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Research Article

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Volumetric Analysis of the Onodi Cell in Relation to Perisphenoidal Anatomical Variations

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Abstract

Objective: This study aimed to evaluate the presence and volume of the Onodi cell (OC) and to investigate its anatomical relationship with surgically important neighbouring structures such as the optic canal (OCa), internal carotid canal (CC), and vidian canal (VC), focusing on canal types and bony dehiscence.

Materials and Methods: High-resolution computed tomography (CT) scans of 110 patients were analysed, with 220 sphenoid sinus sides evaluated. Onodi cells were identified and classified based on their location. Their volumes were measured using manual segmentation in the OSIRIX software. The types of OCa, CC, and VC, as well as the presence or absence of bony dehiscence in these canals, were radiologically assessed. Statistical analyses were performed to evaluate the relationships between the OC volume, canal configurations and dehiscence status.

Results: The OC was present in 30% of cases. Its presence was significantly associated with higher-risk OCa types (Types 3 and 4) and with optic nerve dehiscence. Onodi cell volume was significantly greater in patients with type 3 OCa and type 3 CC. Internal carotid artery and VC dehiscence were also more common in cases with larger OC volumes.

Conclusion: This study is one of the few to quantitatively assess OC volume and its associations with nearby critical neurovascular structures. The findings emphasise that both the presence and size of the OC are important anatomical considerations that should be carefully evaluated preoperatively using high-resolution CT to reduce the risk of complications in endoscopic sinus surgery.

Keywords Onodi cell · optic canal · carotid canal · vidian canal · volumetric analysis · computed tomography

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INTRODUCTION

The complex and highly variable anatomical structure of the paranasal sinuses necessitates thorough preoperative evaluation, particularly in endoscopic surgical procedures. In this context, the Onodi cell (OC), which is the most posterior variant of the posterior ethmoidal air cells, holds special importance due to its superolateral extension to the sphenoid sinus and its close proximity to critical neurovascular structures such as the optic nerve (ON) and the internal carotid artery (ICA). The increasing use of endoscopic sinus surgery mandates the prior identification of anatomical variations that may be encountered during surgery.

The reported prevalence of OC varies widely (21.2%–65.4%) depending on the imaging methods used, evaluation criteria, and the population studied (1-4). Advanced imaging techniques such as high-resolution computed tomography (CT) and cone-beam CT (CBCT) allow for more accurate detection of this anatomical variation (3, 5).

The presence of an OC has been associated with anatomical variations such as bulging or dehiscence of the ON into the sphenoid sinus (1, 6). This increases the risk of ON injury during endoscopic sinus surgery and may lead to surgical complications. Similarly, the close anatomical relationship between the OC and the ICA may raise the risk of carotid canal (CC) dehiscence (7). Furthermore, the presence of an OC can influence the pneumatization patterns of the sphenoid sinus and the number of sphenoid septa, which may complicate surgical access and increase the risk of complications. Therefore, a detailed evaluation of the presence and morphological characteristics of the OC, along with its relationship to adjacent structures, plays a critical role in surgical planning.

This study aimed to evaluate the presence and volumetric characteristics of the OC and its relationship with surgically critical structures such as the optic canal (OCa), CC, and vidian canal (VC). Additionally, the statistical association between the volume of the OC and the presence of dehiscence in these structures will be analysed. The findings are expected to contribute to a more accurate prediction of potential surgical risks in preoperative radiological evaluations and to minimise possible complications in endoscopic sinus surgery.

MATERIALS AND METHODS

Study design and sample selection

We conducted a retrospective cross-sectional study by analysing paranasal CT images obtained from a tertiary care centre between January 2021 and December 2021. The study was approved by the Hitit University Faculty of Medicine Clinical Research Ethics Committee (Date: 31.03.2022, No: 2022-24) and carried out in accordance with the principles of the Declaration of Helsinki.

High-resolution CT scans of 110 patients were retrospectively evaluated in this study. The right and left sphenoid sinuses of each patient were assessed separately, resulting in 220 hemisphenoids. Patients were included if their CT scans had sufficient image quality, contained axial, coronal, and sagittal sections, and demonstrated normal paranasal sinus anatomy. Patients with a history of sinonasal trauma or prior sinonasal surgery, those with nasal polyposis, benign or malignant tumours in the sinonasal region, or scans containing significant imaging artefacts that hindered accurate evaluation were excluded from the study.

