. The overrepresentation of Brahmin/Chhetri individuals (50.3%) may also affect generalizability. While craniofacial variation can differ by ethnicity, this study suggests that most anatomical variants are similarly distributed across ethnic groups in this population. Observed trends may reflect chance or sampling variability rather than true biological differences. Our findings emphasize that clinical assessment should be guided by individual sinonasal anatomy rather than ethnicity, in agreement with the limited studies available, which also found no significant ethnic variations.^{30,31} However, larger multi-ethnic studies are needed to confirm whether subtle ethnic-based variations exist and their potential relevance in surgical planning.

Overall, the high prevalence of anatomical variations in our cohort, many of which were significantly associated with sinonasal disease, emphasizes the importance of preoperative CT imaging for detailed anatomical mapping. Variations in prevalence rates across studies highlight the influence of population characteristics, imaging protocols, and diagnostic definitions. Clinically, identifying these variants aids in surgical planning, reduces the risk of intraoperative complications, and contributes to more effective management of sinonasal disorders.

The strength of this study lies in the systematic evaluation of multiple sinonasal anatomical variations using standardized CT imaging protocols and assessment by experienced radiologists, which enhances the accuracy and reliability of anatomical identification. The clear categorization of sinonasal disease status allowed for robust statistical analysis and meaningful interpretation

of associations. It was conducted at a single center with a retrospective design, which may affect generalizability and introduce selection bias, particularly as patients were referred from the ENT department, often due to existing symptoms or preoperative evaluation, potentially inflating the prevalence of certain anatomical variants. The cohort showed overrepresentation of the Brahmin/Chhetri group (50.3%), while minority ethnic groups were underrepresented, particularly the "Others" category (3.4%), which included diverse populations such as Tharus, Chepang, Muslims, and unclassified castes. Ethnicity was determined primarily by surname, a practical but imperfect proxy, with confirmation attempted via phone contact when uncertain. However, in cases where contact could not be established, individuals were classified as "Others," increasing heterogeneity in this subgroup and potentially reducing the power to detect meaningful ethnic differences. Additionally, the lack of endoscopic or surgical correlation in all cases may affect the accuracy of disease classification and anatomical interpretation. Despite these constraints, the consistent and statistically significant associations observed between obstructive variants such as concha bullosa, agger nasi cells, Haller cells, and uncinate process pneumatization with sinonasal disease support their clinical relevance. These findings underscore that not all anatomical variations are functionally equivalent; rather, those that compromise the osteomeatal complex appear to play a meaningful role in disease pathogenesis.

CONCLUSIONS

This study shows that sinonasal anatomical variations are highly prevalent in the Nepalese population and several are significantly associated with radiologically confirmed sinonasal disease. By providing a comprehensive assessment of sinonasal anatomy in a previously underrepresented population, this study contributes to a better understanding of regional anatomical variation and supports the need for individualized, anatomy-based clinical evaluation in routine otolaryngological practice.

Conflict of interest: None

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