Imaging method and evaluation process

High-resolution CT images were obtained using a multi-detector computed tomography (MDCT) scanner with a slice thickness of 1 mm. Images were evaluated in the DICOM format using OSIRIX software (Pixmeo Sàrl, Geneva, Switzerland). Assessments were performed by an experienced radiologist and confirmed by two authors for consensus. OC was defined as a posterior ethmoidal cell located superior, superolateral, or lateral to the sphenoid sinus and evaluated in three planes (axial, coronal, and sagittal).

Each side of the sphenoid sinus was evaluated separately for each patient. First, the presence of an OC was identified, and those found were classified according to their location as follows (1, 8):

Type 1: Located superior to the sphenoid sinus

Type 2: Located superolateral to the sphenoid sinus

Type 3: Located lateral to the sphenoid sinus

In the sides with an identified OC, the following anatomical structures were evaluated radiologically. Loss of continuity in the canal wall, marked thinning, or absence of the bony cortex was accepted as dehiscence.

Optic canal types (9, 10)**:**

Type 1: The canal courses within the bone, distant from the sphenoid sinus

Type 2: The canal is adjacent to the lateral wall of the sphenoid sinus.

Type 3: The canal is surrounded by the sphenoid sinus cavity.

Type 4: The canal protrudes superolaterally into the sinus wall

In addition, the presence or absence of ON dehiscence (loss of bony continuity) was recorded for each optic canal.

Carotid canal types (11)**:**

Type 1: Extrasinusoidal, with no relation to the sphenoid sinus

Type 2: In contact with the sphenoid sinus wall

Type 3: Protrusion into the sphenoid sinus cavity

The presence or absence of ICA dehiscence was also recorded.

Vidian canal types (12)**:**

Type 1: Extrasinusoidal

Type 2: In contact with the sphenoid sinus wall

Type 3: Located within the sphenoid sinus

Similarly, VC dehiscence (present/absent) was also evaluated. The radiological examples of OC types, associated optic canal variations and dehiscences, as well as CC configurations and dehiscence, are illustrated in Figure 1.

Finally, in cases where an OC was identified, its volume was calculated using the ROI volume calculator tool in the OSIRIX software. Manual regions of interest (ROIs) were drawn on each coronal slice to delineate the boundaries of the OC. These ROIs were then combined to generate a three-dimensional reconstruction of the cell. The segmentation process and volumetric reconstruction are demonstrated in Figure 2. The volumetric measurements were recorded in cubic centimetres (cm^3), and statistical analyses were conducted to assess the relationships between the OC volume and the types of OCa, CC, and VC as well as the presence of dehiscence. Based on the obtained data, the relationship between OC volumes and the types of OCa, CC, and VC, as well as the possible differences according to the presence of dehiscence in these structures, were statistically analysed.

Statistical analysis

All statistical analyses were performed using SPSS software (IBM Corp., Armonk, NY, USA). Descriptive statistics are presented as mean±standard deviation, median (min–max), frequency, and percentage. Normality was assessed using the Shapiro–Wilk test. The relationships between the categorical variables were analysed using the chi-square test. Differences between the volumetric data and the presence of dehiscence or canal types were analysed using Student's t-test, Mann-Whitney U test, or one-way ANOVA (with post hoc Tukey test). A p-value <0.05 was considered statistically significant.

RESULTS

A total of 220 sphenoid sinus sides from 110 patients were statistically analysed. Of the patients, 45.5% (n=50) were male and 54.5% (n=60) were female. The mean age was 37.82±15.66 years (range: 17–82). Among the 220 evaluated sphenoid sinus sides, OC was present in 66 sides (30%) and absent in 154 sides (70%). Descriptive statistics regarding the prevalence, types, and volumes of OCs are presented in Table 1.

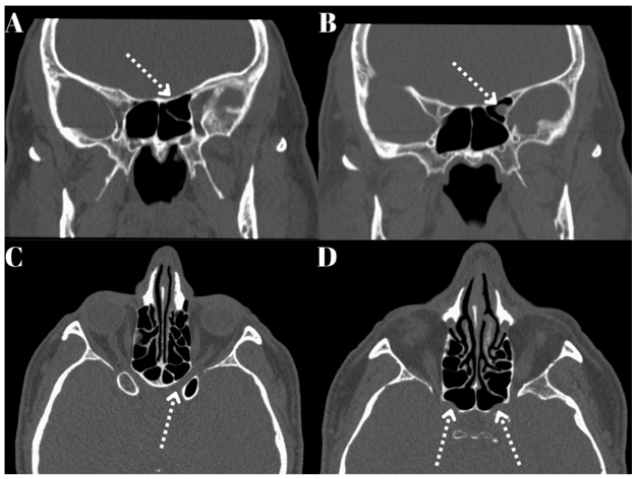


Figure 1. Radiological examples of the Onodi cell and related anatomical variations.

A. Coronal CT image showing a superolaterally located Type 2 Onodi cell (arrow) **B.** Coronal CT image showing a type 4 optic canal coursing through the Onodi cell, accompanied by optic canal dehiscence (arrow) **C.** Axial CT image depicting a type 4 optic canal traversing the Onodi cell on the left side (arrow) **D.** Bilateral type 3 carotid canals protruding into the sphenoid sinus cavity with visible dehiscence (arrows).

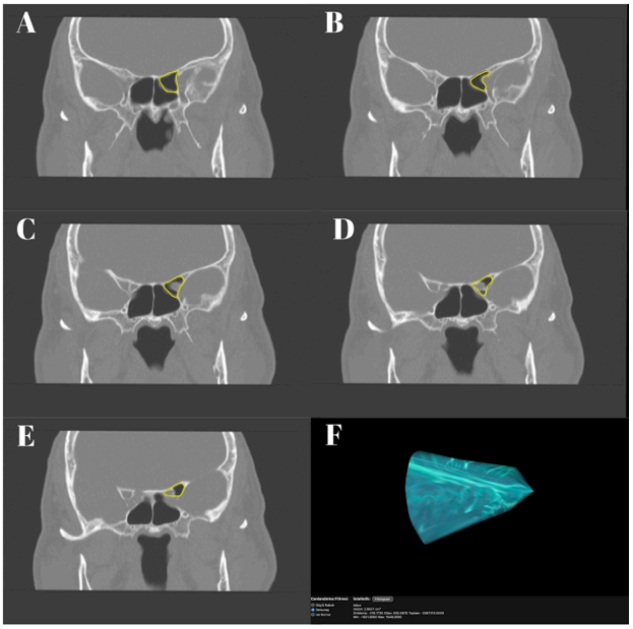


Figure 2. Segmentation and volumetric reconstruction of the Onodi cell.
A-E. Sequential coronal CT slices showing the Onodi cell boundaries manually marked as regions of interest (ROIs). Each slice represents a different level, demonstrating the continuity and extent of the Onodi cell F. Three-dimensional reconstruction image generated by combining the ROIs across all slices, illustrating the calculated volume of the Onodi cell.

Table 1. Descriptive statistics for the incidence, cell types, and volumes of Onodi cells

Onodi cells	n	%
Types		
No	154	70
Type 1	28	12.7
Type 2	22	10
Type 3	16	7.3
	Mean±SD	**min-max**
Volume	1.32±0.63	0.33-2.73

Relationship between OC presence and other anatomical structures

Statistical findings regarding the association between the presence of OC and craniofacial anatomical structures and dehiscence are presented in Table 2.

There was a statistically significant relationship between the presence of OC and OCa types (p=0.001). Type 3 (18.2%) and Type 4 (24.2%) OCa were more frequently observed in the OC-positive group, whereas Type 1 (54.5%) was more common in the OC-negative group. A significant association was also found between the presence of OC and ON dehiscence (p=0.028), with ON dehiscence being more frequent in the OC-positive group (36.4%).

No significant difference was observed between OC presence and CC types (p=0.137). However, a statistically significant relationship was found between OC presence and ICA dehiscence (p=0.022); ICA dehiscence was more common in the OC-positive group (27.3%).

There was no significant difference between OC presence and VC types (p=0.241), nor was there a significant association between OC presence and VC dehiscence (p=0.949).

Relationship between OC volume and other anatomical structures

The statistical comparison of OC volumes among different OCa, CC, and VC types is presented in Table 3. Statistical findings comparing OC volumes with the presence or absence of dehiscence in the craniofacial anatomical structures are provided in Table 4.

OC volumes differed significantly among the various OCa types (p=0.014). According to post-hoc test results, the mean volume in Type 3 was significantly higher than in Type 1 and Type 4 (p=0.012 and p=0.018, respectively). No significant differences were observed between the other groups (p>0.05). There was no statistically significant difference in OC volume between the ON dehiscence-positive and -negative groups (p=0.462).

OC volumes also varied significantly across different CC types (p=0.002). Post-hoc analyses revealed that the mean volume

Table 2. Relationship between the presence of the Onodi cell and craniofacial anatomical structures and dehiscences

		Onodi cells			
		No	**Yes**	**Total**	
		n=154 (%)	**n=66 (%)**	**n=200 (%)**	**p values**
Optic canal	Type 1	84 (54.5)	18 (27.3)	102 (46.4)	
	Type 2	38 (24.7)	20 (30.3)	58 (26.4)	
	Type 3	10 (6.5)	12 (18.2)	22 (10)	
	Type 4	22 (14.3)	16 (24.2)	38 (17.3)	**0.001**[a]
Optic canal dehiscence	No	120 (77.9)	42 (63.6)	162 (73.6)	
	Yes	34 (22.1)	24 (36.4)	58 (26.4)	**0.028**[a]
Carotid canal	Type 1	60 (39)	22 (33.3)	82 (37.3)	
	Type 2	66 (42.9)	24 (36.4)	90 (40.9)	
	Type 3	28 (18.2)	20 (30.3)	48 (21.8)	0.137[a]
Carotid canal dehiscence	No	132 (85.7)	48 (72.7)	180 (81.8)	
	Yes	22 (14.3)	18 (27.3)	40 (18.2)	**0.022**[a]
Vidian canal	Type 1	80 (51.9)	42 (63.6)	122 (55.5)	
	Type 2	42 (27.3)	12 (18.2)	54 (24.5)	
	Type 3	32 (20.8)	12 (18.2)	44 (20)	0.241[a]
Vidian canal dehiscence	No	108 (70.1)	46 (69.7)	154 (70)	
	Yes	46 (29.9)	20 (30.3)	66 (30)	0.949[a]

[a]: Chi-square test with n (%),

Table 3. Statistical comparison of Onodi cell volumes among different types of optic, vidian, and carotid canals

	Types	n	Onodi cell volumes	p values	Post hoc p values
Optic canal	Type 1	18	1.17±0.52	**0.014**[d]	**1-3: 0.012**
	Type 2	20	1.34±0.68		**3-4: 0.018**
	Type 3	12	1.92±0.47		
	Type 4	16	1.2±0.82		
Carotid canal	Type 1	22	1.18±0.61	**0.002**[d]	**1-3: 0.001**
	Type 2	24	1.3±0.65		**2-3: 0.009**
	Type 3	20	1.83±0.45		
Vidian canal	Type 1	42	1.24±0.62	0.396[d]	-
	Type 2	12	1.42±0.7		
	Type 3	12	1.49±0.63		

[d]: One-way ANOVA with mean±standard deviation reported, followed by post-hoc Tukey HSD tests where applicable

Table 4. Statistical findings comparing Onodi cell volumes across groups with craniofacial anatomical structures and associated dehiscences

	Onodi cell volumes		p values
Optic canal dehiscence (No/Yes) (n=42/24)	1.36±0.6	1.24±0.69	0.462[b]
Carotid canal dehiscence (No/Yes) (n=48/18)	1.26±0.6	1.63±0.77	**0.043**[b]
Vidian canal dehiscence (No/Yes) (n=46/20)	1.2±0.61	1.58±0.62	**0.024**[b]

[b]: Student's t-test with mean±standard deviation

in Type 3 was significantly higher than that in Type 1 and Type 2 (p=0.001 and p=0.009, respectively). No other significant intergroup differences were observed (p>0.05). The OC volume was significantly higher in the ICA dehiscence group (1.63±0.77 cm^3) compared to the non-dehiscence group (1.26±0.60 cm^3) (p=0.043).

OC volume did not significantly differ between VC types (p=0.396). However, OC volumes were significantly higher in the VC dehiscence group (1.58±0.62 cm^3) than in the non-dehiscence group (1.20±0.61 cm^3) (p=0.024).

DISCUSSION

In our study, 220 sphenoid sinus sides from 110 patients were individually evaluated, and the prevalence of OC was found to be 30%. This rate aligns with previously reported prevalence ranges in the literature (21.2–65.4), emphasising once again that the frequency of OC detection can vary significantly depending on the imaging technique used, evaluation criteria, and the population studied (1-3). For instance, studies using high-resolution CT have reported higher prevalence rates, whereas studies using more conventional imaging methods have reported rates as low as 10%–15% (5, 13). Cadaveric dissection studies also support this discrepancy; Driben et al. reported that OC was identified in 39% of cases via cadaveric dissection, but only 7% of the same cases via CT imaging (14). These findings highlight that the methodology used in the preoperative detection of OC is a critical factor, and they underscore the importance of CT resolution and the experience of the interpreter in surgical planning. Furthermore, as previously reported, OCs are most frequently located superiorly, superolaterally, or laterally. Our finding that the most commonly observed variant was superior (Type 1) is consistent with these reports (2).

A statistically significant relationship was found between the presence of OC and OCa types (p=0.001). In patients with OC, the higher-risk OCa variants, Type 3 (18.2%) and Type 4 (24.2%), were more frequently observed, while the safer Type 1 variant (54.5%) was more prevalent in the OC-negative group. This finding indicates that OC is not merely an anatomical variation but may also influence the optic canal morphology. Similar results have been reported in the literature, where OC has been particularly associated with the Type IV OCa configuration. In this configuration, the ON prominently protrudes into the sphenoid sinus, directly contacts the sinus wall, and is separated by an average bony thickness of only 0.28 mm (15). This anatomical configuration significantly increases the risk of iatrogenic ON injury during endoscopic sinus surgery. Studies by Fadda et al. and Ravindra & Devika also emphasise that ON protrusion into the sinus and the presence of Type IV canal configurations occur more frequently in patients with OC and pose the highest surgical risk (16, 17). Accordingly, our findings underline the clinically significant anatomical association between the OC and OCa configurations, reinforcing the necessity of a detailed preoperative radiological evaluation.

In our study, ON dehiscence was observed in 36.4% of the OC-positive group, which was significantly higher than that in the OC-negative group. Numerous studies in the literature support this association (1, 2, 16). For example, in a CBCT study by Movahhedian et al., ON dehiscence was found in 38.8% of OC-positive cases, and a significant correlation between the two structures was reported (18). Similarly, in a study by Dias et al., the prevalence of OC was 7.92%, while ON dehiscence was observed in 21.29% of these cases (19). In another combined cadaveric and CT-based study, ON dehiscence was identified in four of six cases with OC (66.6%) (7). These findings indicate that the close proximity of the OC to the ON within the sphenoid sinus may contribute to the thinning or dehiscence of the bony wall. Therefore, the presence of OC may serve as a predictive marker for ON dehiscence and

should be considered a potential risk factor for ON injury during endoscopic procedures.

Uniquely, our study included volumetric measurements and revealed a significant relationship between OCa types and OC volumes (p=0.014). In particular, patients with the Type 3 OCa variant had significantly larger OC volumes than those with the Type 1 and Type 4 variants. Although we found a correlation between canal type and OC volume, there was no statistically significant difference in OC volume between patients with and without ON dehiscence (p=0.462). This indicates that factors beyond volume, such as cell orientation, angulation, or individual variations in sphenoid bone structure, may influence ON dehiscence. A similar conclusion was reached in a study by Dieguez et al. using a semi-automated segmentation method based on 3D CT data, where no significant correlation was found between OC volume and ON contact or dehiscence (6). As one of the few volumetric studies in the field, it supports our findings. While many studies have focused on the association between OC presence and ON dehiscence, there is a lack of volume-based analyses to establish a direct correlation. Thus, OC volume alone may be insufficient to predict ON dehiscence, and further research involving comprehensive volumetric assessments is warranted.

Our study also found a significantly higher rate of ICA dehiscence in the OC-positive group (p=0.022). In the literature, OC, especially when located superolaterally, has been linked to increased ICA protrusion into the sphenoid sinus or thinning of the bony wall, resulting in higher dehiscence rates (1, 18). Movahhedian et al. reported a significant correlation between the presence of OC and ICA dehiscence, emphasising its clinical significance as a surgical risk factor (18). Additionally, our study found that OC volume varied significantly across different CC types (p=0.002). Specifically, patients with Type 3 CC had significantly larger OC volumes compared to those with Type 1 and Type 2 CC (p=0.001 and p=0.009, respectively). Furthermore, the mean OC volume was significantly greater in the ICA dehiscence group (1.63±0.77 cm^3) than in the non-dehiscence group (1.26±0.6 cm^3) (p=0.043). These findings indicate that both the presence and size of the OC may influence the CC morphology and the development of dehiscence. Previous studies have also noted that increased sphenoid sinus pneumatization is associated with higher rates of ON and ICA protrusion and dehiscence (1, 18). Moreover, Dieguez et al. reported a positive correlation between OC volume and pneumatization extending towards the clinoid processes (6). These findings support the hypothesis that large OCs may exert greater pressure on adjacent neurovascular structures or weaken the bony continuity in these regions. However, the number of studies that quantitatively investigate the direct relationship between OC volume and ICA dehiscence remains limited. In this regard, our study serves as a pioneering contribution to the literature by highlighting the potential impact of OC volume on CC variants and dehiscence.

Our study did not find a statistically significant association between OC presence and VC types (p=0.241) or VC dehiscence (p=0.949). Similarly, OC volume did not differ significantly among the different VC types (p=0.396). However, in patients with VC dehiscence, the mean OC volume (1.58±0.62 cm^3) was significantly higher than in those without dehiscence (1.2±0.61 cm^3) (p=0.024). This result indicates that a larger OC volume may contribute to the weakening of the bony continuity around the VC, potentially facilitating the development of dehiscence. Previous studies have reported that in cases where the OC extends posterolaterally into the sphenoid sinus, it is often associated with multiple septations and posterior pneumatization (3). These configurations may cause the VC to protrude into the sinus or to appear medially located. However, a limited number of studies have systematically evaluated the relationship between OC and VC types or dehiscence. Therefore, our study provides an important finding regarding the potential effect of OC volume on VC dehiscence and highlights the need for further studies with larger sample sizes and volumetric approaches.

One of the strengths of our study is the quantitative measurement of OC volume and its comparison with surrounding critical anatomical structures using a volumetric approach, which is rarely addressed in the literature. However, this study also has limitations. Its retrospective, single-centre design may affect the generalizability of the results. Manual segmentation although widely used, may introduce a degree of observer variability, even though the assessments were reviewed and confirmed by multiple reviewers. Moreover, the lack of direct clinical or surgical correlation limits the ability to interpret the findings in a procedural context. Further prospective and multicenter studies are needed to validate these results and support their clinical application.

CONCLUSION

Our study demonstrated that the presence and volume of the OC are associated with variations of the OCa, CC and VC. In OC-positive cases, riskier optic canal types and a higher rate of ON dehiscence were observed. Additionally, significant associations were found between OC volume and CC types and dehiscence. OC volume was also higher in patients with VC dehiscence. These findings indicate that not only the presence but also the volumetric size of the OC is a critical anatomical

variation that should be considered during surgical planning. Detailed preoperative assessment of the OC using high-resolution CT is of critical importance in reducing the risk of surgical complications.

Ethics Committee Approval	Ethics committee approval was received for this study from the ethics committee of Hitit University Faculty of Medicine Clinical Research Ethics Committee (Date: 31.03.2022, No: 2022-24).
Informed Consent	Written informed consent was obtained from patients who participated in this study.
Author Contributions	Conception/Design of Study- G.A.U., B.N.U., Z.B.A., O.G., S.A.F.; Data Acquisition- G.A.U., B.N.U., Z.B.A., O.G., S.A.F.; Data Analysis/Interpretation- G.A.U., B.N.U., Z.B.A., O.G., S.A.F.; Drafting Manuscript- G.A.U., B.N.U., Z.B.A., O.G., S.A.F.; Critical Revision of Manuscript- G.A.U., B.N.U., Z.B.A., O.G., S.A.F.; Final Approval and Accountability- G.A.U., B.N.U., Z.B.A., O.G., S.A.F.
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